Lithium-Ion Cell Charge Control Unit

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Abstract

Life-test data of Lithium-Ion battery cells is critical in order to establish their performance capabilities for NASA missions and Exploration goals. Lithium-ion cells have the potential to replace rechargeable alkaline cells in aerospace applications, but they require a more complex charging scheme than is typically required for alkaline cells. To address these requirements in our Lithium-Ion Cell Test Verification Program, a Lithium-Ion Cell Charge Control Unit was developed by NASA Glenn Research Center (GRC). This unit gives researchers the ability to test cells together as a pack, while allowing each cell to charge individually. This allows the inherent cell-to-cell variations to be addressed on a series string of cells and results in a substantial reduction in test costs as compared to individual cell testing.

The Naval Surface Warfare Center at Crane, Indiana developed a power reduction scheme that works in conjunction with the Lithium-Ion Cell Charge Control Unit. This scheme minimizes the power dissipation required by the circuitry to prolong circuit life and improve its reliability.

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Purpose

- Cost savings for Lithium-Ion Verification Test Program (see paper by McKissock, B., et al, in these proceedings)
- Life test program assesses individual cell performance during low-Earth-orbit cycling under different operating conditions (end-of-charge voltage, temperature, depth-of-discharge)
- Testing one cell per channel was not cost effective
- Testing multiple cells per channel did not allow for individual cell control
- Drove requirements for charge control units – control necessary on individual cell level, not pack level
  - Cell level cut-off voltage
  - Allow each cell to fully charge - allow cells to taper individually once cut-off voltage is reached
  - Keep track of charge capacity accepted by individual cells

Design Challenges

- Will operate with large currents
  – Electronic components must withstand them
- Power generated must be effectively dissipated
  – Thermal management is necessary
- Charge Control Unit must operate in conjunction with main power supply
  – Must ensure proper operation and interfacing with test equipment
  – Worked closely with Engineers at the test facility at the Naval Surface Warfare Center in Crane, Indiana throughout the development process

