Li-Ion Charge Balancing and Cell Voltage Monitoring for Performance and Safety

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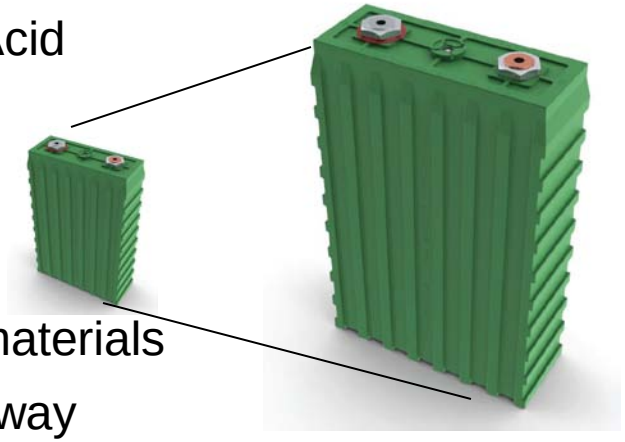
Outline / Objectives of this talk

- **Basic advantages of Li-Ion Technology**
- **Challenges of using Li-Ion effectively and safely**
- **What is required?**
  - Individual cell management
  - Charge management
  - How to deal with dead cells in huge battery arrays
- **Individual Cell Management approaches**
  - Typical topologies
    - Bypass, individual isolated, charge sharing
  - Advantages and disadvantages
- **Major investments and the future**
  - Aeroflex, Boeing, and other satellite systems have invested millions in charge sharing balancing
  - Others in utility space are investing in ???
- **Questions and Answers**

Introduction

- **Li-Ion batteries are gaining attention as an attractive energy storage mechanism**
  - 2~4 x the volumetric energy density of Lead Acid
  - Longer cycle life and calendar life
  - High energy recovery efficiency
  - Large format cells are becoming available
  - $$ Research into new chemistries, process, materials
  - Government funded large format cells on the way



- **However Li-Ion has a need for battery management to maintain long life and for safety**
  - Battery management includes cell balancing and cell voltage monitoring
- **What is Balancing / Why balance?**
- **Why monitor?**

What is / Why Balance Cells?

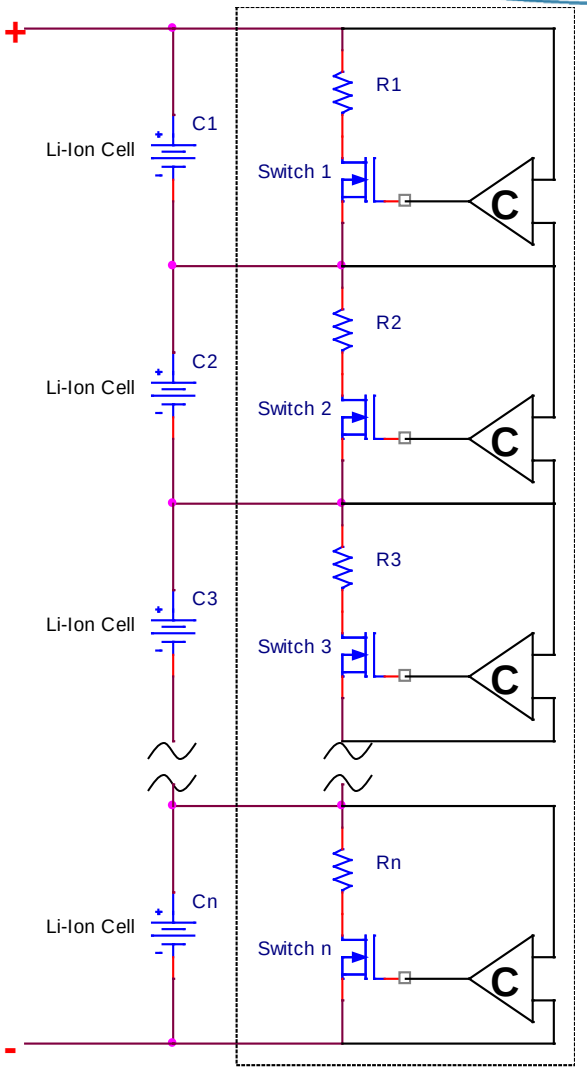
- **Balancing is a process to equalize stored charge (voltage) between cells in a battery. It is a differential current applied to individual cells**
- **Cells in a battery (a series string) have varying characteristics - leakage & capacity - that causes some cells to increase in voltage, others to reduce in voltage with charge cycling and with time**
- **Lithium-ion cells, unlike other types of cells, do not have inherent cell balancing mechanism. For this reason, they are usually balanced by electronic balancing circuits.**
- **Balancing helps keep cells in their Safe Operating Area**
  - The safe operating area is chemistry dependent
  - Upper voltage is bound by over charge limits
    - Li-Ion chemistry degrades or may have energetic release of stored energy upon over charge
  - Lower voltage bound by permanent damage
- **Balancing maximizes the safe energy storage capacity of the battery**
  - Balancing increases useful life

