Lithium Ion Medium Power Battery Design

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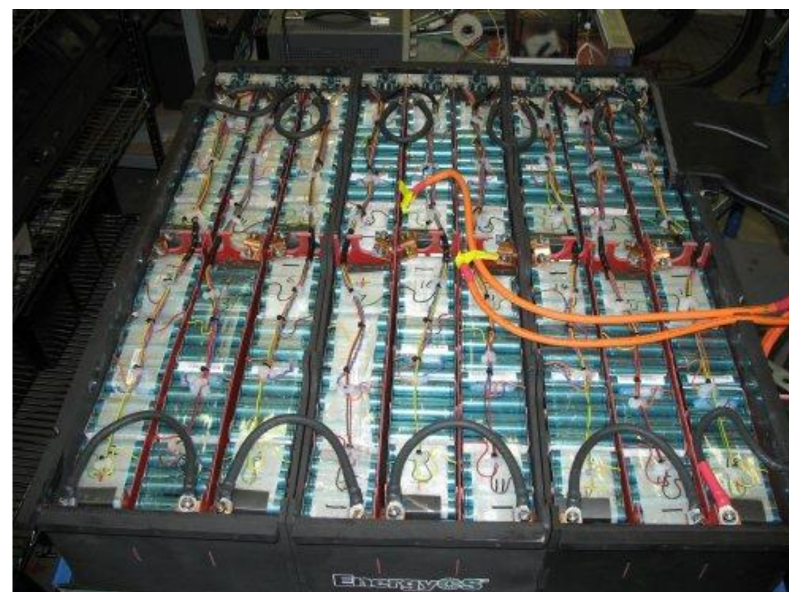
Outline

- Project Introduction
- Project Goals
- Equipment
- General Behavior
- Behavior of Cell Combinations
- Cell Balancing
- State of Charge
- Balancing Design
- Future Work

Current Uses

Tesla Motors Inc.

- 6831 Lithium Ion Cells
- 11 “sheets” of 621
- Each sheet has monitoring PCB and dedicated Microprocessor
- All 11 microprocessors linked to main PCB through CAN bus



Why Lithium Ion

- High Energy Density
- High Capacity
- High Discharge/Regenerative Capability
- Light Weight

Project Goals

- Develop effective cell layout interconnection and packaging to yield compact medium power battery with appropriate capacity (1000W for an hour)
- Incorporate a battery management subsystem to:
  - Accurately monitor state of cells during charging and discharging
  - Ensure soft failure mode in the event of cell degradation
- Ensure overall design is in compliance with industry standards

Battery Specifications

- A123 Systems:
  - <u>Cell Characteristics</u>
    - Nominal Capacity – 2.3 Ah
    - Nominal Voltage – 3.3 V
  - <u>Charging Parameters</u>
    - Charge Current – 3.0 A
    - Charge Voltage –3.6 V
    - Cut-off Charge Current for CV – .05 A
    - Float charge voltage – 3.45 V
    - Max. Charge Voltage 3.8 V
    - Max Charge Current – 10 A
  - <u>Discharging Parameters</u>
    - Discharge cut-off voltage – 2.0 V
    - Max. continuous Discharge Current 60 A

Charger

- E-Station BC8-10

  <u>**Capabilities:**</u>

  - 26.4 V
  - 10 A
  - 8 Li-Ion Cells in Series
  - Temperature Sensor
  - USB interface
  - Graphing and real-time Monitoring Software