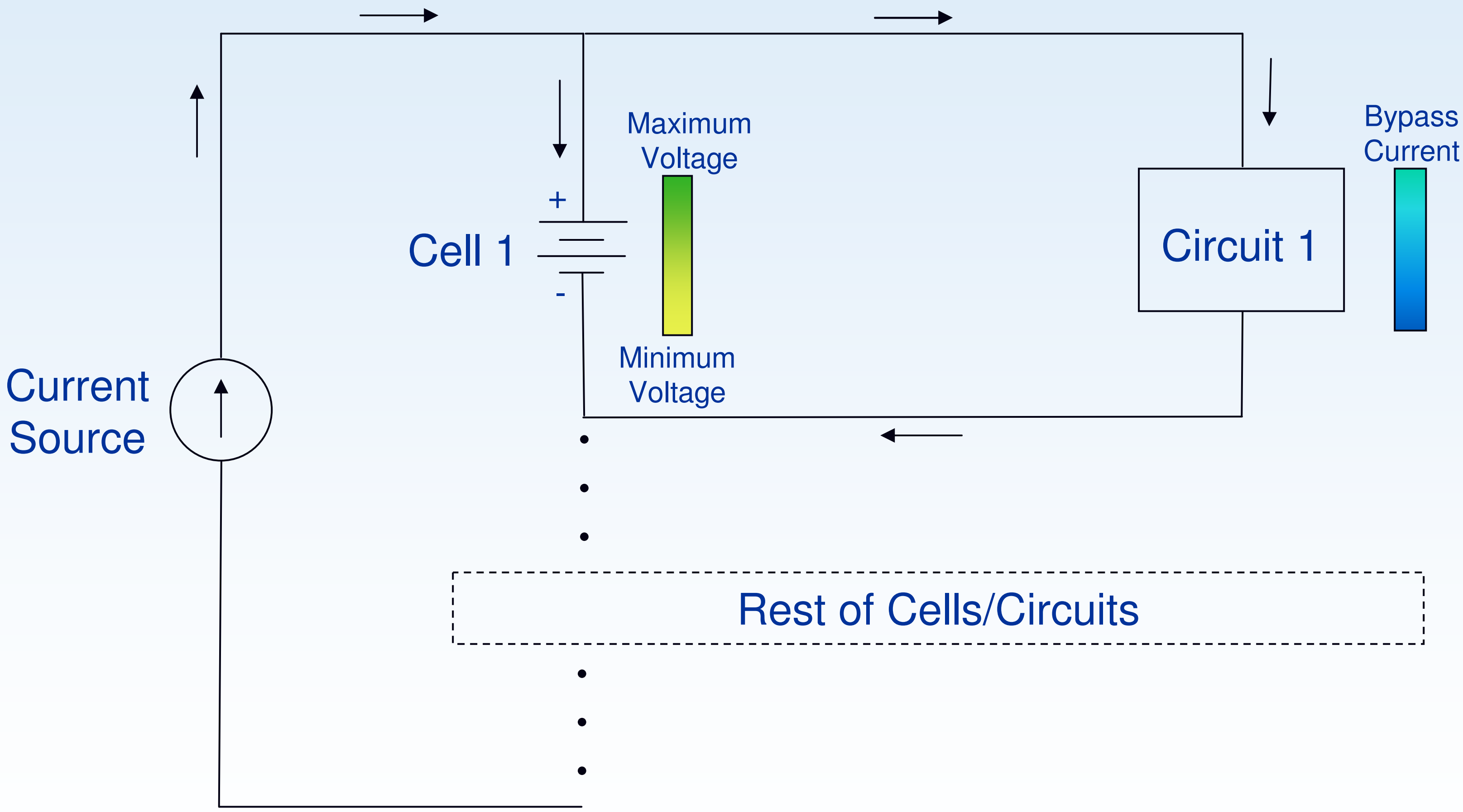
Features of Charge Control Units

- Allows for the charging of multiple series-connected cells using one main power supply channel
- Can operate continuously with charge currents up to 36 amps
  - Higher currents may be possible
- Allows for the selection of individual cell voltage cut-off values
- Allows individual cells to taper independently once they reach their voltage cut-off value
  - Remaining cells are allowed to continue charging at full current

Features of Charge Control Units (cont.)

- Contains opto-isolators that can interface with main power supply to signal when circuitry is active
  - Main power supply software can optionally transition to other modes
- Current shunts or sensors can be connected in series with cells to record current through individual cells
  - Provides the ability to keep track of capacity and energy into each cell
- Integral thermal management
- Self-powered

Cell Bypass Operation



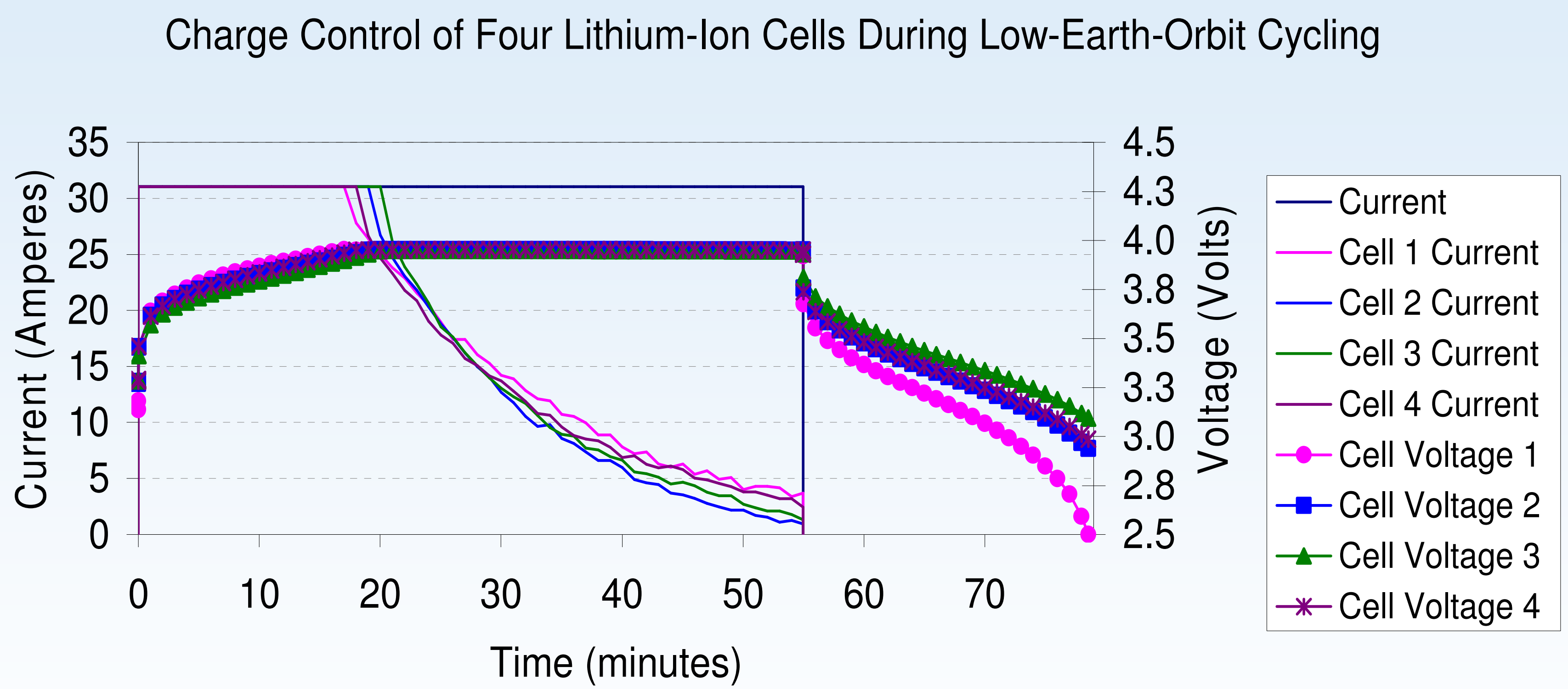
Explanation of *Cell Bypass Operation* depicted on Previous Slide

- The animation depicts the operation of a charge control circuit when connected in parallel across a battery cell that is being charged by a constant DC current source.

- At the beginning of charge, all current generated by the source flows into Cell 1. Circuit 1 is pre-tuned to activate at a specific voltage, the maximum voltage of Cell 1. When Cell 1 achieves its maximum voltage, Circuit 1 activates. The current is then divided between Cell 1 and Circuit 1. Enough current continues to flow into Cell 1 to maintain its voltage at the maximum. The remaining current flows through Circuit 1.

- The remaining cells in the pack continue to be charged at full current until they reach their maximum voltage. The operation continues for each remaining Cell and Circuit in the pack until the end of the charge period.