Why Monitor?

- **A Cell Monitor allows visibility into the state of charge of all the cells in a battery.**
  - Allows proactive maintenance on the battery if cells become too divergent
- **Monitoring is a Safety mechanism to take action (terminate charge) if a cell enters an over voltage condition**
- **Monitoring is a fail safe tool to be used in addition to balancing**
  - One does not replace the other.

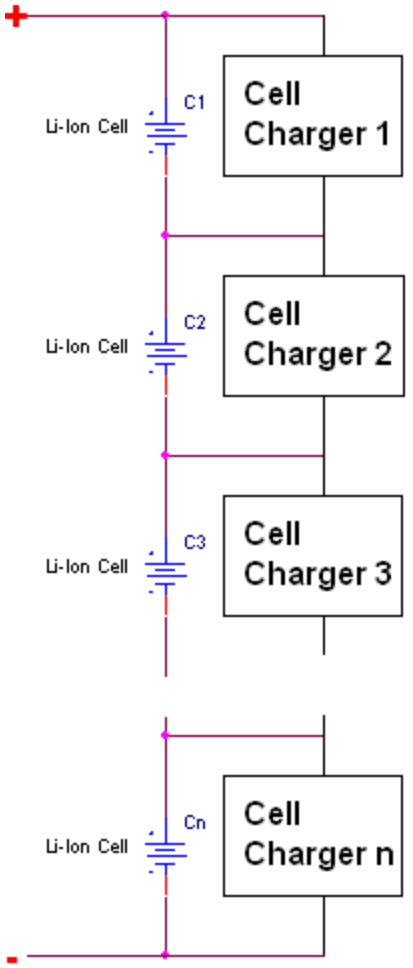
Some Balancing Approaches
Cell Bypass

- **Resistance bypass, fixed or variable threshold**
  - o A circuit monitors each cell voltage
  - o As a cell approaches full charge, turn on a switch to bypass current around the cell.
  - o This limits additional charge into the cell allowing other cells to ‘catch up’ in charge
  - o Balances at full state of charge, end of charge cycle
  - \+ Commonly employed in IC chip solutions, portable products
  - \+ Relatively simple- low cost and reliable
  - – The bypassed cell current is dissipated as heat
  - \+ If few cells are over charged; efficiency is not too bad
  - – If few cells are under charged; poor efficiency -most of the charging energy is dissipated as heat!
  - – Separate Cell Monitor is required