General Behavior

Charging Constraints

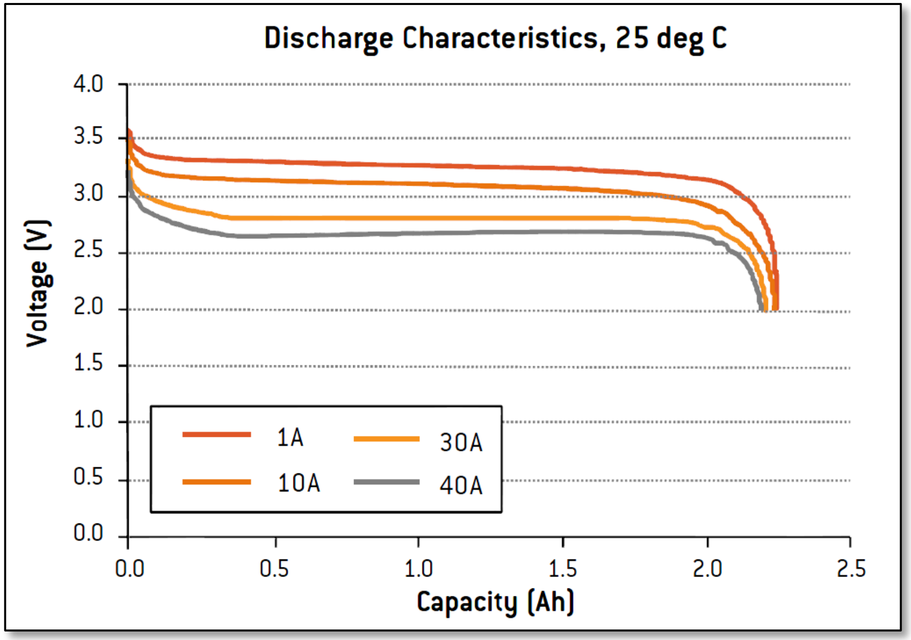
- Constant Current
- Constant Voltage

Combination Behavior

- Series=> add Voltage
- Parallel=> add Capacity

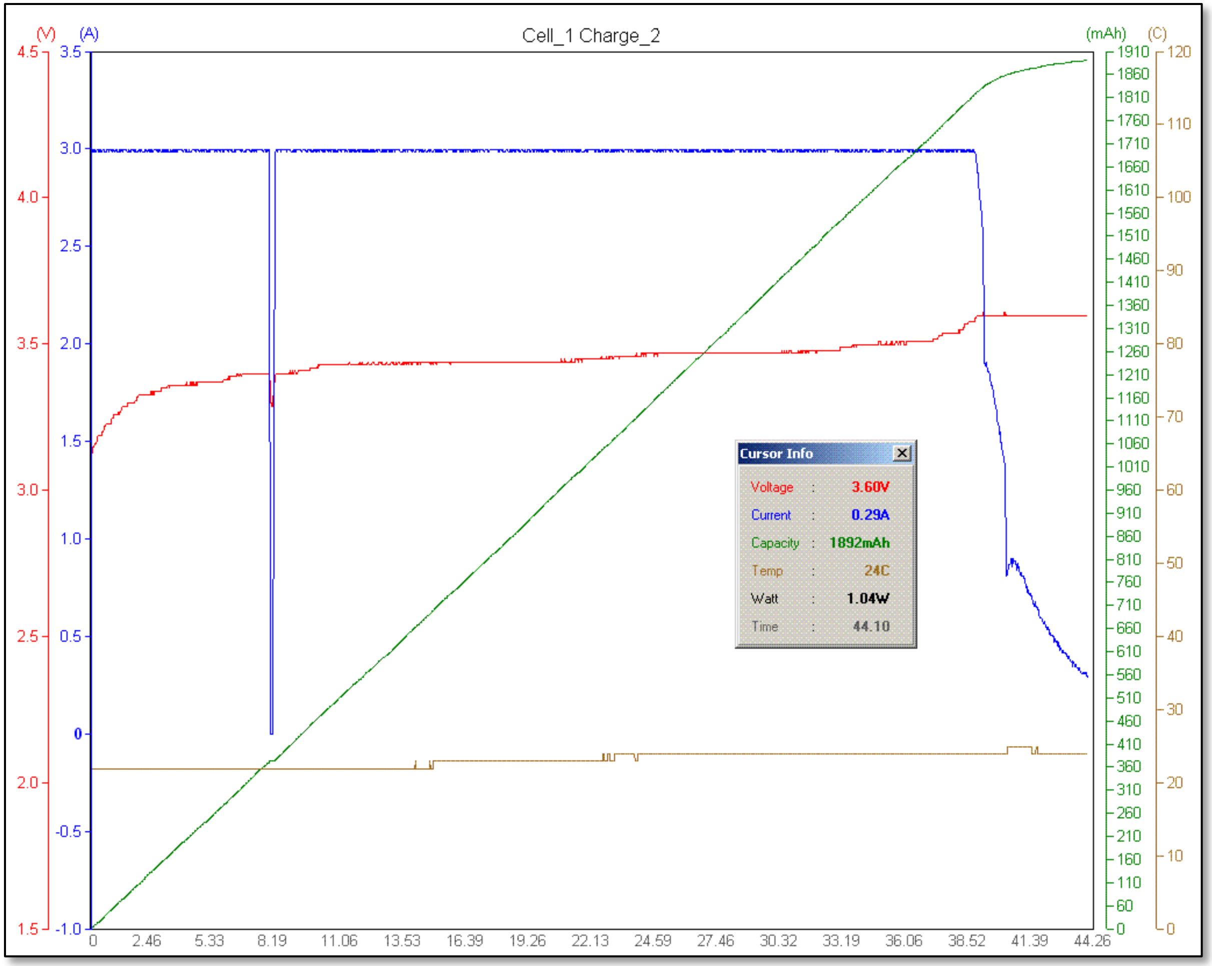
General Concerns

- Sudden voltage drop
- Temperature dependent



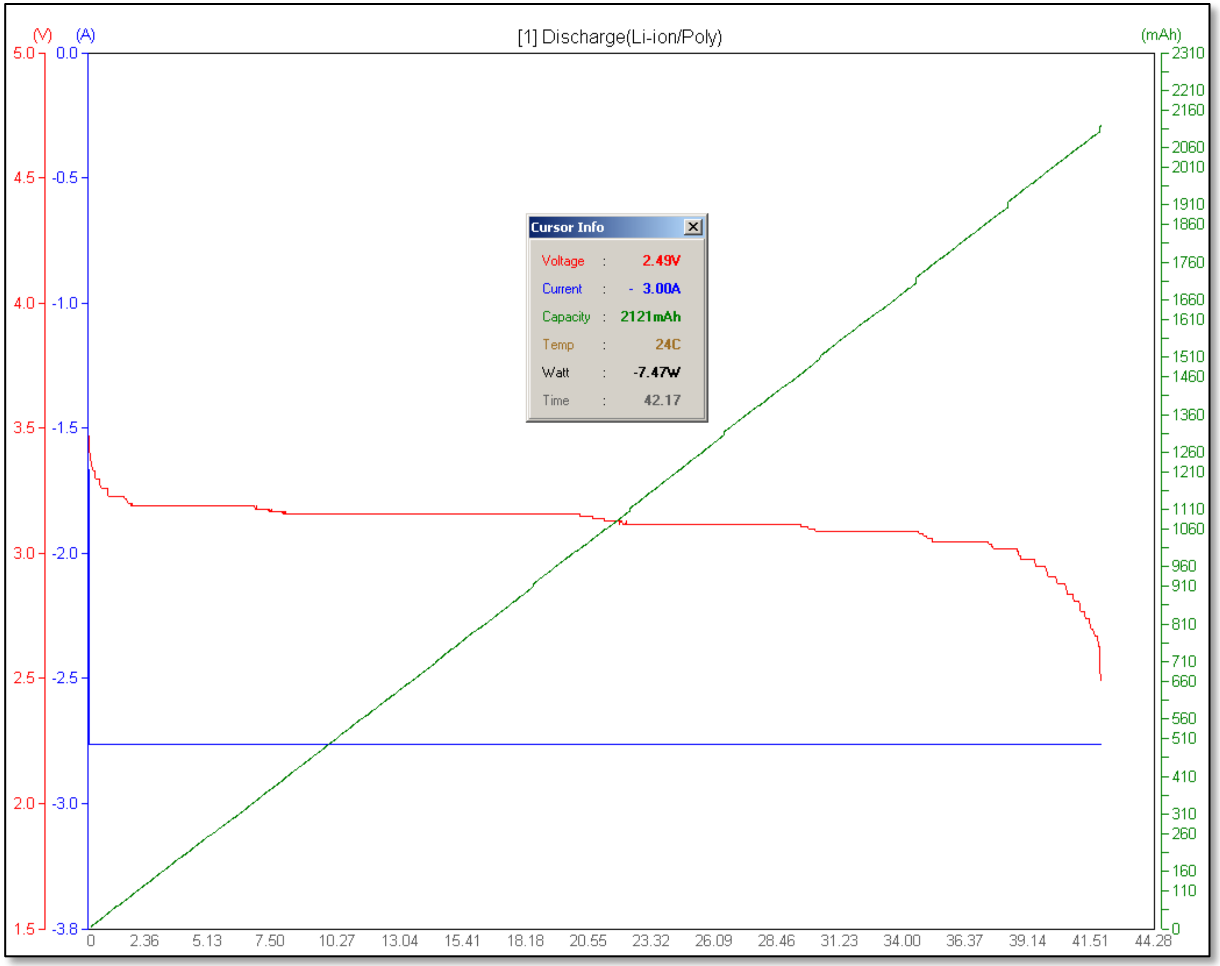
Behavior

Single Cell– Charge



Behavior

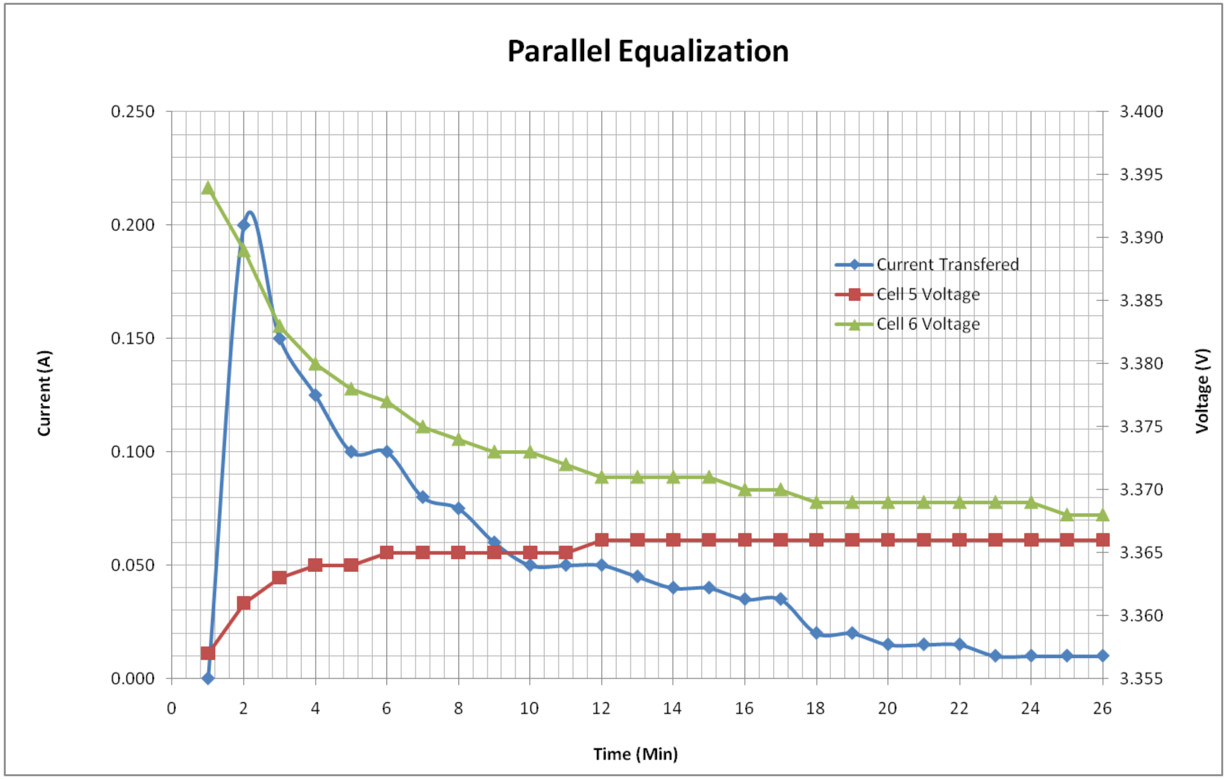
Single Cell–Discharge

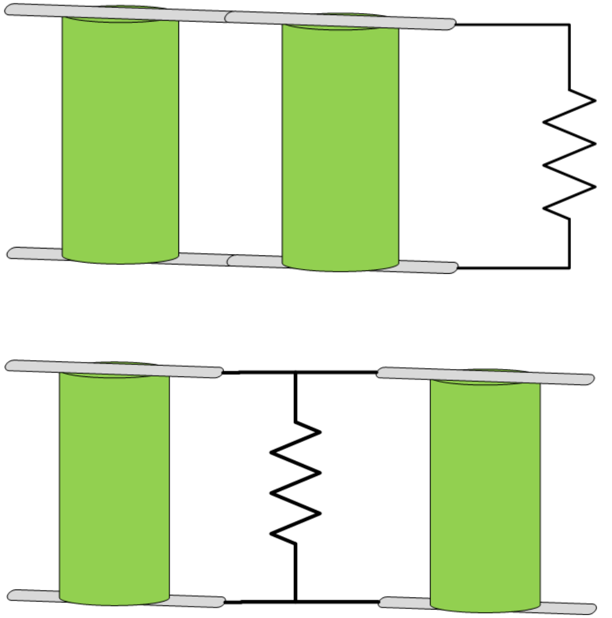


Behavior (Parallel)

- Symmetry Between Cells in Parallel

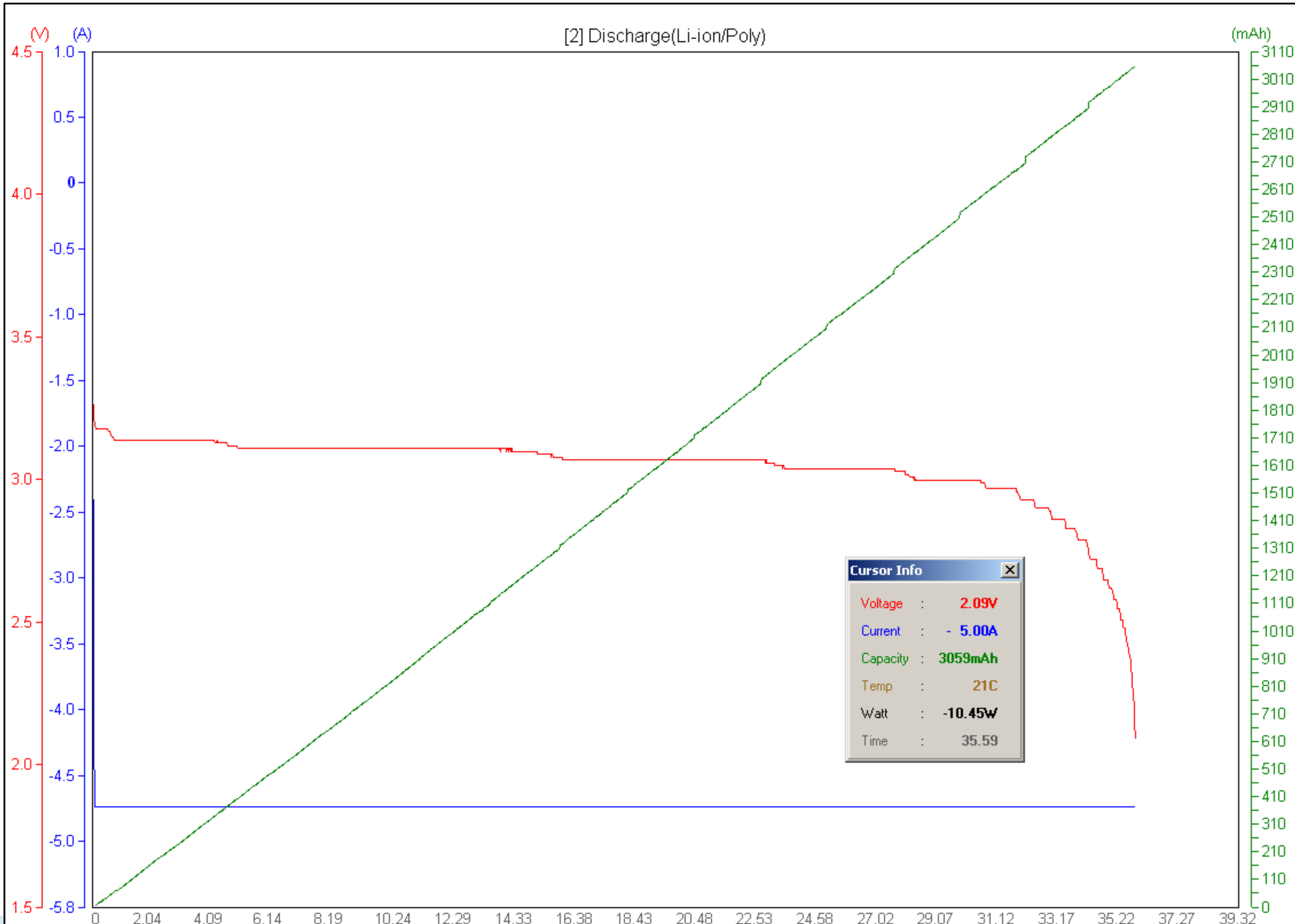
$$R_{TH} = V_{drop} \left(\frac{R_L}{V_{drop} + V_{OC}}\right)$$





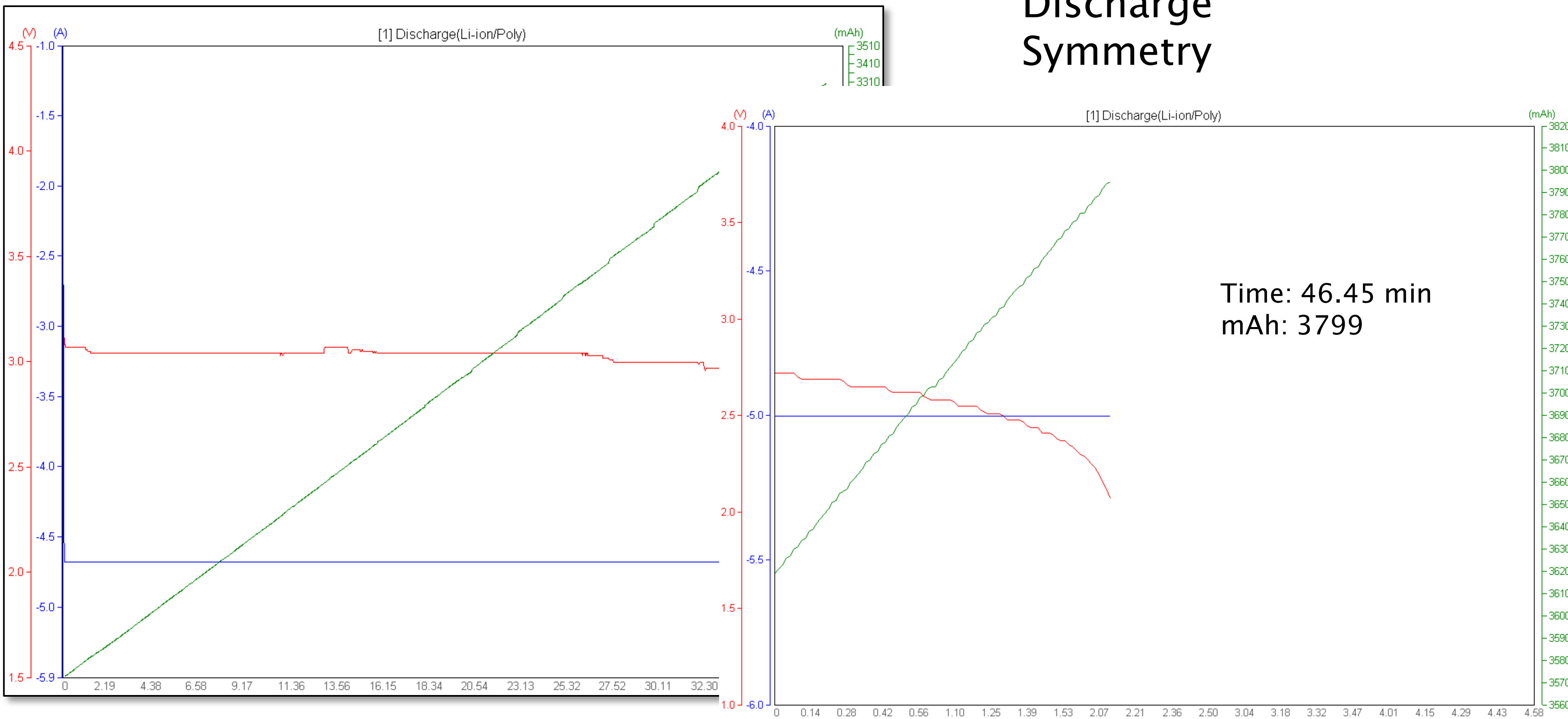
Behavior (Parallel)

Parallel Cell–Discharge No Symmetry



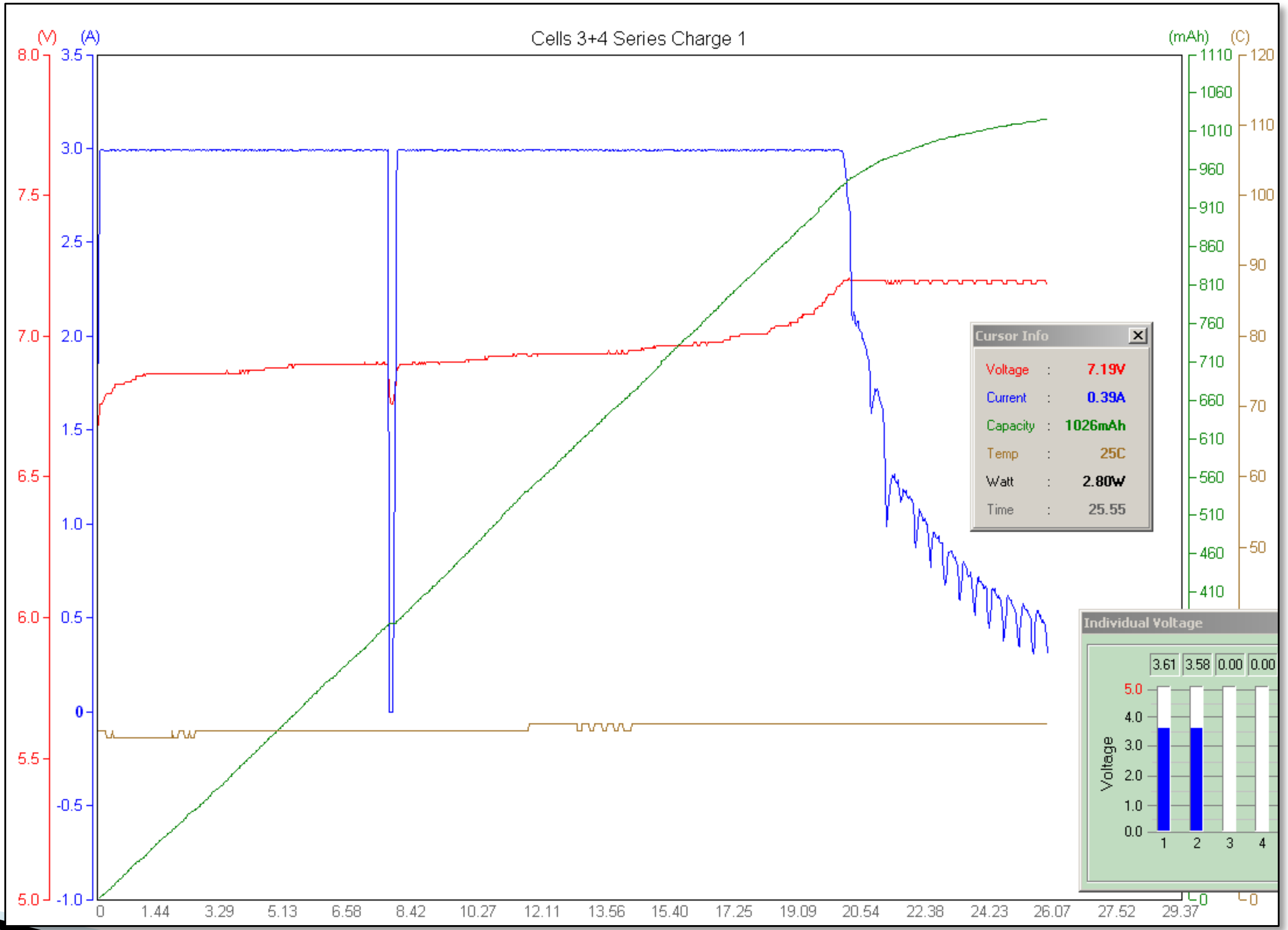
Behavior (Parallel)