Charge Control during LEO Cycling



Charge Current = 31 Amps, Cell Cut-off Voltage = 3.95 Volts

Explanation of *Charge Control during LEO Cycling* depicted on previous slide

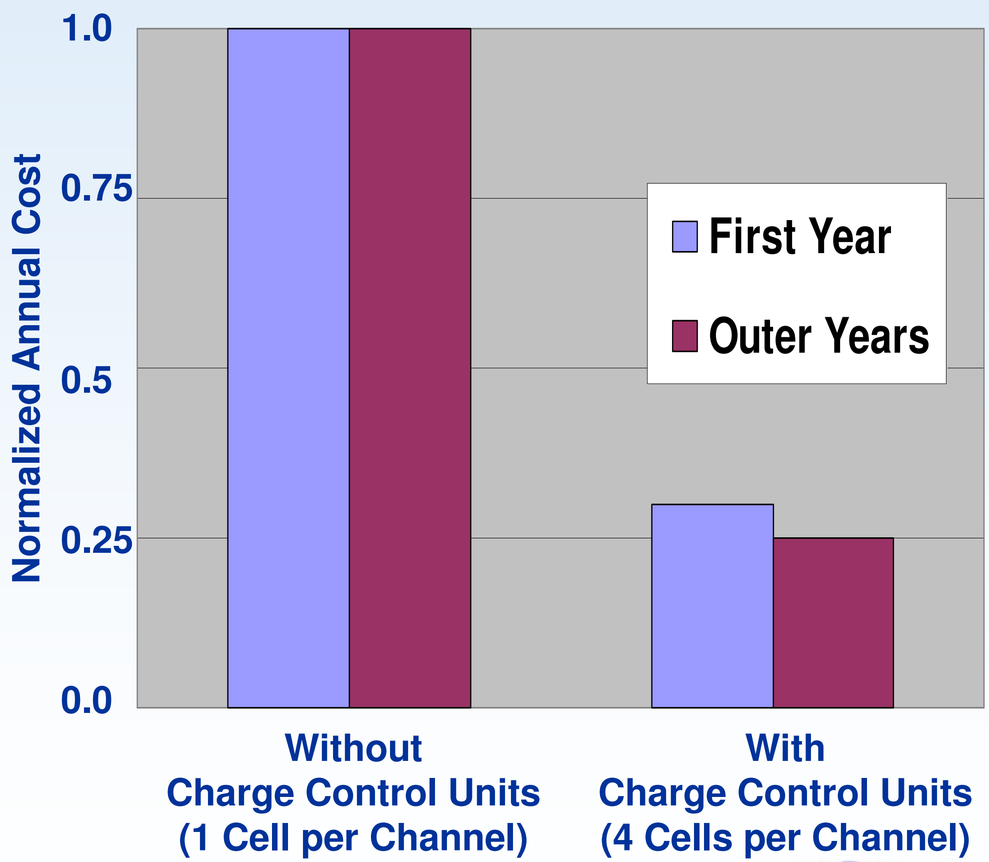
- Four Lithium-ion Battery Cells are connected in series. A Charge Control Circuit is connected in parallel across each cell. Each circuit is pre-tuned to activate at a cell voltage of 3.95 volts. A constant current of 31 Amps is being generated by the source. The cells were LEO cycled using a 55 minute charge period and a 35 minute discharge period.

- Cell 1 is the first cell to reach the maximum voltage. The illustration shows the current through Cell 1 tapering off while the current through all other cells remains at the charging current. Cell 1's voltage remains constant at 3.95 volts.

- As the remaining cells sequentially reach the maximum voltage, the current through each cell tapers off. Each cell voltage is maintained at 3.95 volts. The cells are then discharged.

Cost Savings using Charge Control Units and Cells in Packs

- In the first year, the cost of testing cells in packs using charge control units is less than ⅓ the cost of testing one cell per channel
- For outer years, the cost of testing cells in packs using charge control units is ¼ the cost of testing one cell per channel
- An overall cost saving of 73% is achieved for a three year test program



Future of Charge Control Units

- Several units are currently in use for NASA Glenn Research Center's Lithium-Ion Verification Test Program being conducted at the Naval Surface Warfare Center in Crane, IN
- A total of 30 units will be interfaced with Crane's main test equipment and integrated into the Lithium-Ion Verification Test Program
- An Invention Disclosure has been filed internally
  - Patent application is in consideration
  - Could lead to possible Space Act Agreement with an industry partner to further optimize, license and commercialize the product

Conclusions

- The Lithium-Ion Charge Control Unit allows multiple series-connected cells to charge independently of each other using only one main power supply channel
- Cost savings are achieved through the use of the Unit without sacrificing individual cell performance
- Unit is not optimized, designed for laboratory testing
- Operational enhancements have been made through a Power Dissipation Reduction Strategy developed by Evan Hand at NSWC Crane
  - Will be presented next

Acknowledgements

- This work was funded by the NASA Aerospace Flight Battery Systems Program

GRC Charger Power Dissipation Reduction Strategy

Evan Hand

NAVSEA Crane

Crane, IN

GRC Charger Power Dissipation Reduction Strategy

Advantages:

- **Precision regulation**
- **Relatively inexpensive**
- **Powered entirely from the cell voltage**
- **Requires no power conditioning or filtering**