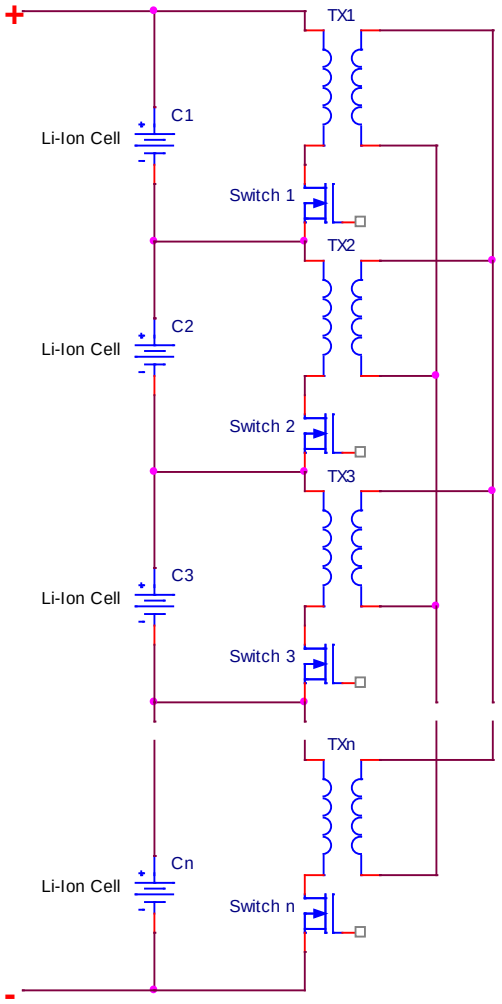
Individual Charger per Cell

- **Individual Cell Chargers**
  - o One isolated charger per cell
    - Constant current bulk charge
    - Constant voltage balance charge
  - – High parts count- higher cost
  - – High parts count - lower reliability
  - \+ High efficiency
  - – Failure Mode Effects needs study
    - E.g. If one of n chargers fail then one cell goes dead or is stressed or take the battery out of service until it is repaired
  - – Separate Cell Monitor Required



Charge Sharing Balancer

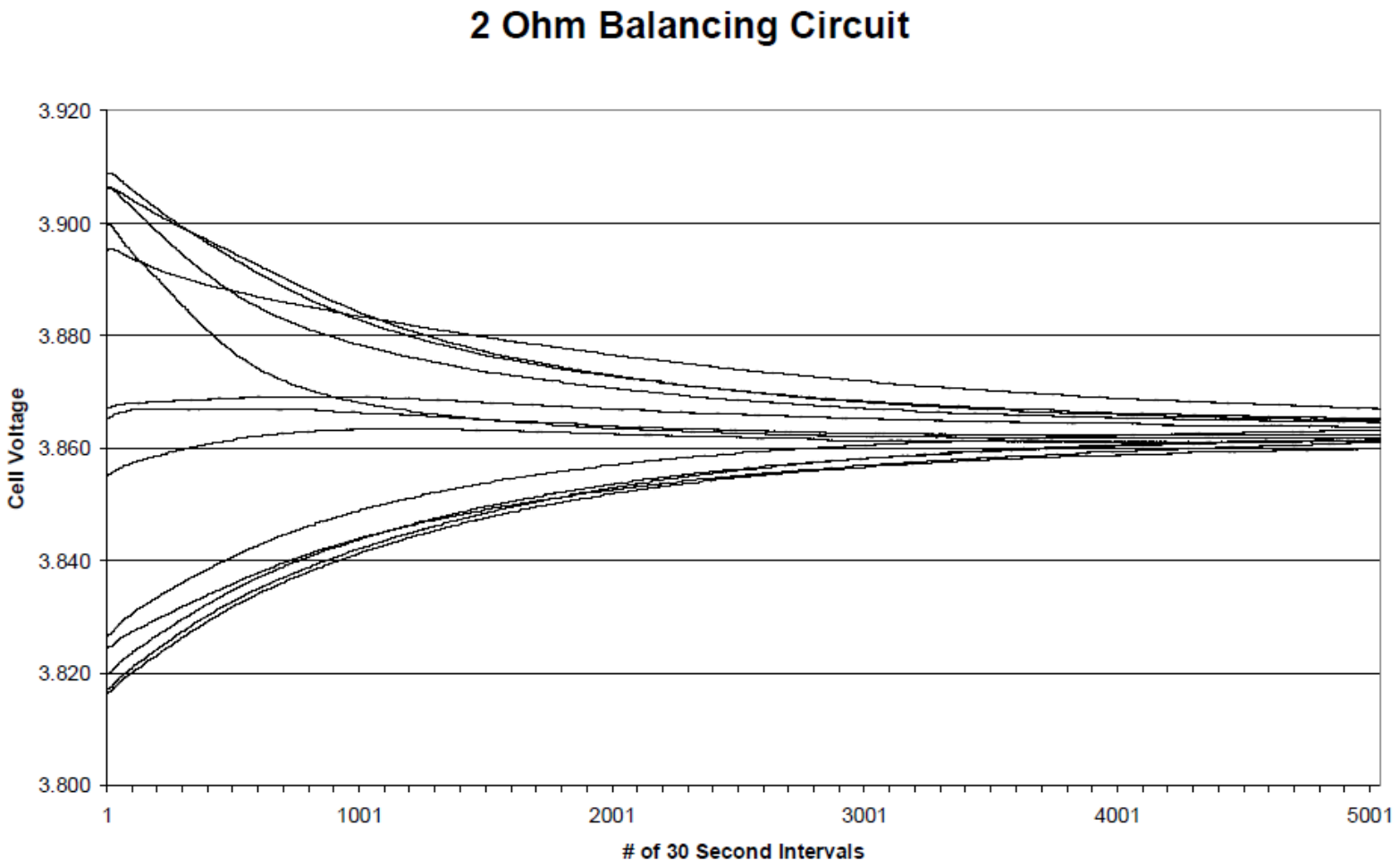
- **Transformer Coupled Charge Sharing**
  - o Series Cells are effectively parallel connected through the transformer action by synchronous switching
  - o In parallel, higher charged cells share their charge with lower charged cells
  - o Balances autonomously- no decision processes required
  - o Can balance at any state of charge
    - Continuous balancing is possible
  - \+ Relatively simple- low cost and reliable
  - \+ High efficiency
  - \+ Scalable
  - \+ Failure Mode Effects Analyzed
  - \+ Good Cell voltage monitoring is easily added