Parallel Cells – Discharge Symmetry



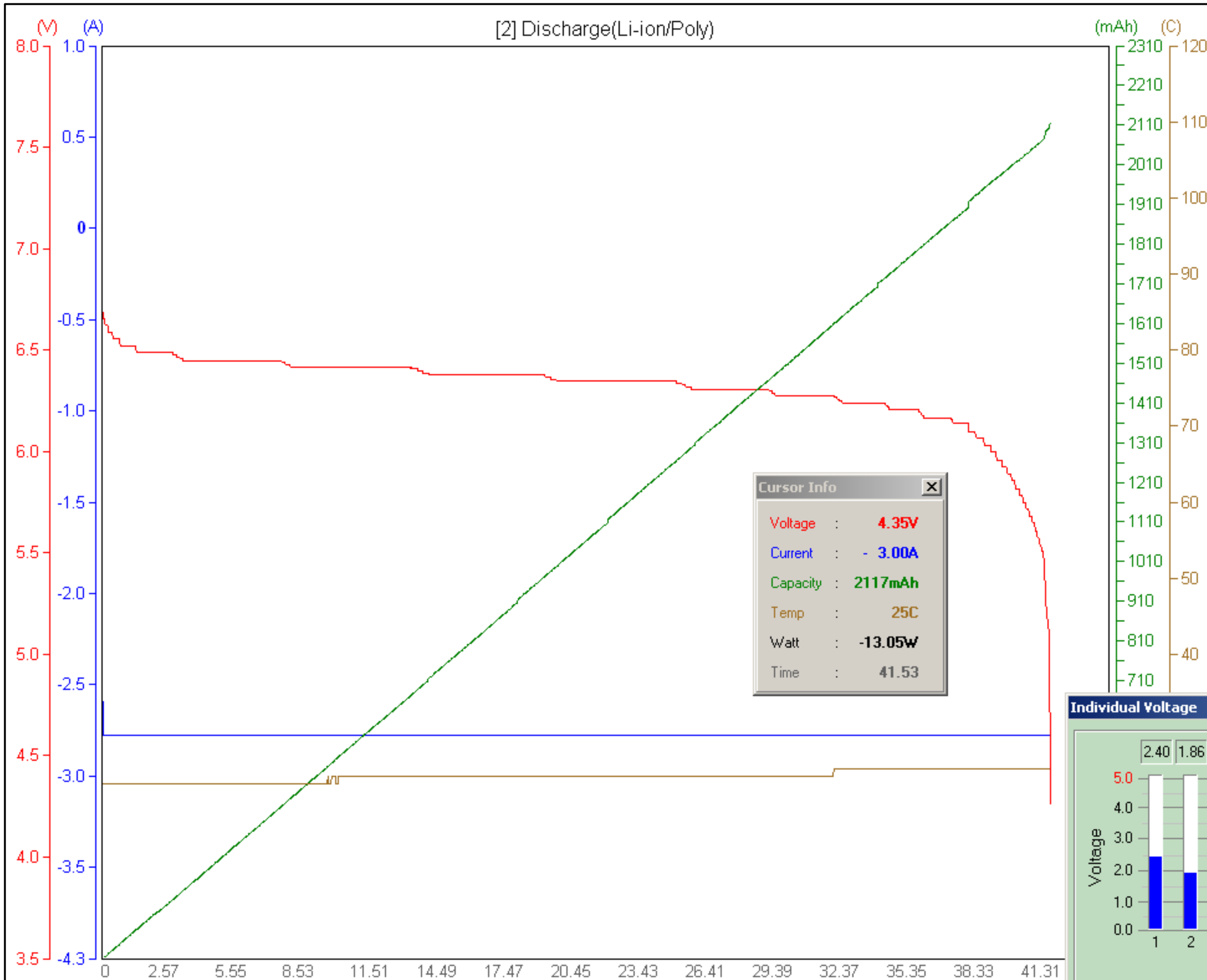
Behavior (Series)

Cell Charge–Series



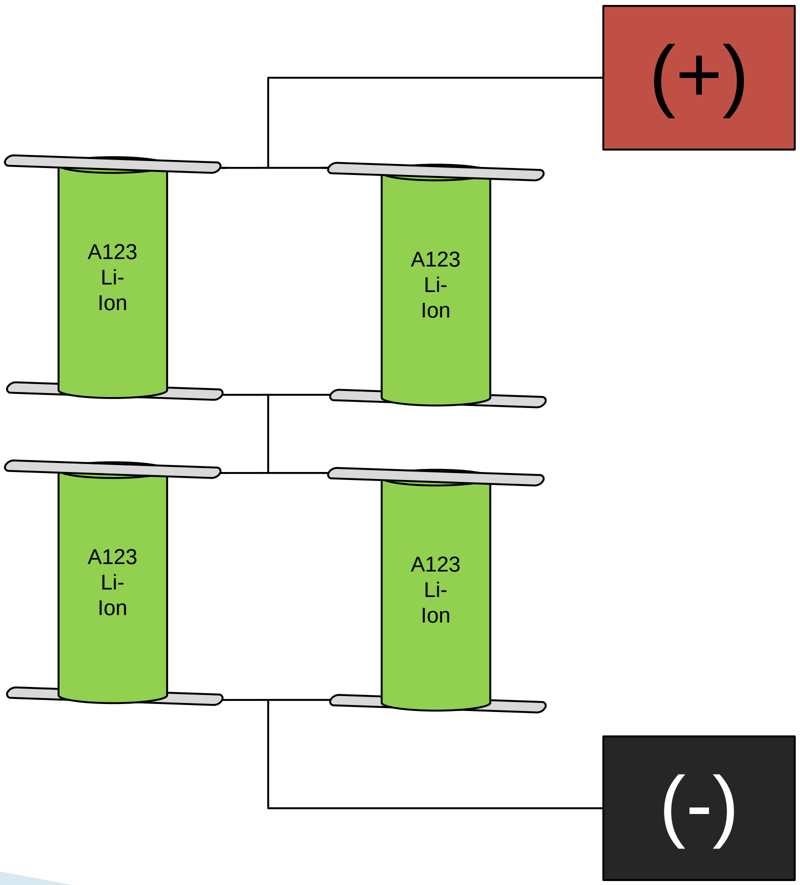
Behavior (Series)

Cell Discharge – Series

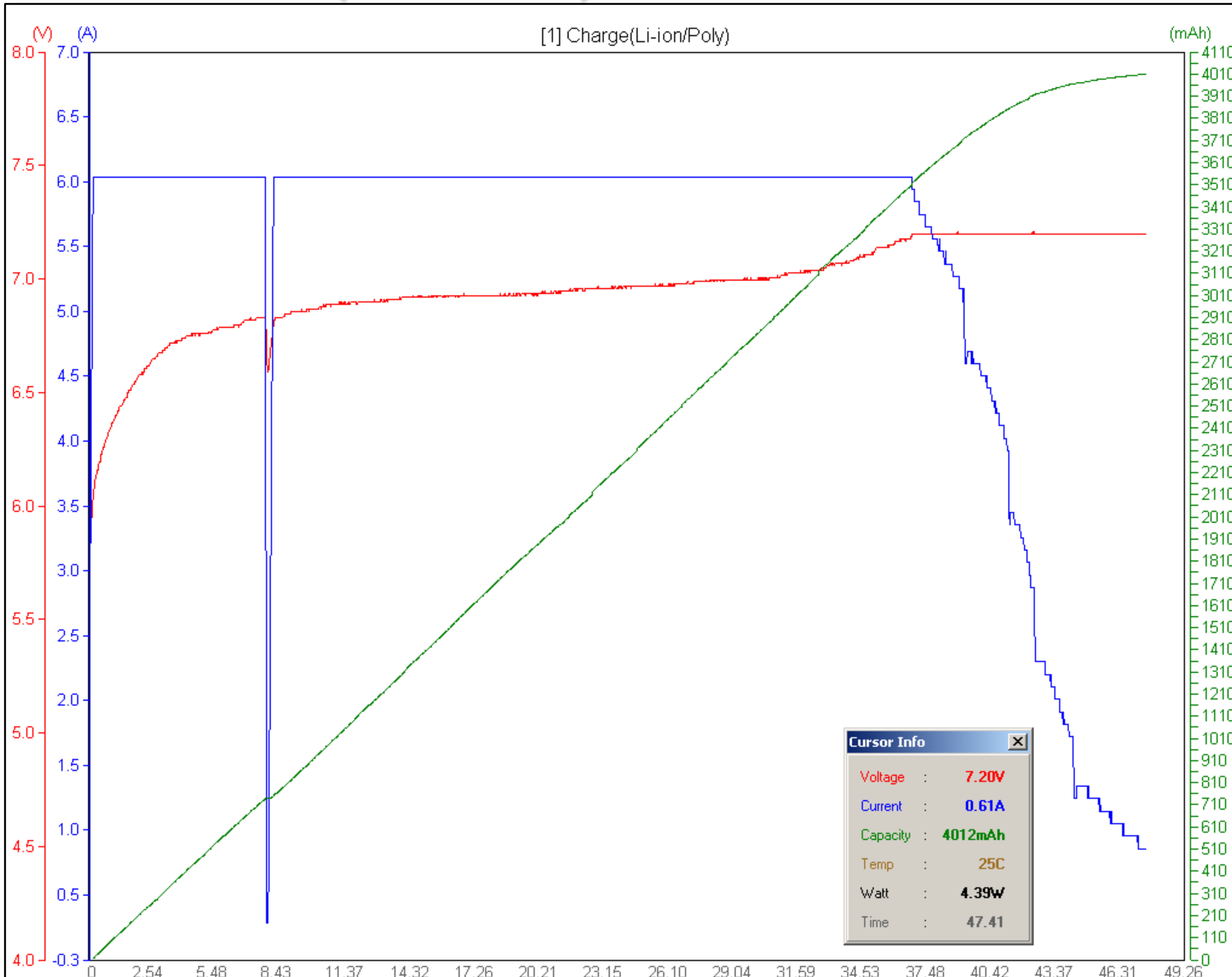


Behavior (Pack)

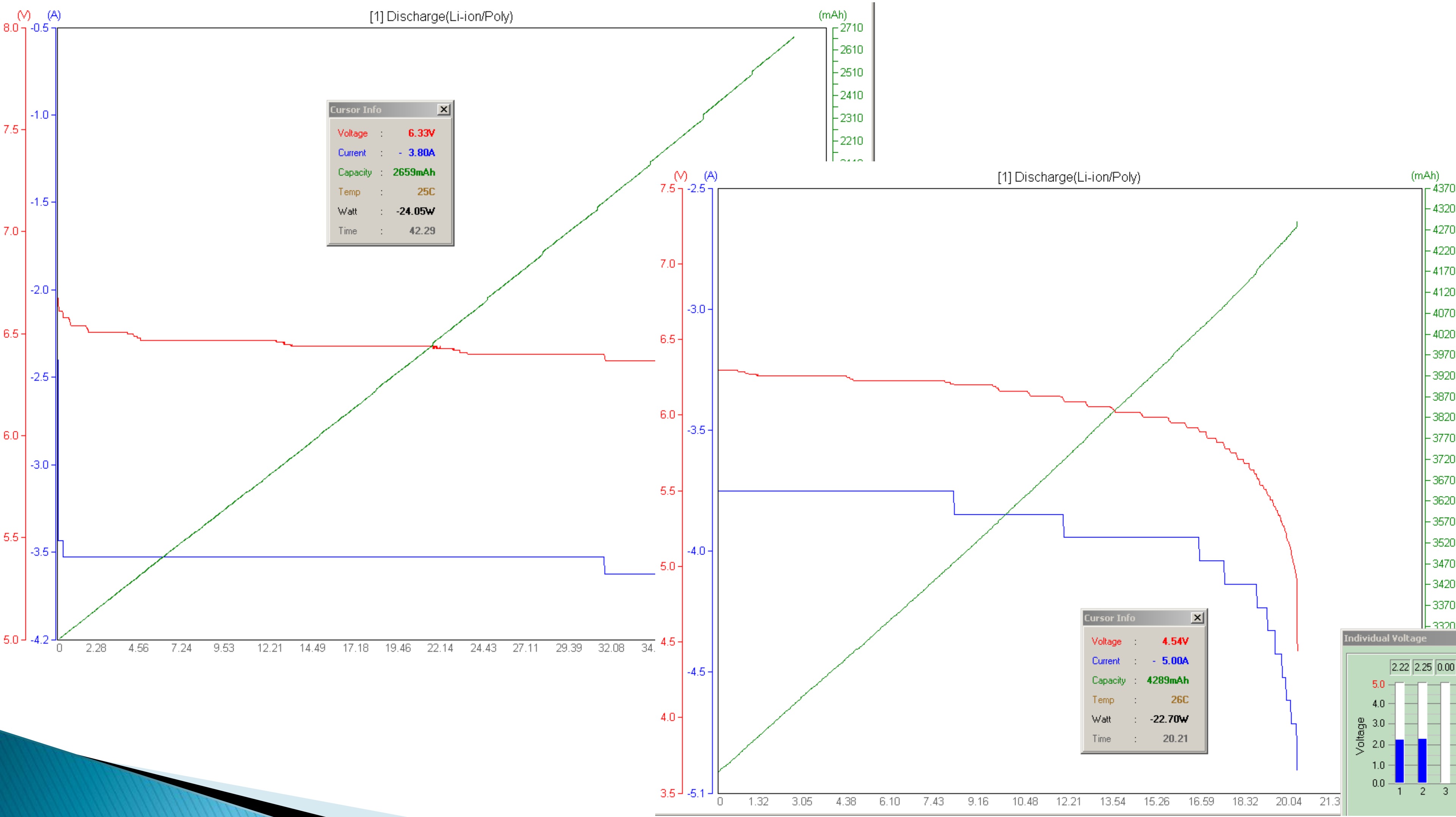
- Using Both Series and Parallel to Achieve shared Characteristics



Behavior (Pack)



Behavior (Pack)