Disadvantages:

- **Shunt regulation – dissipates lots of power**
- **Requires supplemental cooling**
- **Requires some power from cell for operation**

NAVSEA WARFARE CENTERS CRANE

GRC Charger Power Dissipation Reduction Strategy

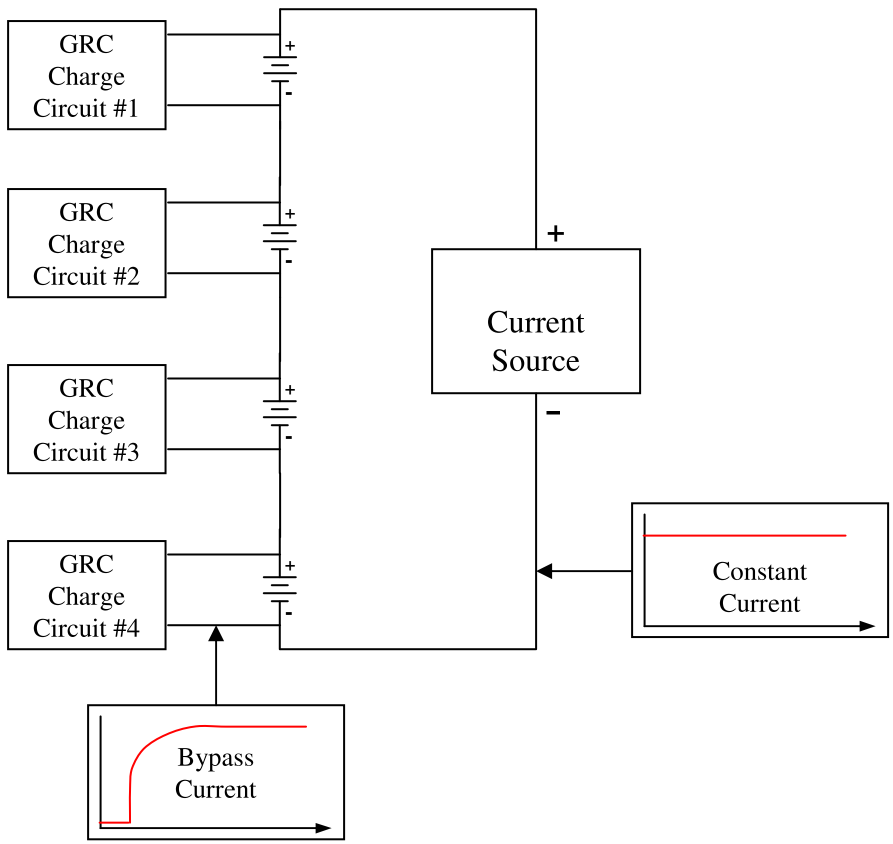
Basic Configuration:

Dissipates lots of power

25A X 4V = 100W per circuit

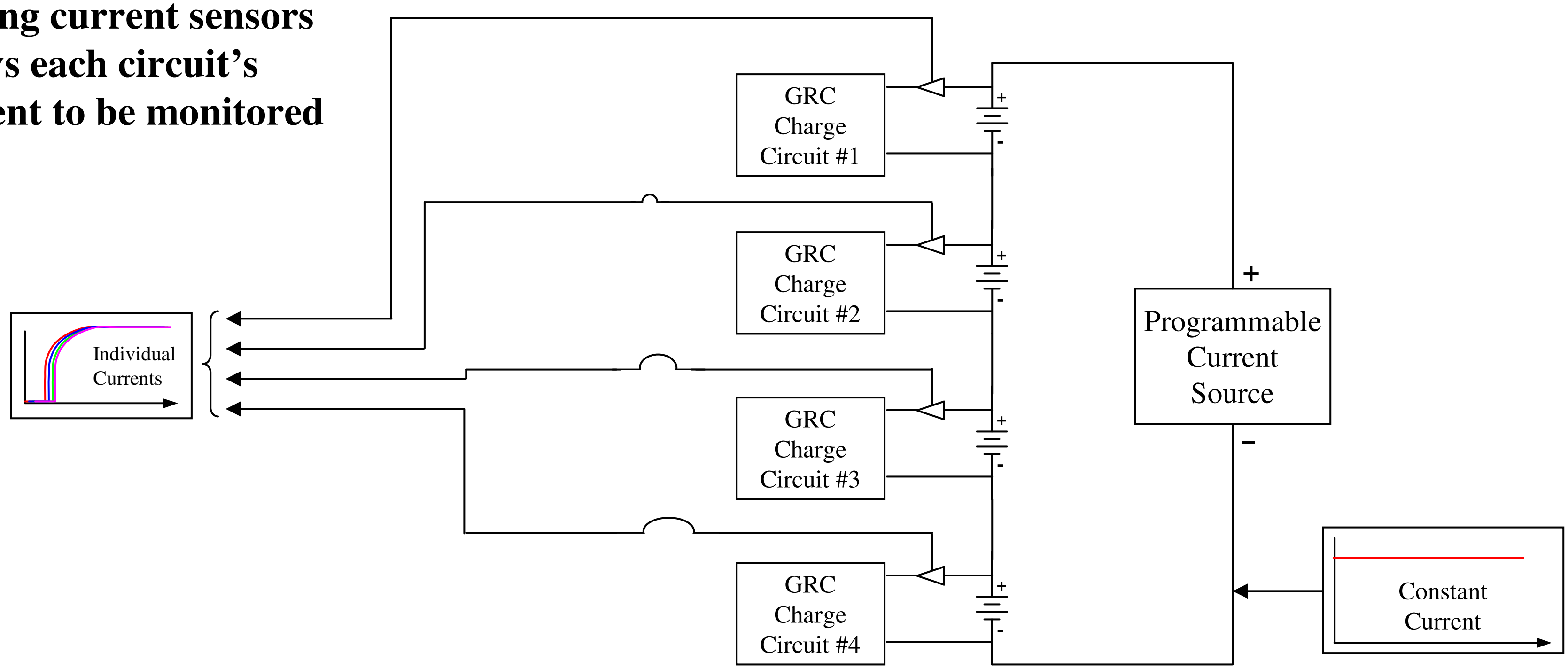
Design for continuous operation

Charge source must supply full current all the time



GRC Charger Power Dissipation Reduction Strategy

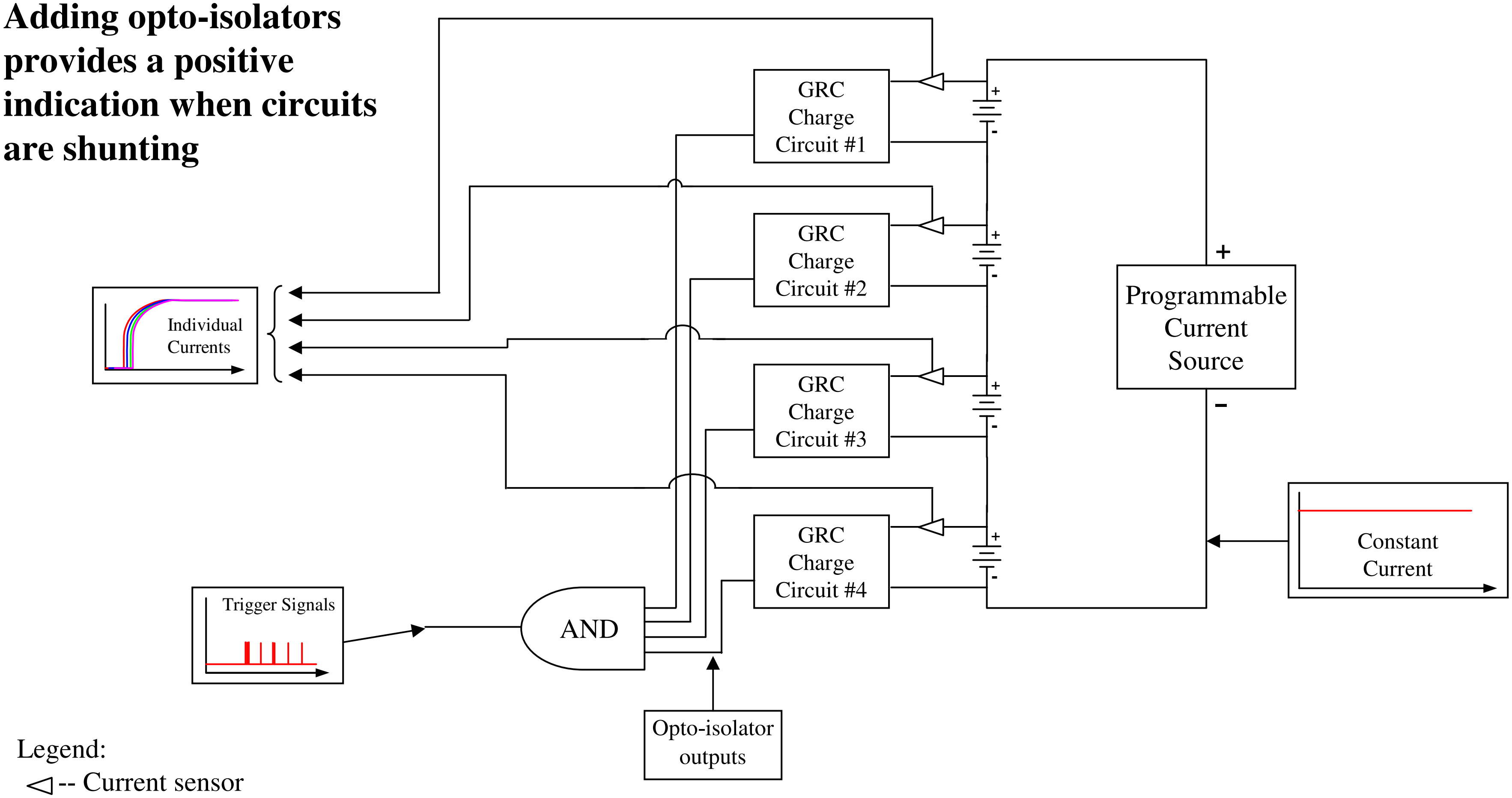
Adding current sensors allows each circuit's current to be monitored