US Patent Granted to Boeing March 2005

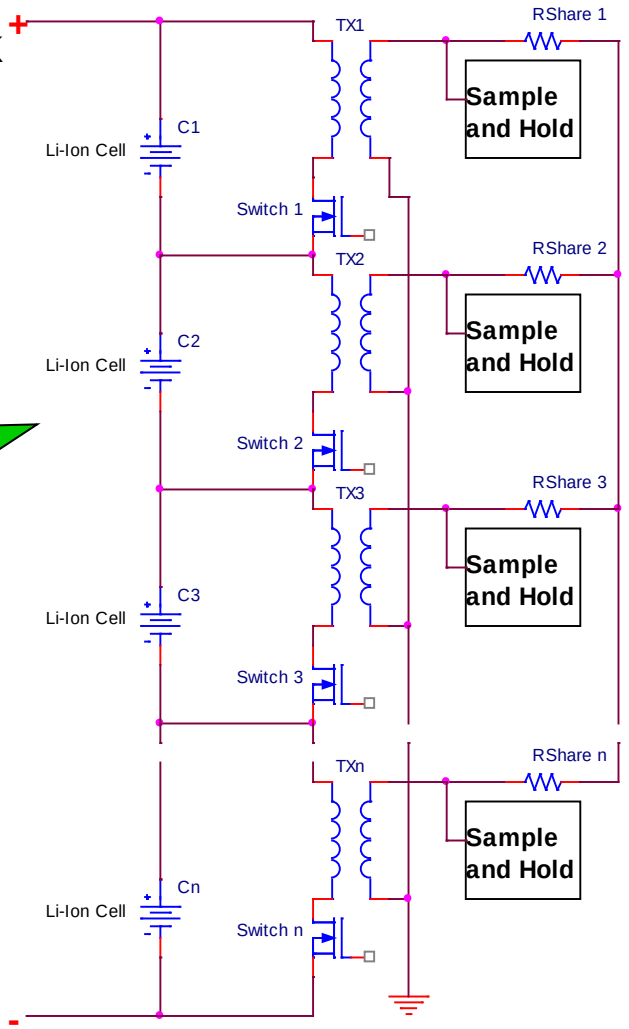
Charge Sharing Balancer

- **Test Results, 13 cell string**



Cell Voltage Monitoring

- **Differential Measurements**
  - Suffer from common mode issues as cell stack increases
- **Switching Matrix**
  - Complex switching using semiconductors or relays
- **Isolation Amplifiers**
  - Elegant but Costly
- **Transformer Coupled**
  - Easily added as part of Charge Sharing Balancer
  - Transformer isolation is robust, reliable



Feature Summary

Technology	Cost	Reliability	Efficiency	Failure Mode Effects	Cell Monitor
Cell Bypass	+	+	-	?	-
Individual Cell Charger	-	-	+	?	-
Sharing Balancer	+	+	+	+	+

Any Questions?

The worlds largest battery installation;
13,760 Ni-Cad cells, 5,000V 27MW/15min 46MW/5min