Cell Balancing

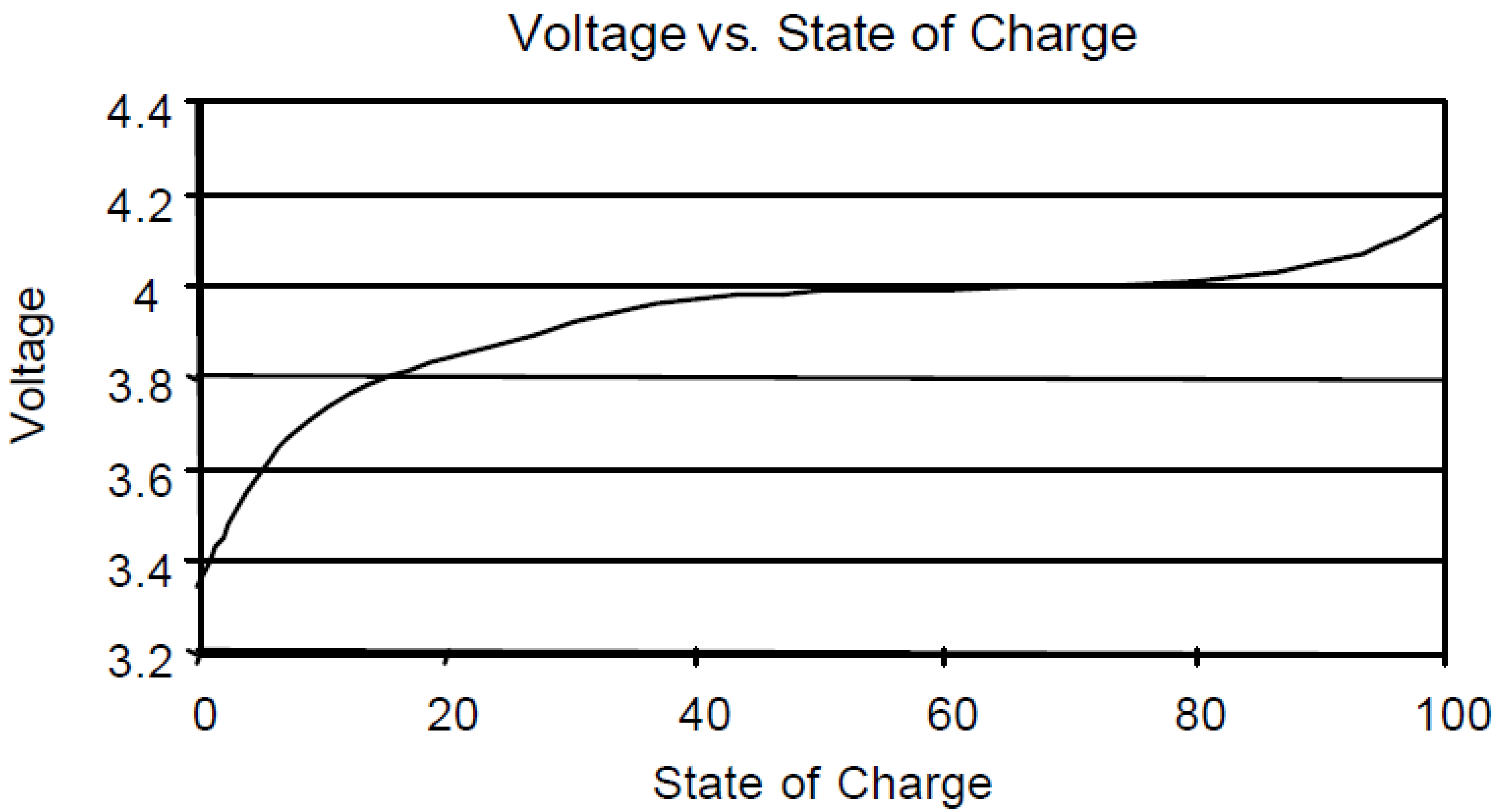
- Why
- SOC (State of Charge)
- Balancing Approaches
- Balancing Design
- Future Designs

Why

- Capacity
- Varying SOC
- Total Capacity

SOC (State of Charge) vs. Capacity

- SOC – A measure of the amount of electrochemical energy left in a cell or battery. Expressed as a percentage of Battery Capacity.
- SOC = Capacity Left / Total Capacity
- Capacity – The rated amount of AH which can be delivered under specified conditions of temperature, rate of discharge and final battery voltage.
- Capacity = Current * Time


Voltage vs. State of Charge
Voltage
4.4
4.2
4
3.8
3.6
3.4
3.2
0
20
40
60
80
100
State of Charge

(Moore, 2001)

Effects of Cell Balancing

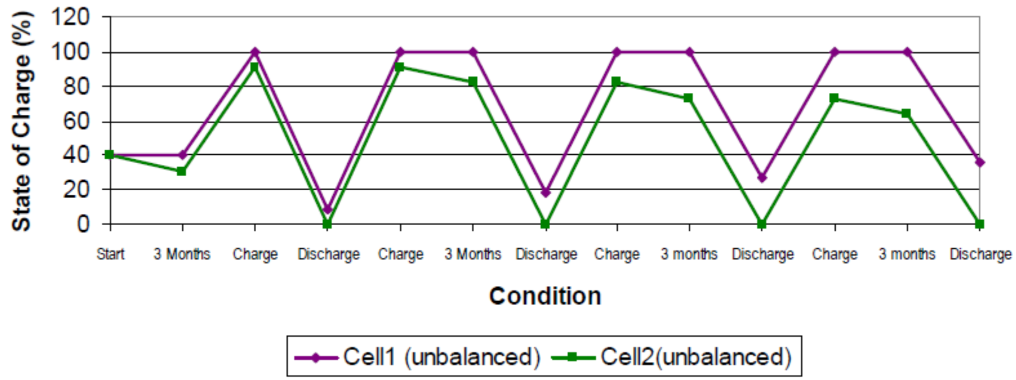


Fig. 1: Cell Capacity With No Cell Balancing

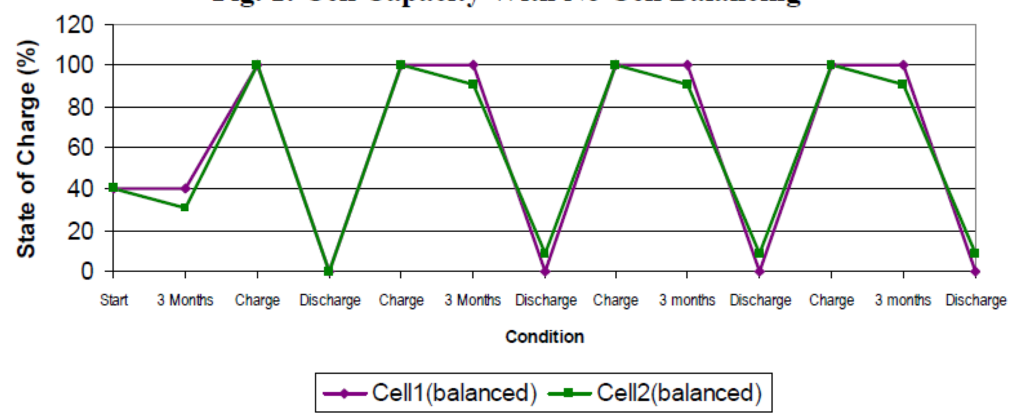
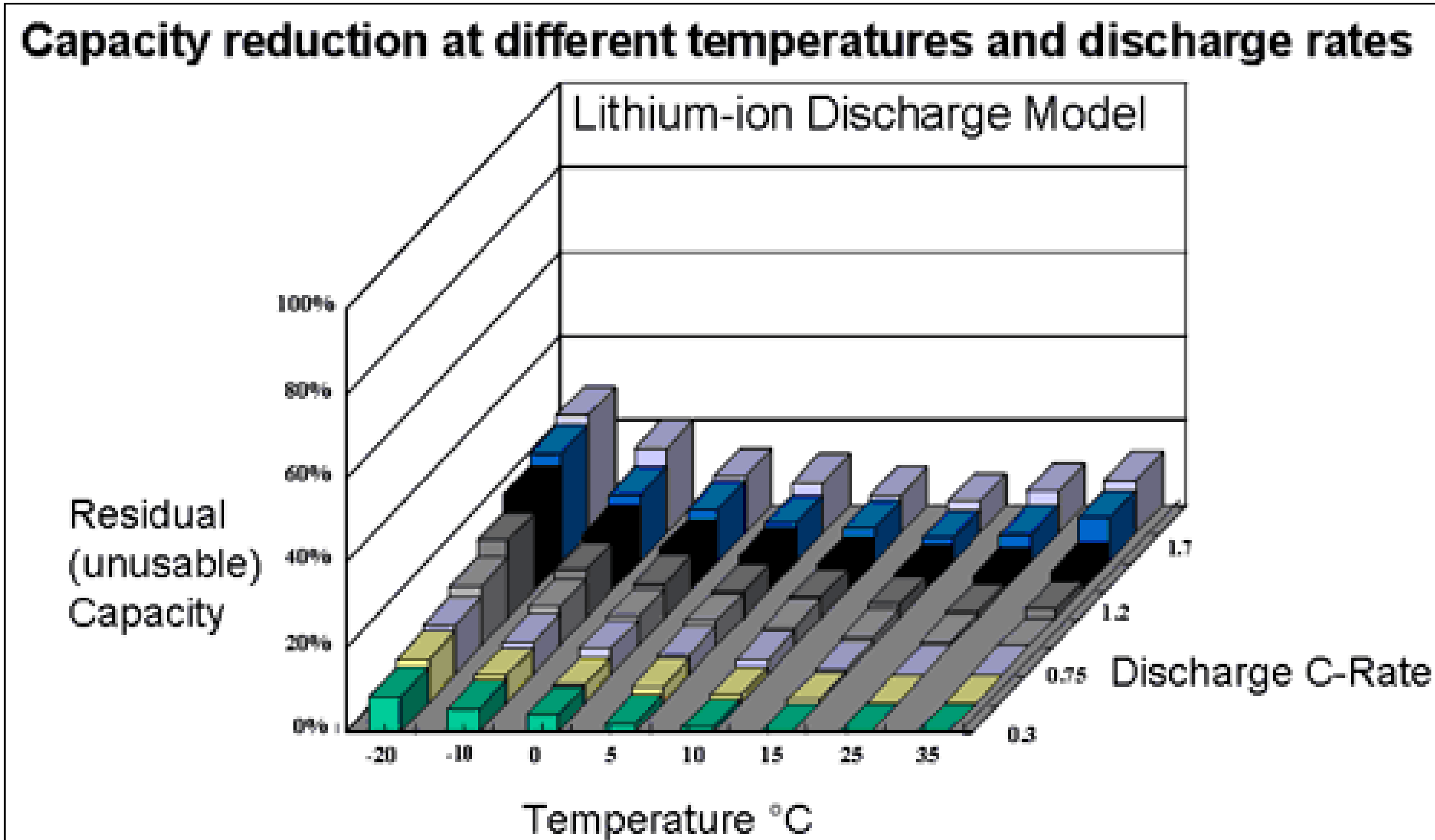


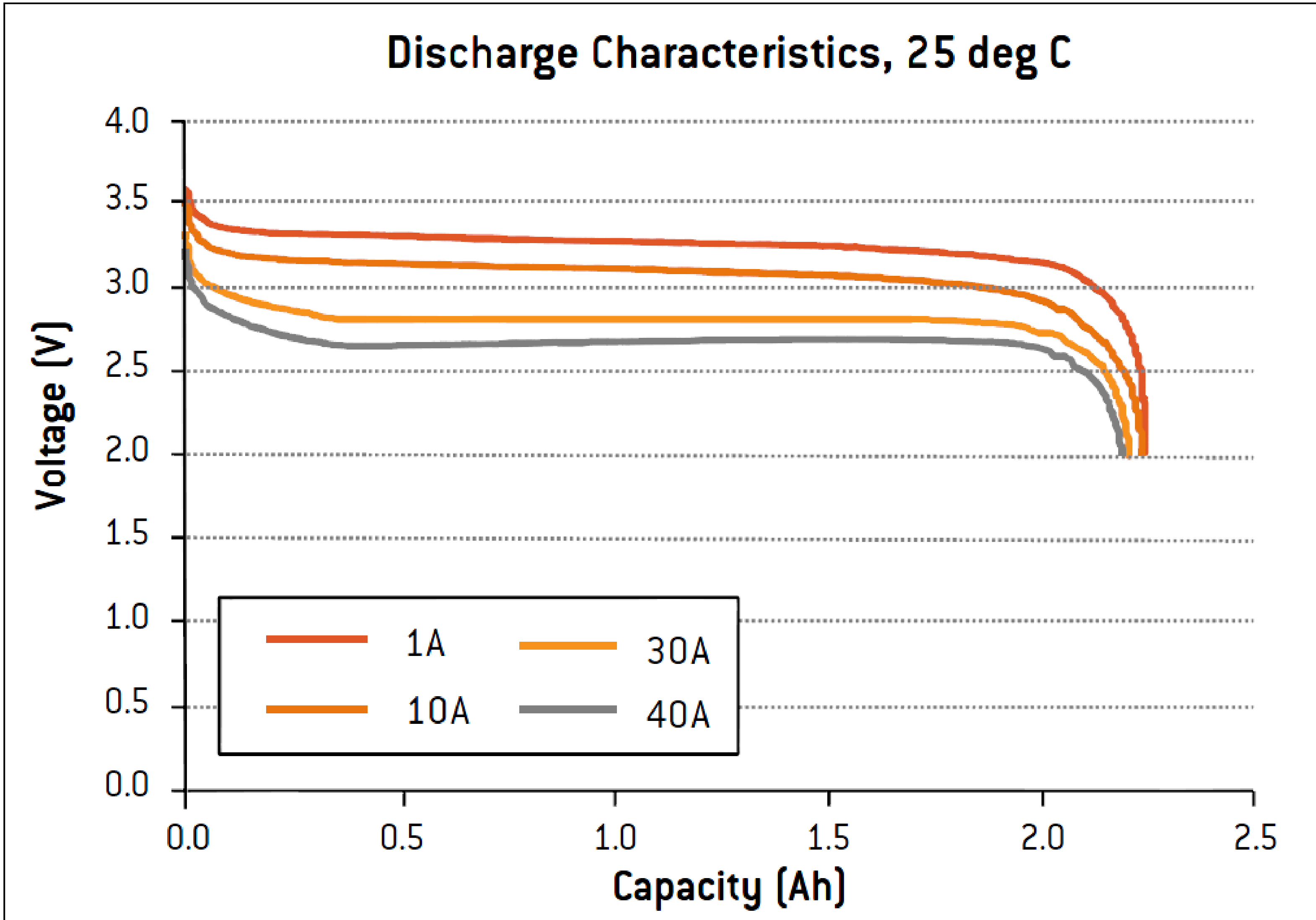
Fig. 2: Cell Capacity With Cell Balancing