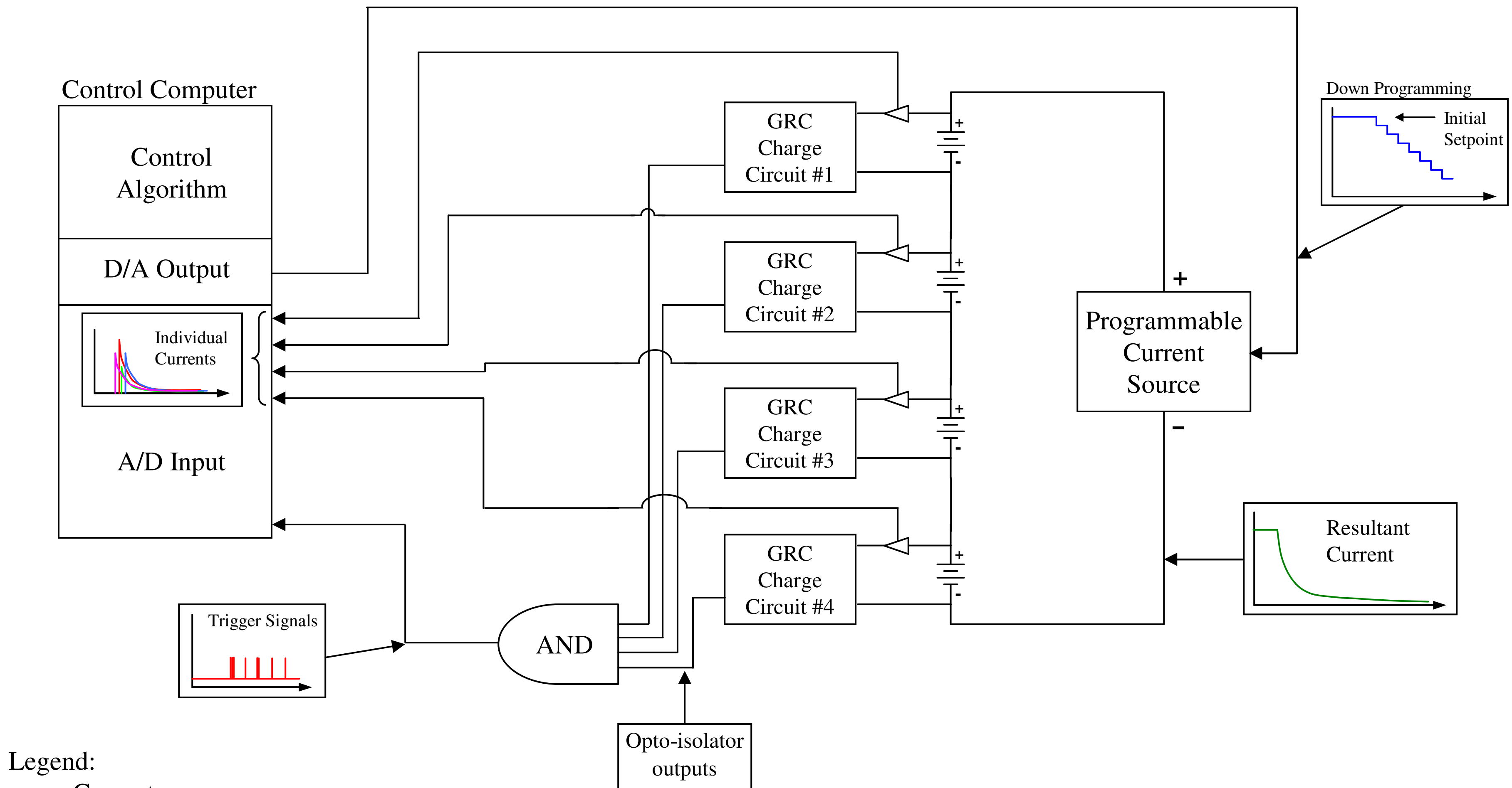
Legend:
◁ -- Current sensor

GRC Charger Power Dissipation Reduction Strategy

Adding opto-isolators provides a positive indication when circuits are shunting

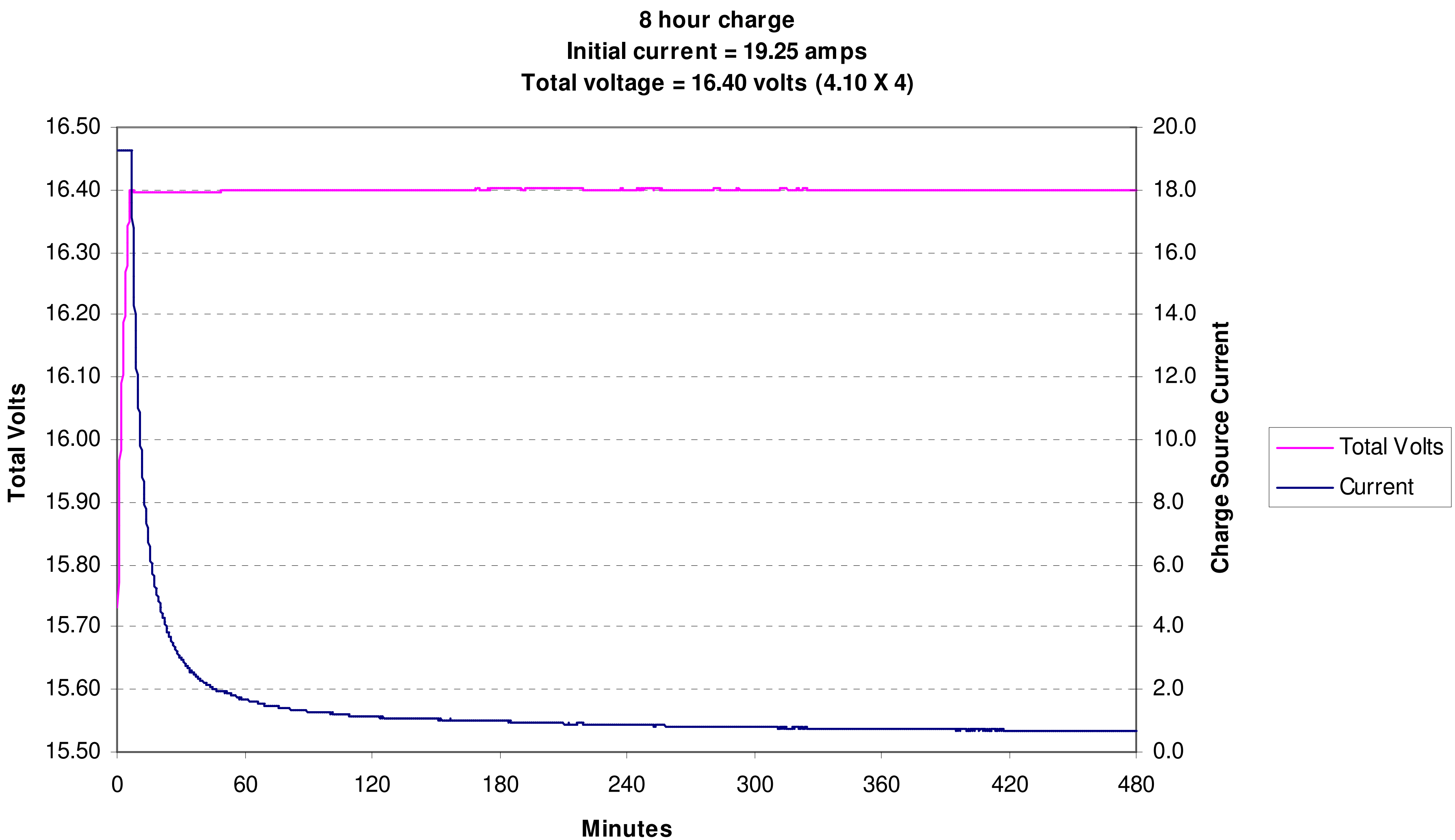


GRC Charger Power Dissipation Reduction Strategy

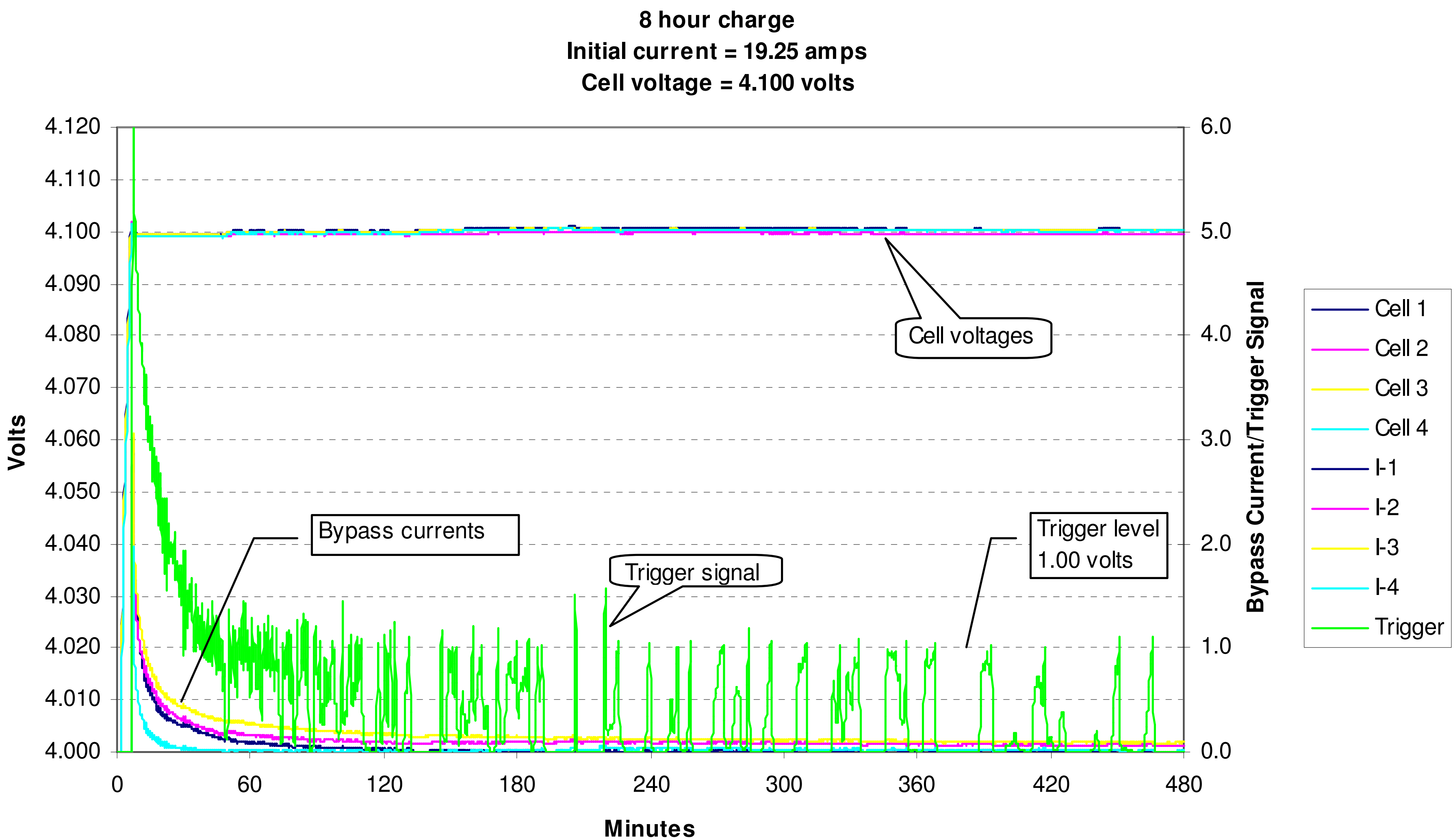


Legend:
◁ -- Current sensor

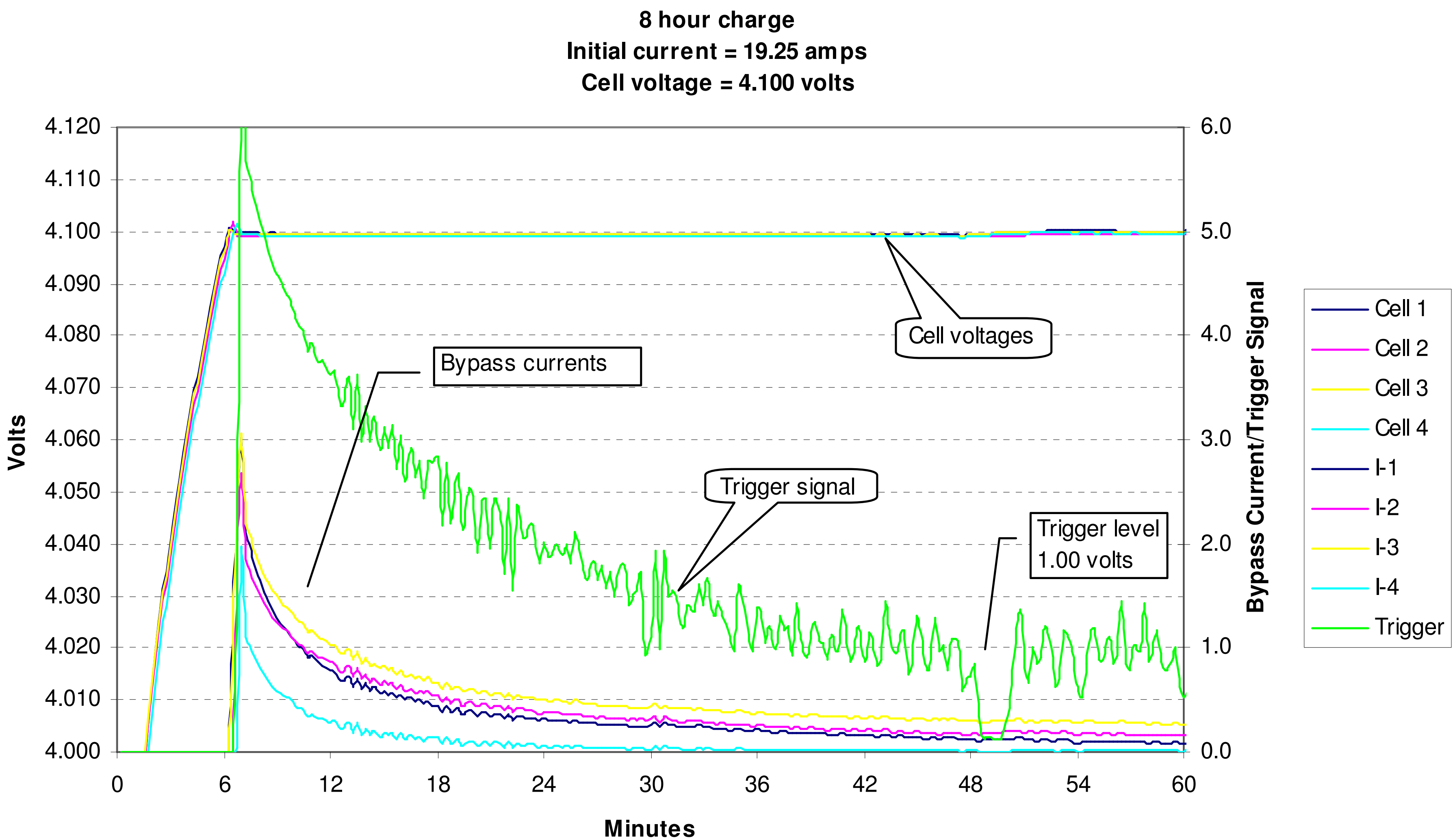
GRC Charger Power Dissipation Reduction Strategy



GRC Charger Power Dissipation Reduction Strategy



GRC Charger Power Dissipation Reduction Strategy



GRC Charger Power Dissipation Reduction Strategy

Advantages:

Precision regulation

Relatively inexpensive

Powered entirely from the cell voltage

Requires no power conditioning or filtering

After Power Reduction:

Shunt regulation – minimizes power dissipation 12W peak vs. 100W continuous

Requires supplemental cooling – simplifies cooling requirements

Requires some power from cell for operation – manageable by design

Improved reliability – components running cooler