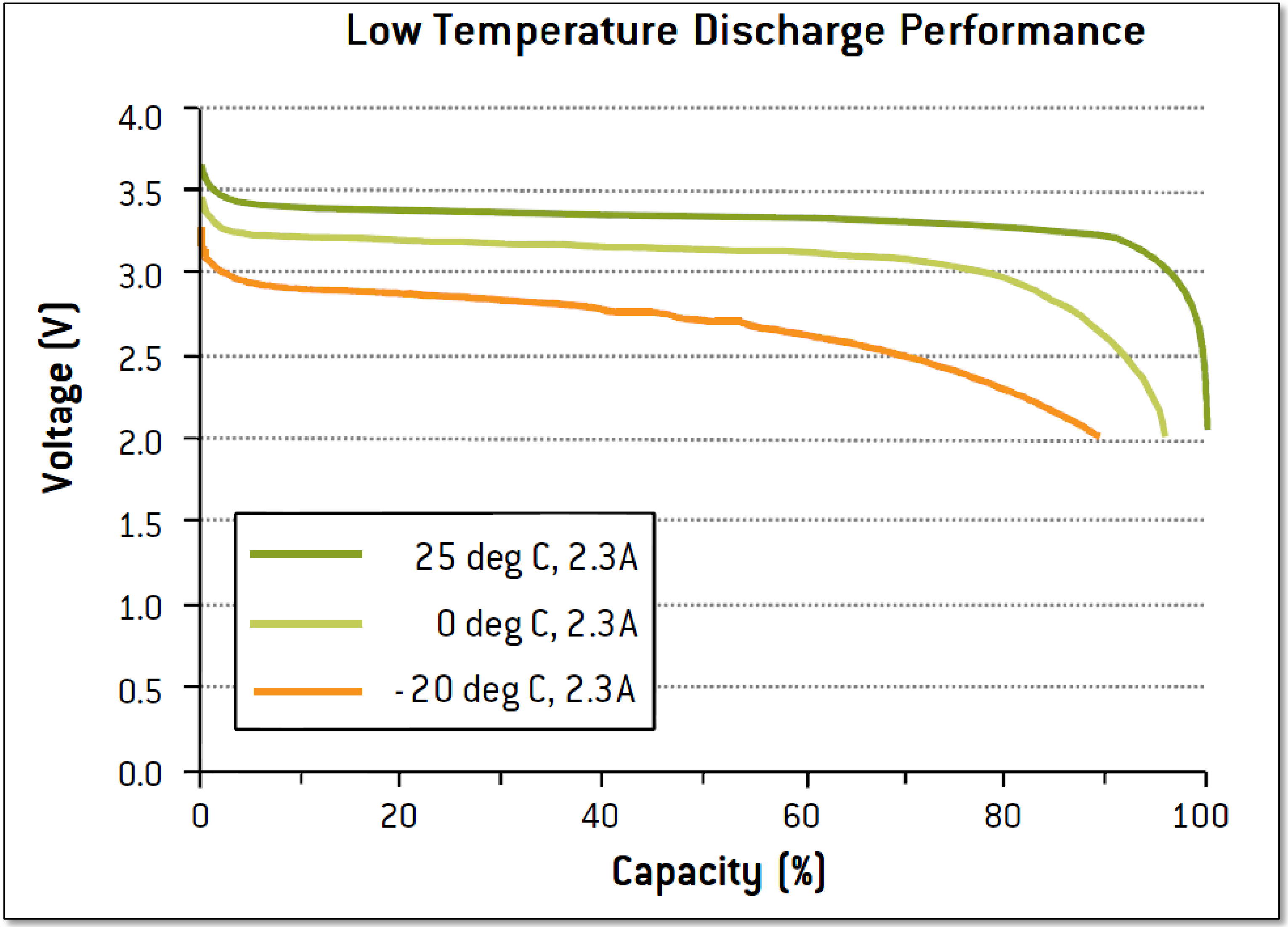
SOC (State of Charge)

- Voltage
- Temperature
- Rate of charge or discharge



(Woodbank, 2005)


Discharge Characteristics, 25 deg C
Voltage (V)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
2.5
Capacity (Ah)
1A
30A
10A
40A

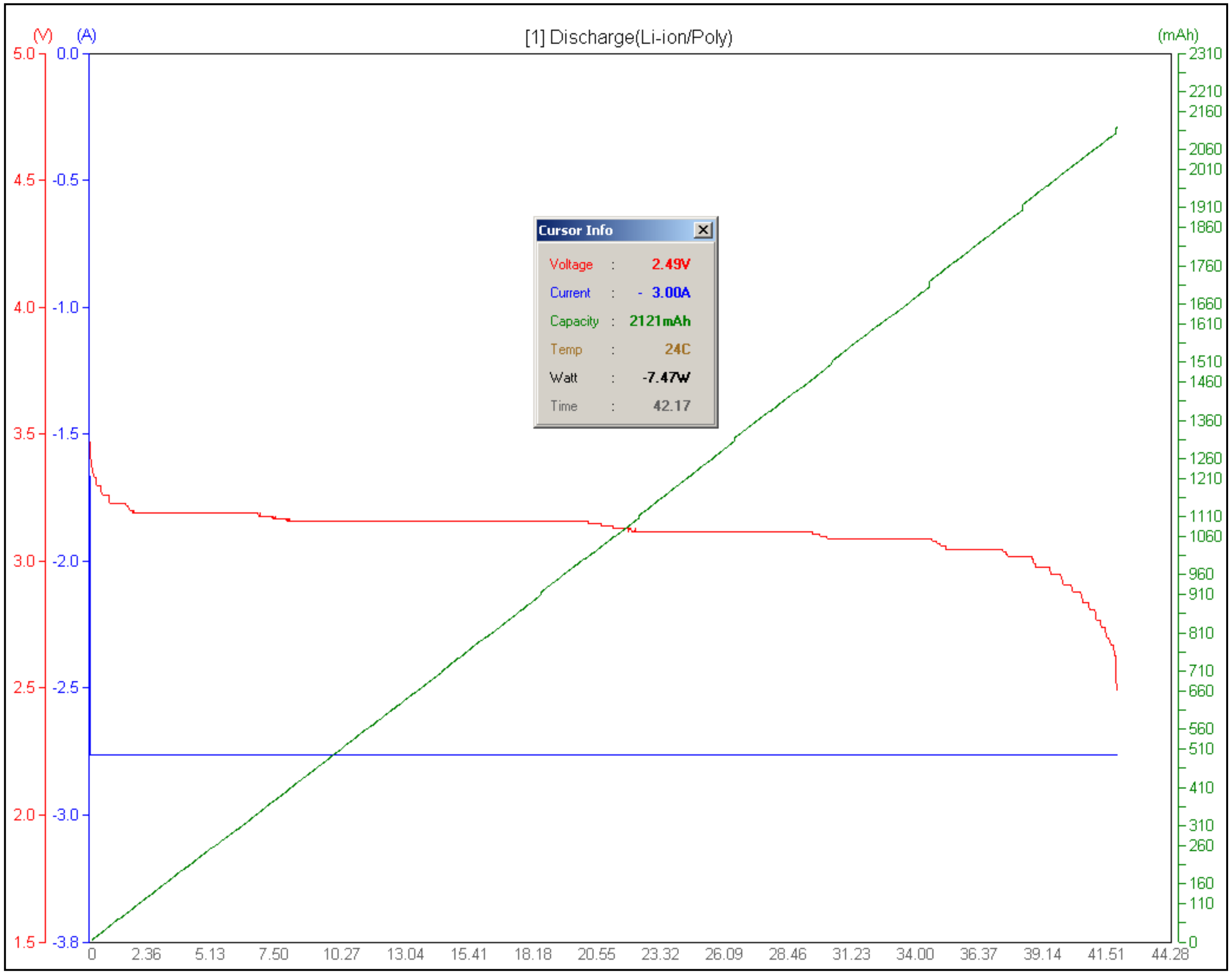


Low Temperature Discharge Performance
Voltage (V)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
20
40
60
80
100
Capacity (%)
25 deg C, 2.3A
0 deg C, 2.3A
-20 deg C, 2.3A

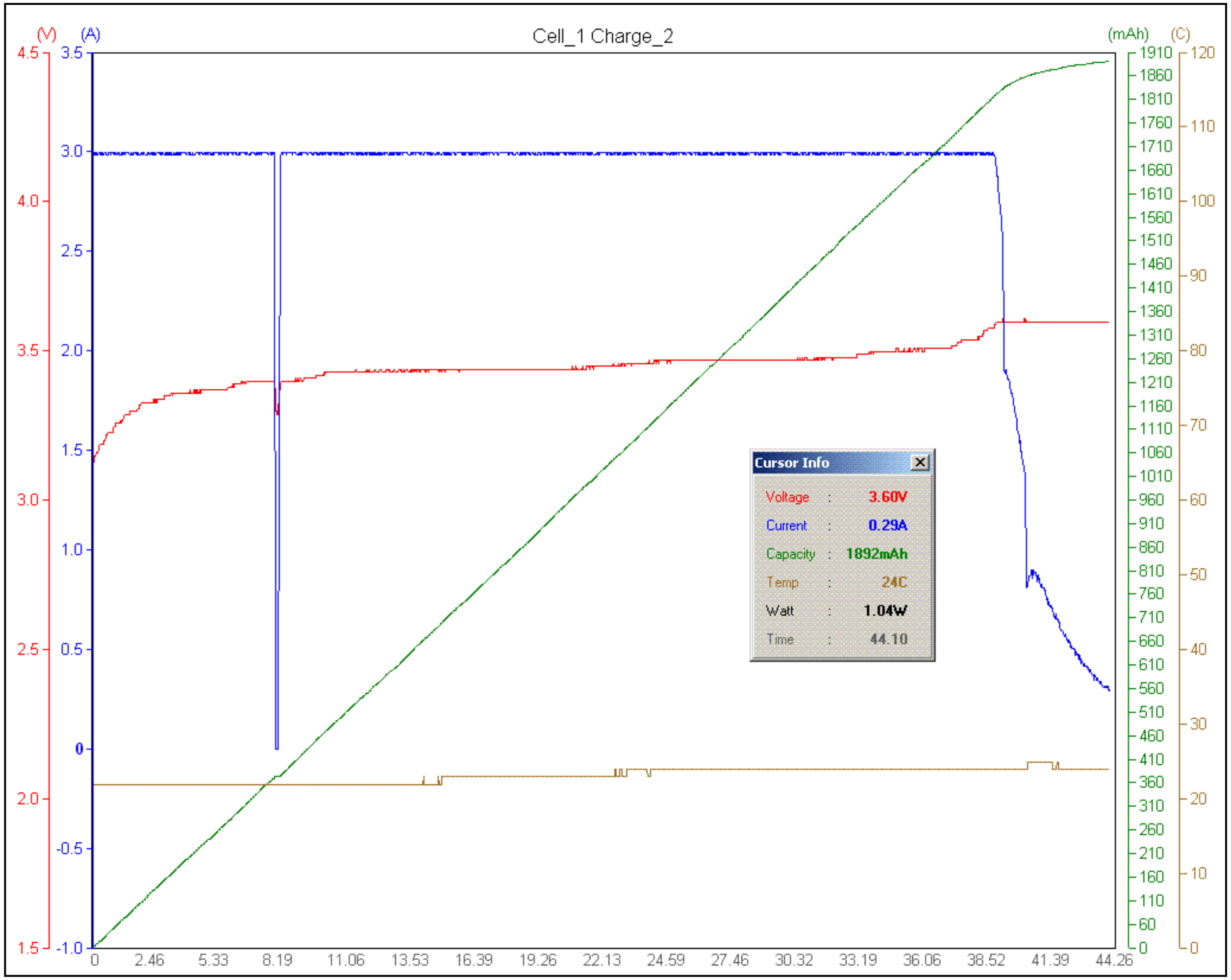
Balancing Approaches

- Passive
  - Dissipation
  - More efficient for low power applications
- Active
  - Transfer of energy
  - More efficient for high power applications

Cell Discharge

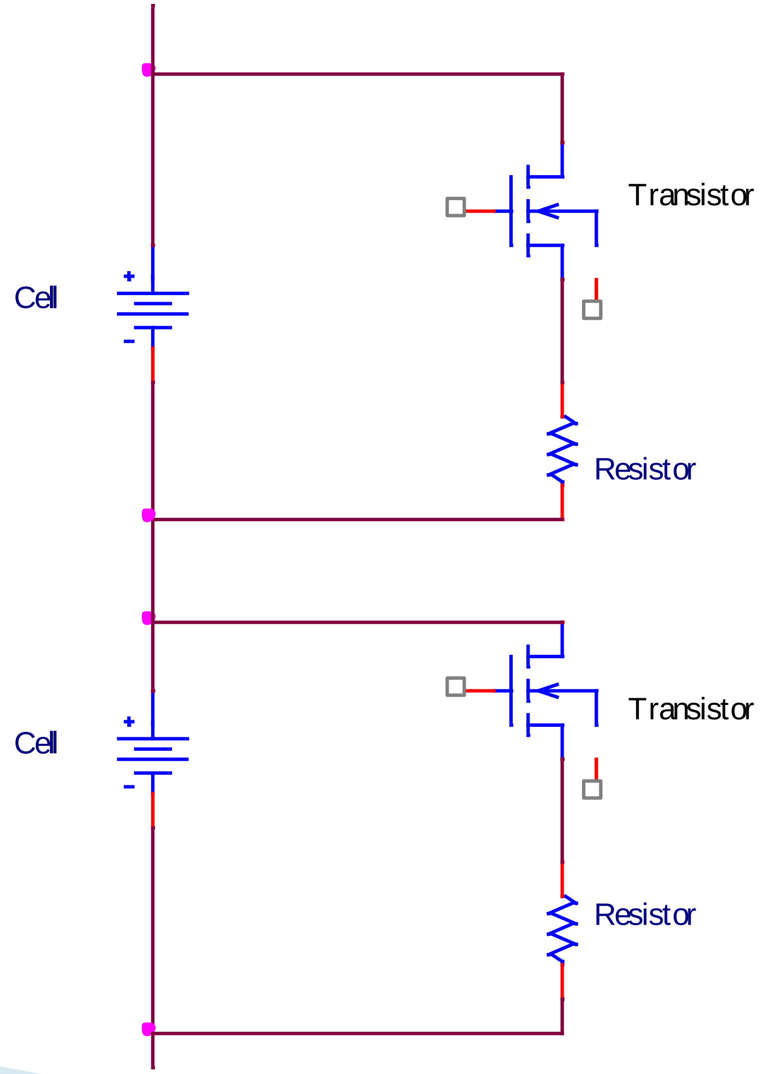


Cell Charge

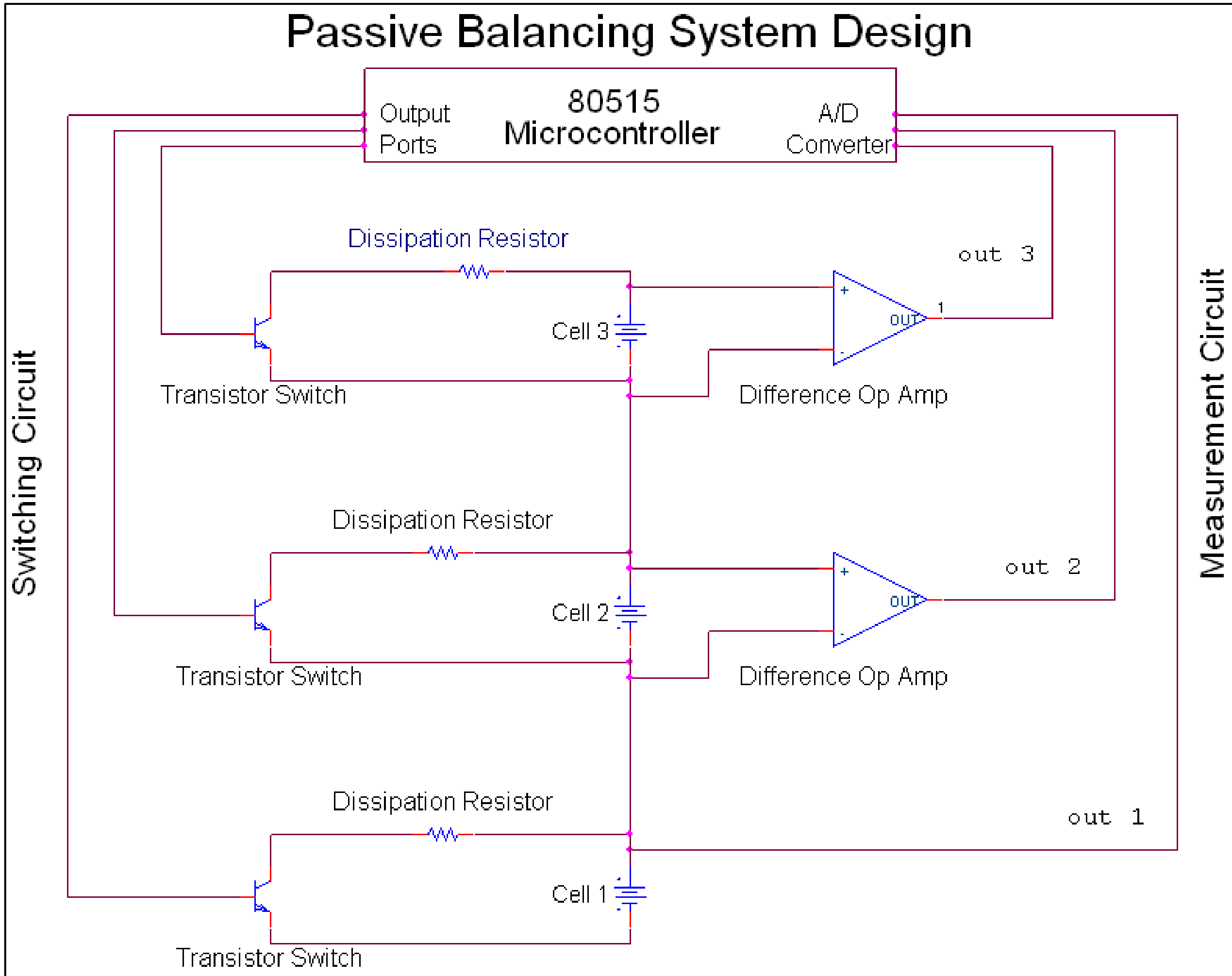


Cell_1 Charge_2
(V)
(A)
(mAh)
(C)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
-0.5
-1.0
1910
1860
1810
1760
1710
1660
1610
1560
1510
1460
1410
1360
1310
1260
1210
1160
1110
1060
1010
960
910
860
810
760
710
660
610
560
510
460
410
360
310
260
210
160
110
60
0
120
110
100
90
80
70
60
50
40
30
20
10
0
0
2.46
5.33
8.19
11.06
13.53
16.39
19.26
22.13
24.59
27.46
30.32
33.19
36.06
38.52
41.39
44.26
Cursor Info
Voltage : 3.60V
Current : 0.29A
Capacity : 1892mAh
Temp : 24C
Watt : 1.04W
Time : 44.10

Passive Balancing



Circuitry


Passive Balancing System Design
80515
Microcontroller
Output
Ports
A/D
Converter
Dissipation Resistor
out 3
Cell 3
Transistor Switch
Difference Op Amp
Switching Circuit
Measurement Circuit
Dissipation Resistor
out 2
Cell 2
Transistor Switch
Difference Op Amp
Dissipation Resistor
out 1
Cell 1
Transistor Switch

Design Results

- 300mA shunting current
- 2 mV per minute
- 1.2 W

Future Work

- Cell Interconnect Switching (Soft Failure and Current Interrupt)
- Active Balancing for use in High Power Applications
- Interface all Monitoring Circuitry with Microprocessor
- Obtain Larger Capacity Cells

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- Martinez, Carlos. “Cell Balancing Maximizes the Capacity of Multi-Cell Li-Ion Battery Packs.” 2005. Analog Zone. 2009 <http://www.analogzone.com/pwrt0207.pdf>.
- Stephen W. Moore, Peter J. Schneider. Copyright © 2001 Society of Automotive Engineers, Inc.
- http://www.mpoweruk.com/soc.htm. Copyright © Woodbank Communications Ltd 2005

Questions?

Typical Energy Storage Systems

- Lead Acid
  - 1859
- Nickel Metal Hydride
- Lithium-Ion

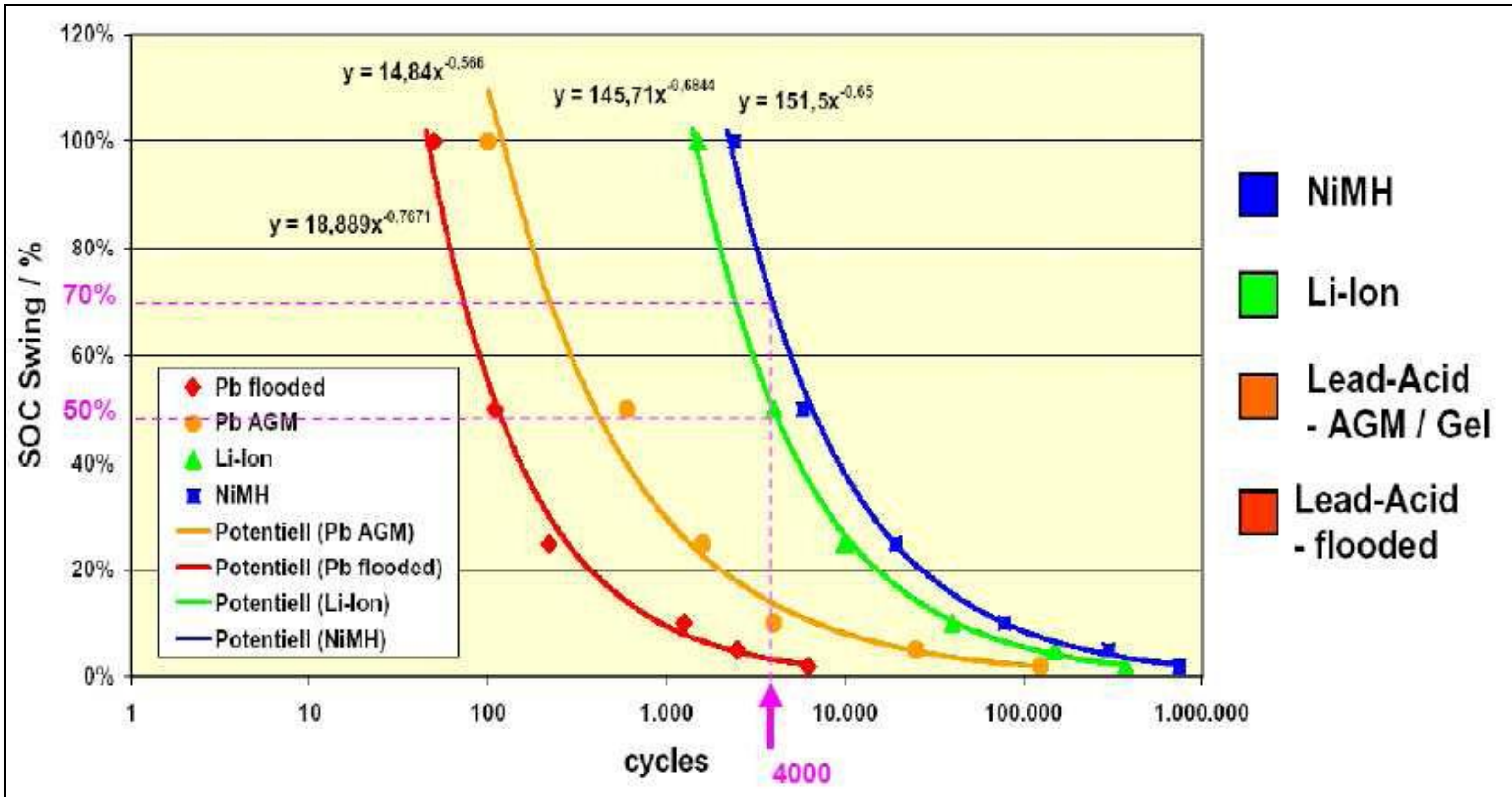
Battery Comparison

Key (relative to each other)

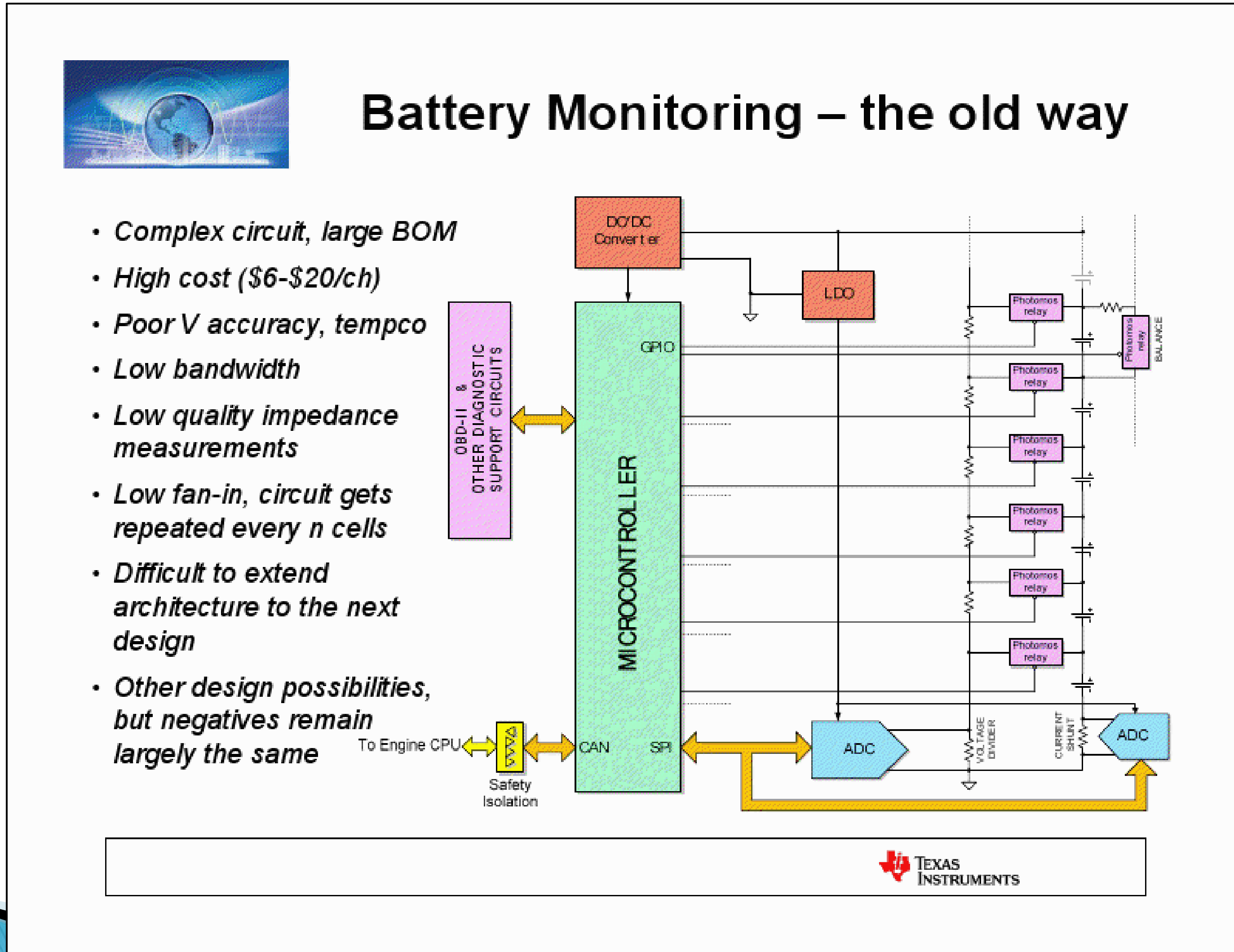
Key
Poor
Fair
Good

Attribute	Lead Acid	NiMH	Li-Ion
Weight (kg)	Poor	Fair	Good
Volume (lit)	Poor	Good	Good
Capacity/Energy (kWh)	Poor	Fair	Good
Discharge Power (kW)	Good	Fair	Good
Regen Power (kW)	Poor	Fair	Good
Cold-Temperature (kWh & kW)	Good	Fair	Poor
Shallow Cycle Life (number)	Fair	Good	Good
Deep Cycle Life (number)	Poor	Good	Fair
Calendar Life (years)	Poor	Fair	Fair
Cost ($/kW or $/kWh)	Good	Poor	Poor
Safety- Abuse Tolerance	Good	Good	Fair
Maturity - Technology	Good	Good	Fair
Maturity - Manufacturing	Good	Fair	Poor

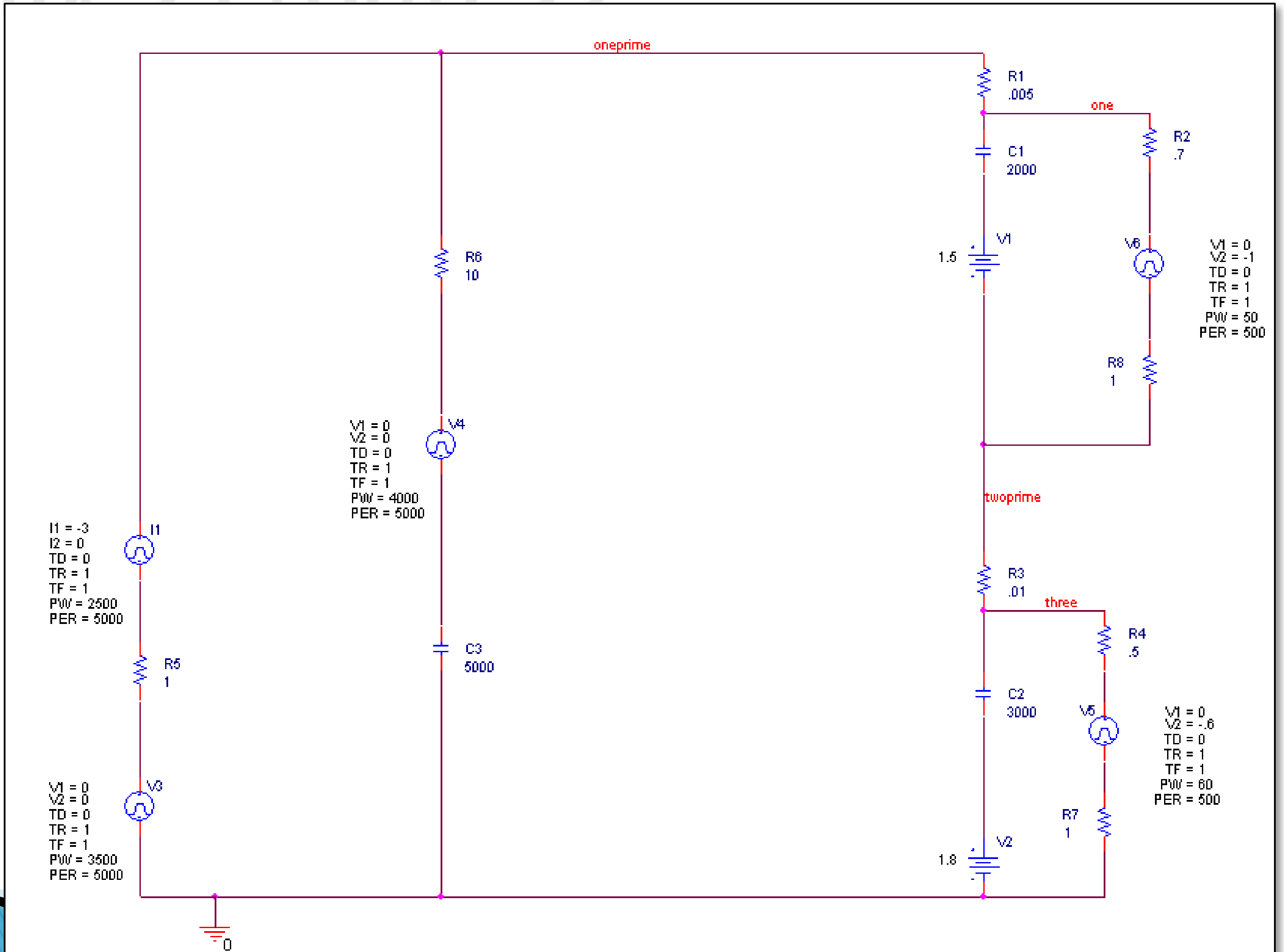
Battery Comparison (cont.)



Battery Comparison (cont.)



Jeremy’s Progress

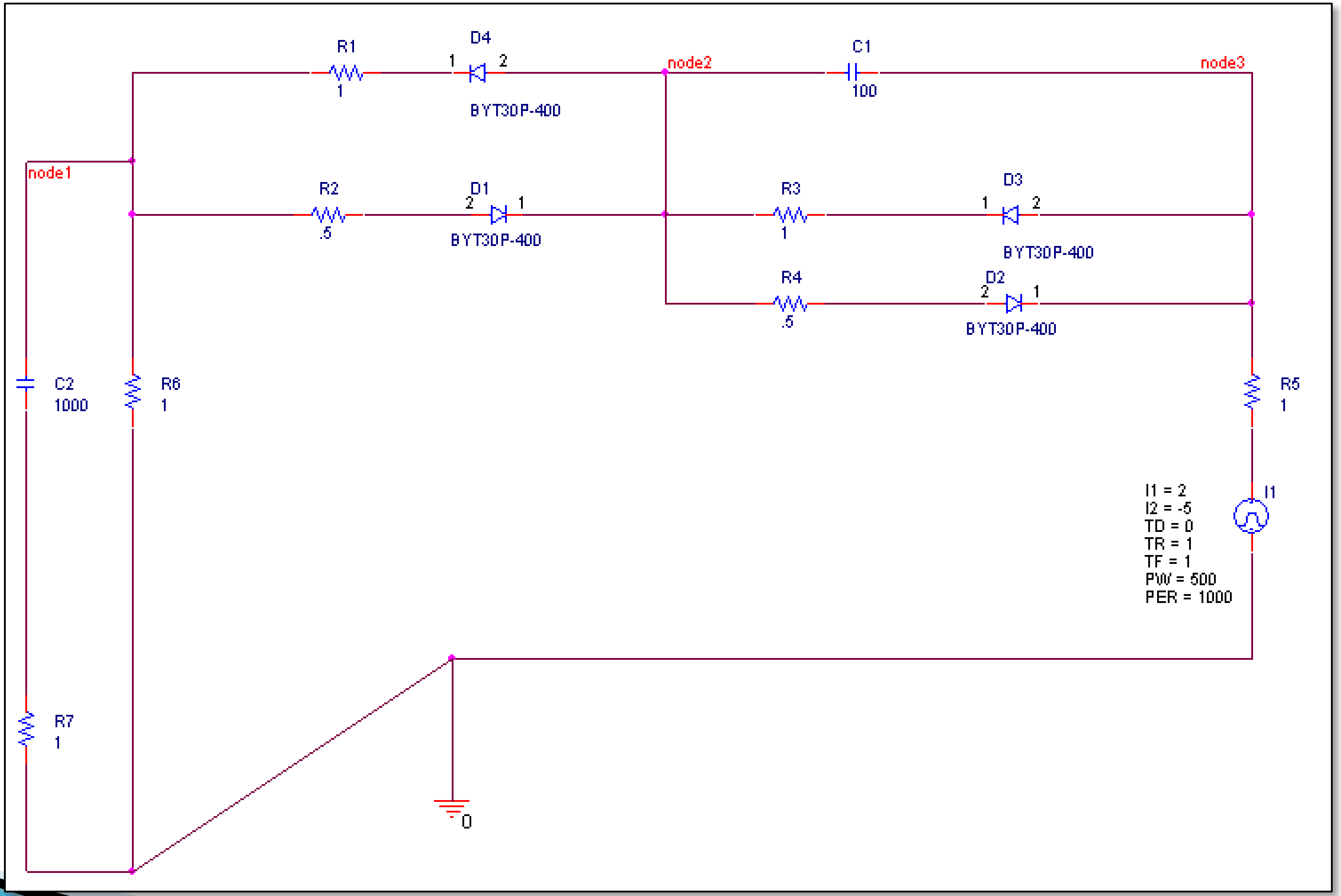


Jeremy's Progress

- Investigation of Monitoring System:
- Purchased DC1393B Monitoring Demo Board – Complete
- Purchased 590B USB interface for Demo Board
- – Complete

- Investigation of Battery Model
- In progress

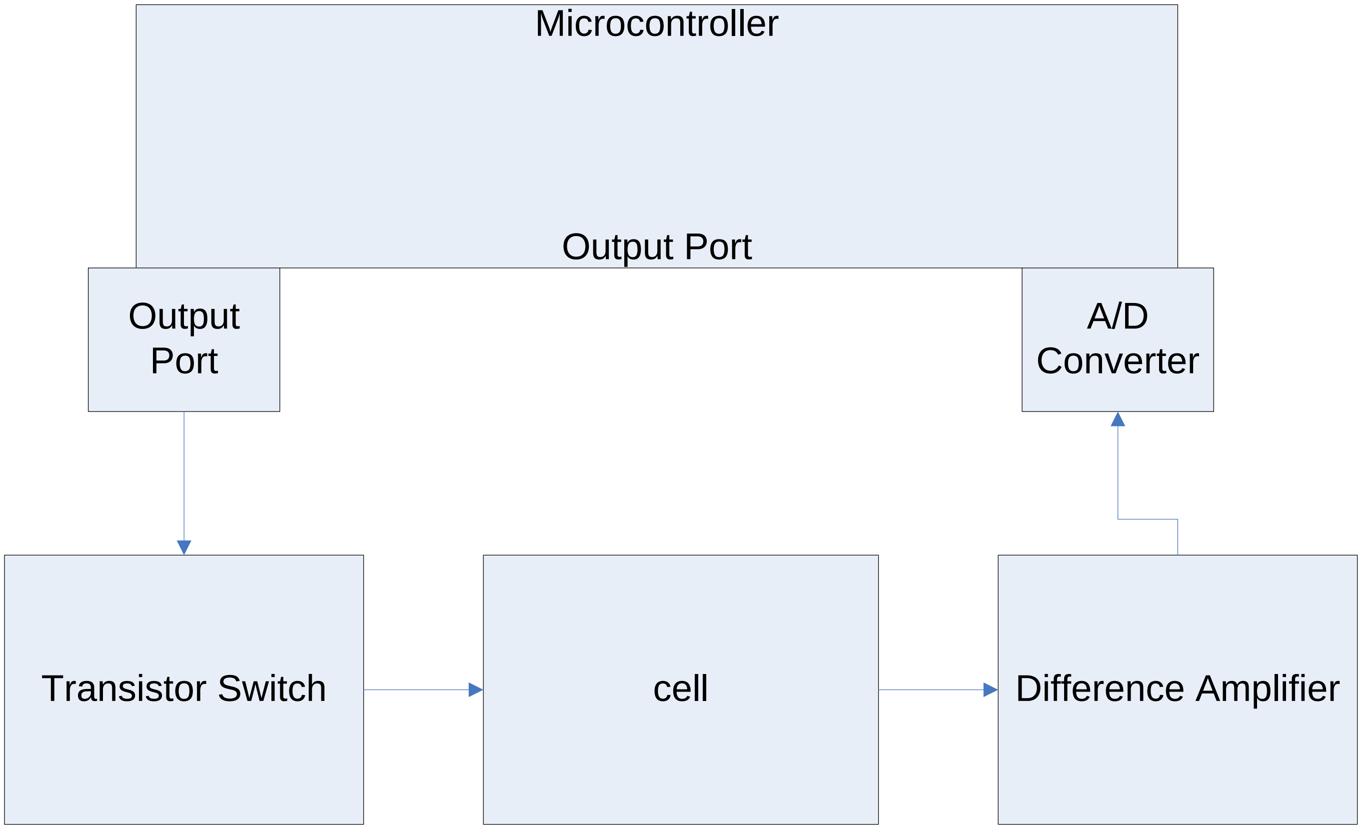
Jeremy's Progress



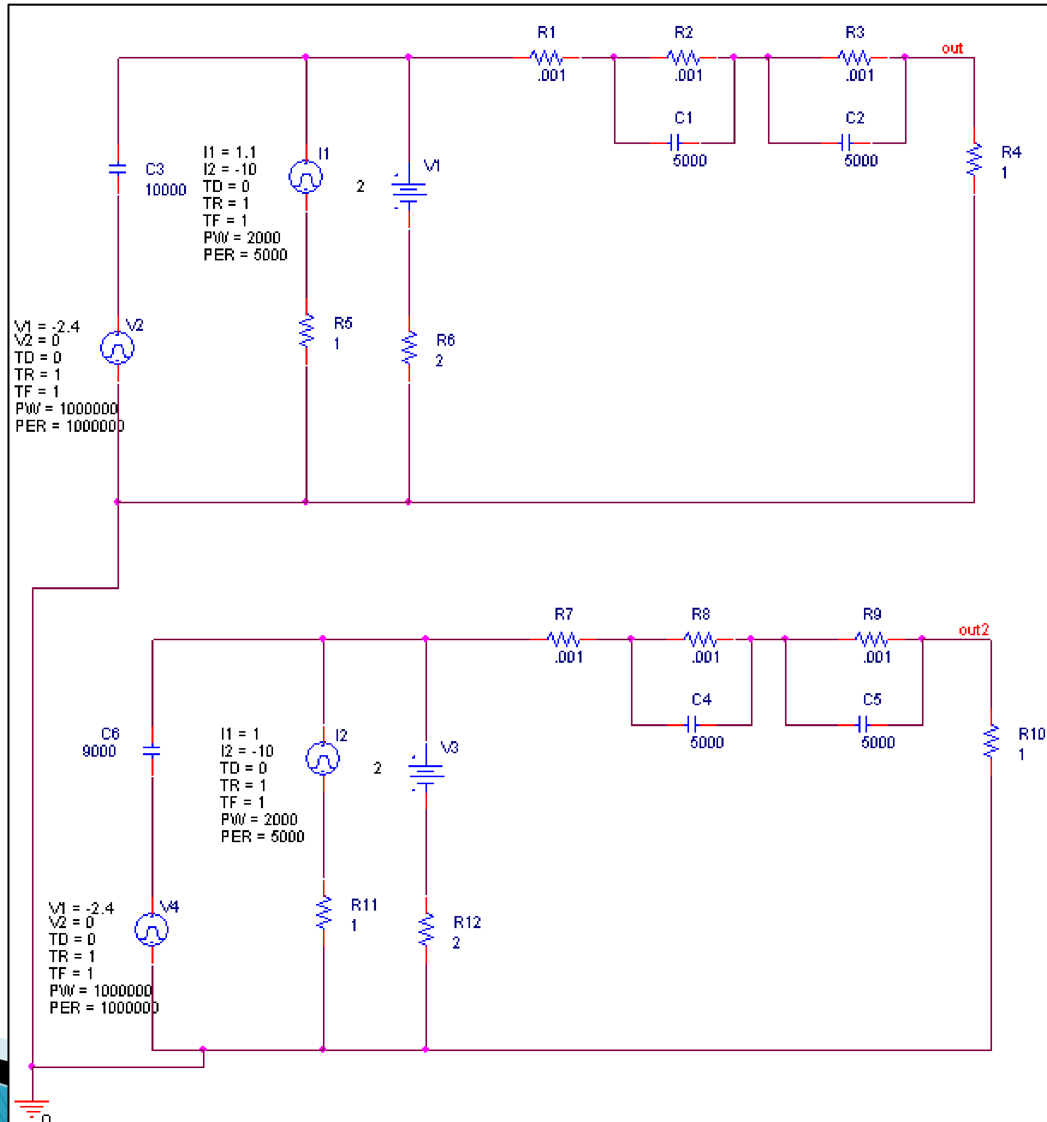
Updated Schedule

Project Schedule				
Week	**Time**		**Task - Jeremy**	**Task - Charlie**
1	18-Jan	24-Jan	Investigation of monitoring system	Research Lab Charger
2	25-Jan	31-Jan	Investigation of monitoring system	Research => Purchase Lab Charger
3	1-Feb	7-Feb	Finalize Purchases	Research Charging Cicuit Topologies
4	8-Feb	12-Feb	Investigation of battery model	Study Battery Datasheets and Information
5	15-Feb	14-Feb	Investigation of battery model	Develop Battery Testing Procedure
6	22-Feb	28-Feb	Investigation of battery model/ presentation/ experiments	Charge & Discharge test on cells
7	1-Mar	7-Mar	Develop exact battery model	Charge & Discharge test on series combinations
8	8-Mar	14-Mar	Design balancing circuitry	Charge & Discharge test on parallel Combinations
9	15-Mar	21-Mar	Design protection circuitry	Design => Test => Implement Charging Circuit
10	22-Mar	28-Mar	Implement batt. monitoring sys. Based on chipset	Design => Test => Implement Charging Circuit
11	29-Mar	4-Apr	Observe embedded balancing system of charger	Implement and test an 8 series Stack w/ Batt. Management
12	5-Apr	11-Apr	Build balancing and protection circuitry	implement 2nd & 3rd 8 series stack
13	12-Apr	18-Apr	Testing and trouble shooting balancing system	implement Battery Pack & Test for Specifications
14	19-Apr	25-Apr	Implement microprocessor?	Prepare final project report
15	26-Apr	2-May	Prepare presentation and final project report	Prepare Presentation
16	3-May	9-May	Presentations	Presentations
17	10-May	16-May	Presentations	Presentations
				NOTE: Subject to Variation

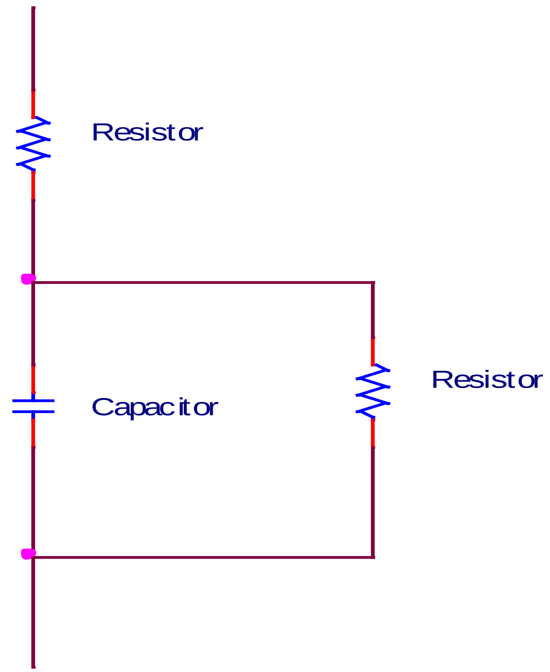
Balancing Design



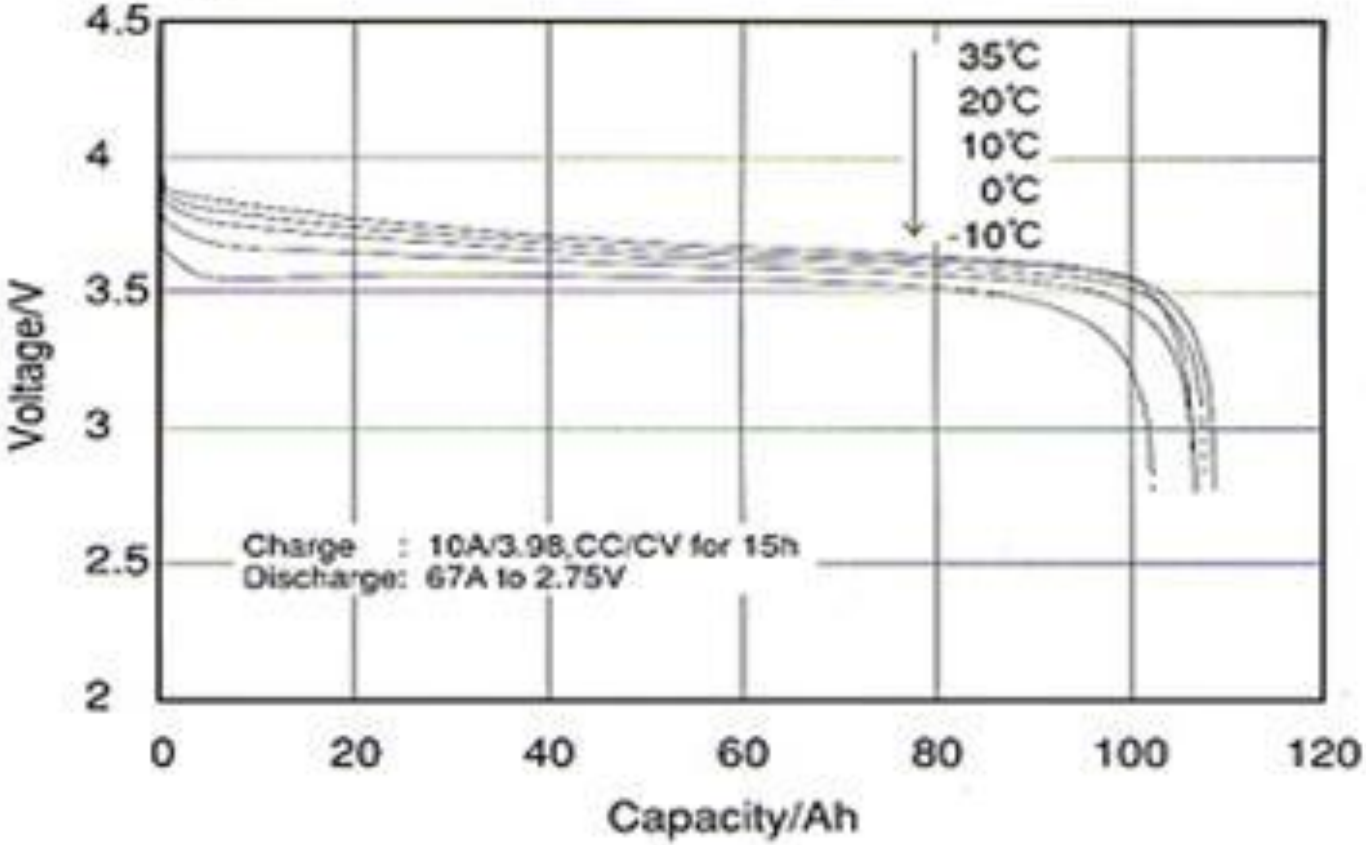
State of Charge vs Open Circuit Voltage



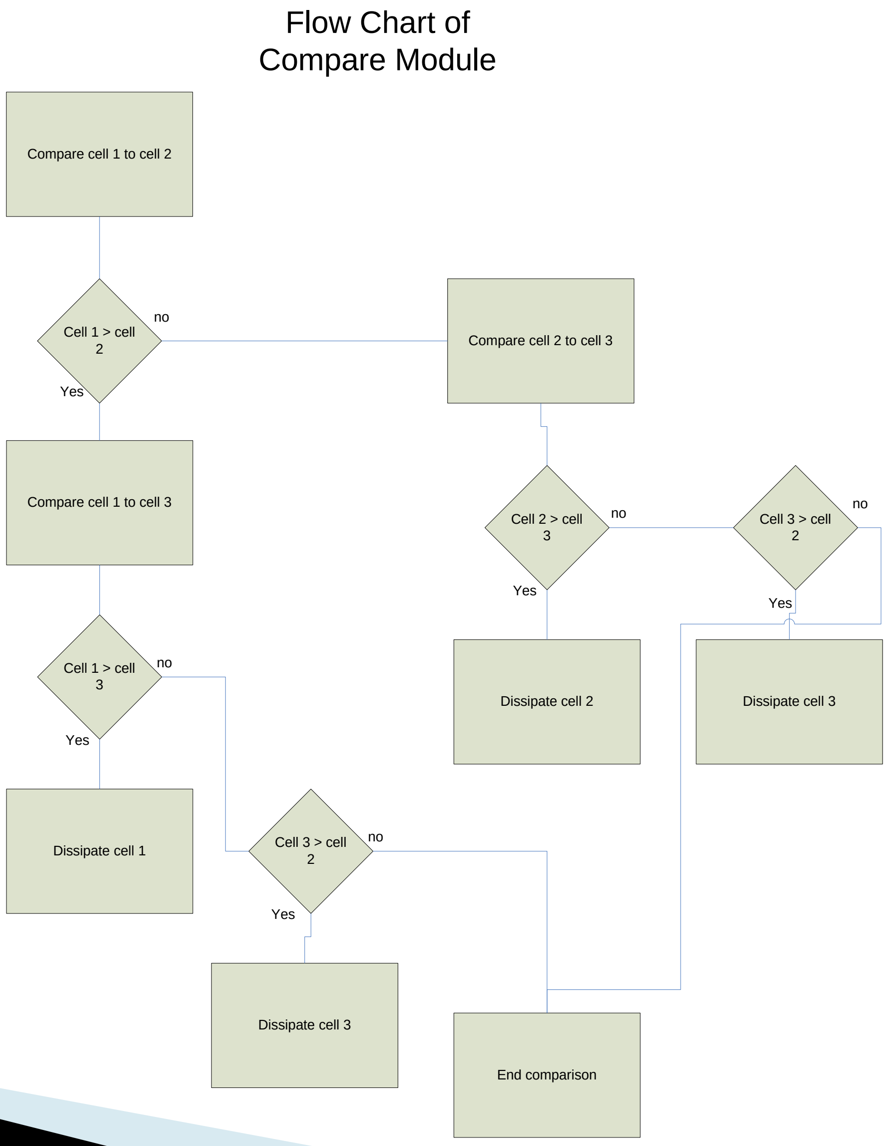
Basic Battery Model

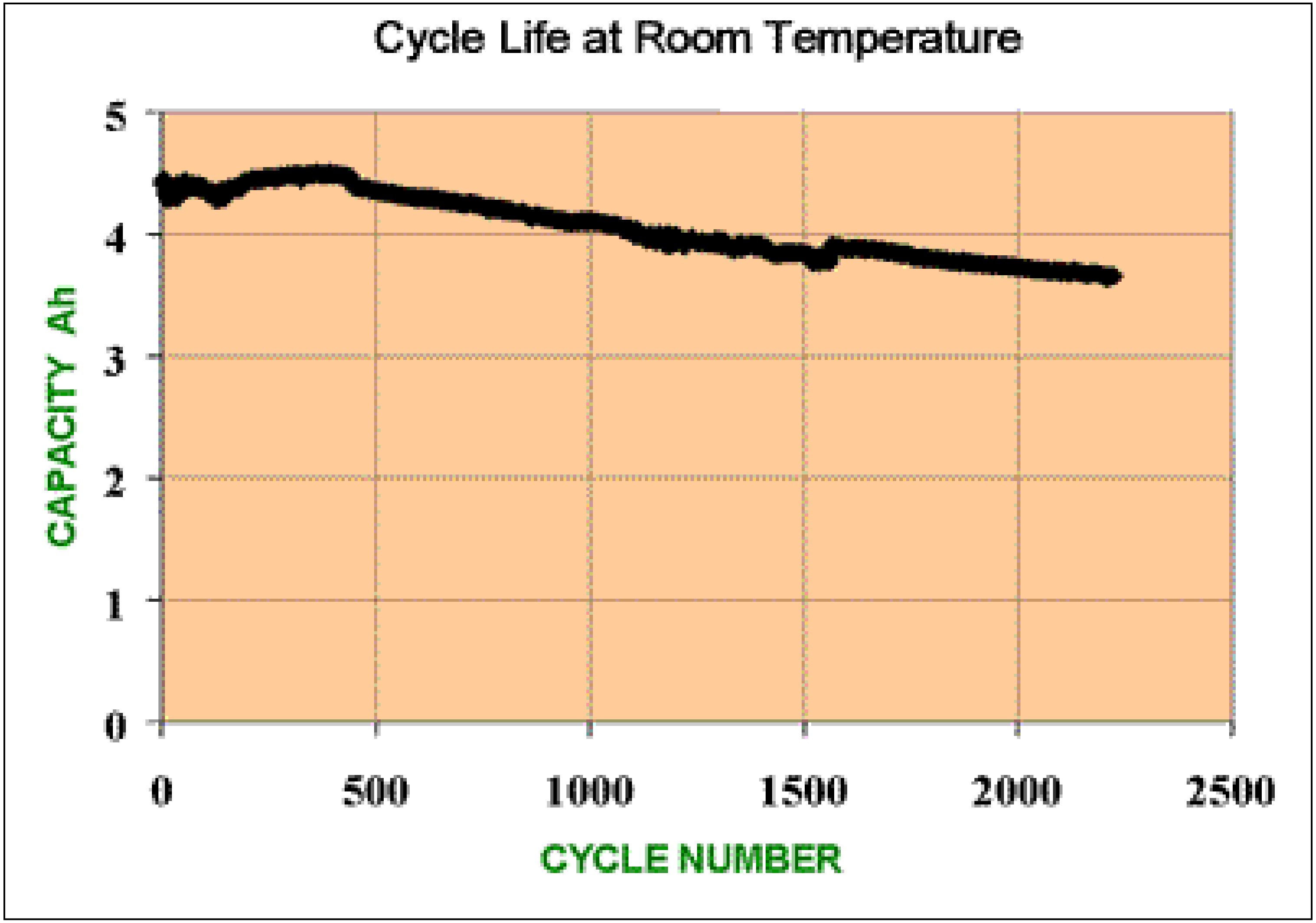


Discharge characteristics of 100Ah Li-ion cell.



Switching Circuitry




Cycle Life at Room Temperature
CAPACITY Ah
5
4
3
2
1
0
0
500
1000
1500
2000
2500
CYCLE NUMBER

Behavior (Series)

Summary