Development of a Smart High-power Battery for CubeSats

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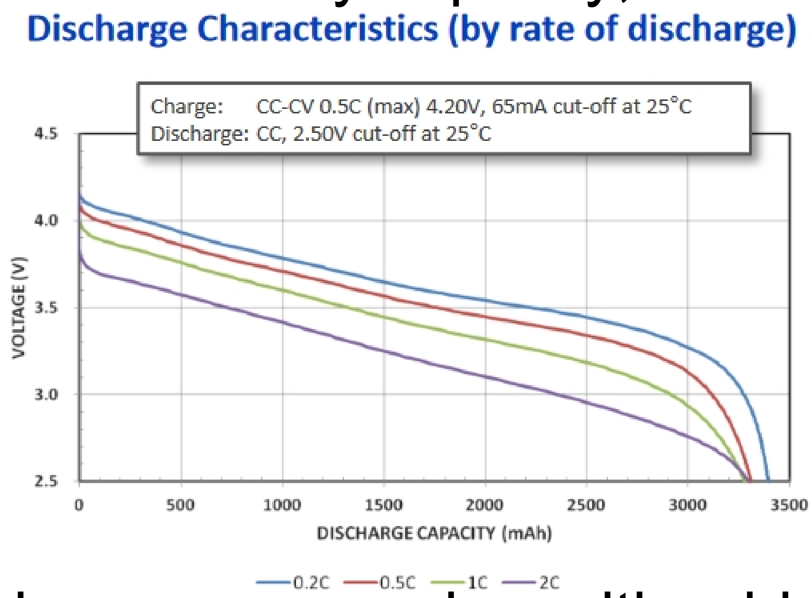
Desirable Features

- Better estimate of battery capacity, to include aging effects



Panasonic 18650B discharge curves

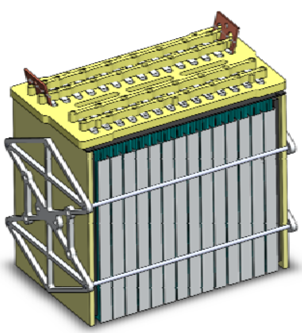
- P = V x I; higher power requires either higher battery voltages and/or higher battery currents
- Local intelligence may be required to recover from various types of faults
- Smart inhibits offer interesting possibilities

How Can We Improve?

- Safety – not a laughing matter
- Power – it's never enough
- Lifetime – it's never enough
- Capacity – it's never enough
- Reliability – no excuses for failure
- Obsolescence – we want our design to last
- Telemetry – provide fully formatted data or go home
- Linkage to EPS design – 2S batteries force 6-8.4V buses
- Charging – as fast as possible, limited by many factors
- Special features – At-a-glance status, clean POR
- Interface – Connectors, harnesses, etc.

Prismatic vs Cylindrical Lithium Cells

- Prismatic
  - Plastic pouch construction
  - Rectangular (L x W x T) or form-fitting
  - Can be combined into packs
  - External protection circuitry
  - Theoretically higher current
  - Flat form factor more conducive to heater design
  - Requires physical constraint for best power & to avoid bulging
  - No built-in pressure relief valve



- Cylindrical
  - Steel can construction
  - Cylindrical (dia x L)
  - Can be combined into packs
  - External or internal protection circuitry
  - Built-in pressure relief valve
  - Inherently "tight" layers
  - Mechanically very tough
  - A standard, mass-produced cell
  - Extra mass of steel case
  - Interstitial spaces better thermally?

The Ubiquitous 18650 Cell

- 18mm dia x 65(.0)mm long
- Panasonic, LG Chem, Samsung, A123, and many other top-tier manufacturers
- Multiple chemistries available:
  - Lithium-Ion
  - LiPeFO4 (Lithium Iron Phosphate): non-explosive, long life
  - Other, more esoteric chemistries
- Cells are combined in series (S) and parallel (P) combinations into batteries. For Li-Ion,
  - Each cell has a capacity (in mAh), a measure of stored energy
  - Every ‘S’ adds +3.7V (nominal) in battery voltage
  - Every ‘P’ delivers additional current (in A)
  - The resultant series-parallel pack can deliver power based on its voltage (S) and current (P) rating

What If …

- … we could pick from various 18650 cell models?
  - Can offer different battery capacities (in Wh), to satisfy safety requirements
- … we could support multiple ‘S’ configurations?
  - Can support EPSes that operate at 7.4V (2S), 11.1V (3S), 14.8 (4S) and maybe 29.6 (8S) battery voltages
- … we could support multiple ‘P’ configurations?
  - Can greatly increase available power (via more Amps)
  - Can potentially reduce battery charge time
- … we could support multiple battery chemistries?
  - Can use Li-Ion for higher energy density
  - Can use Lithium Phosphate for higher power and more safety
- … we could have insight into battery condition, over lifetime?
  - Can predict real-time performance, e.g. “How long can I pull 17.6A? 139 minutes.”
  - Can accurately report on battery condition over time, e.g. “Fully charged, now at 87% of maximum.”

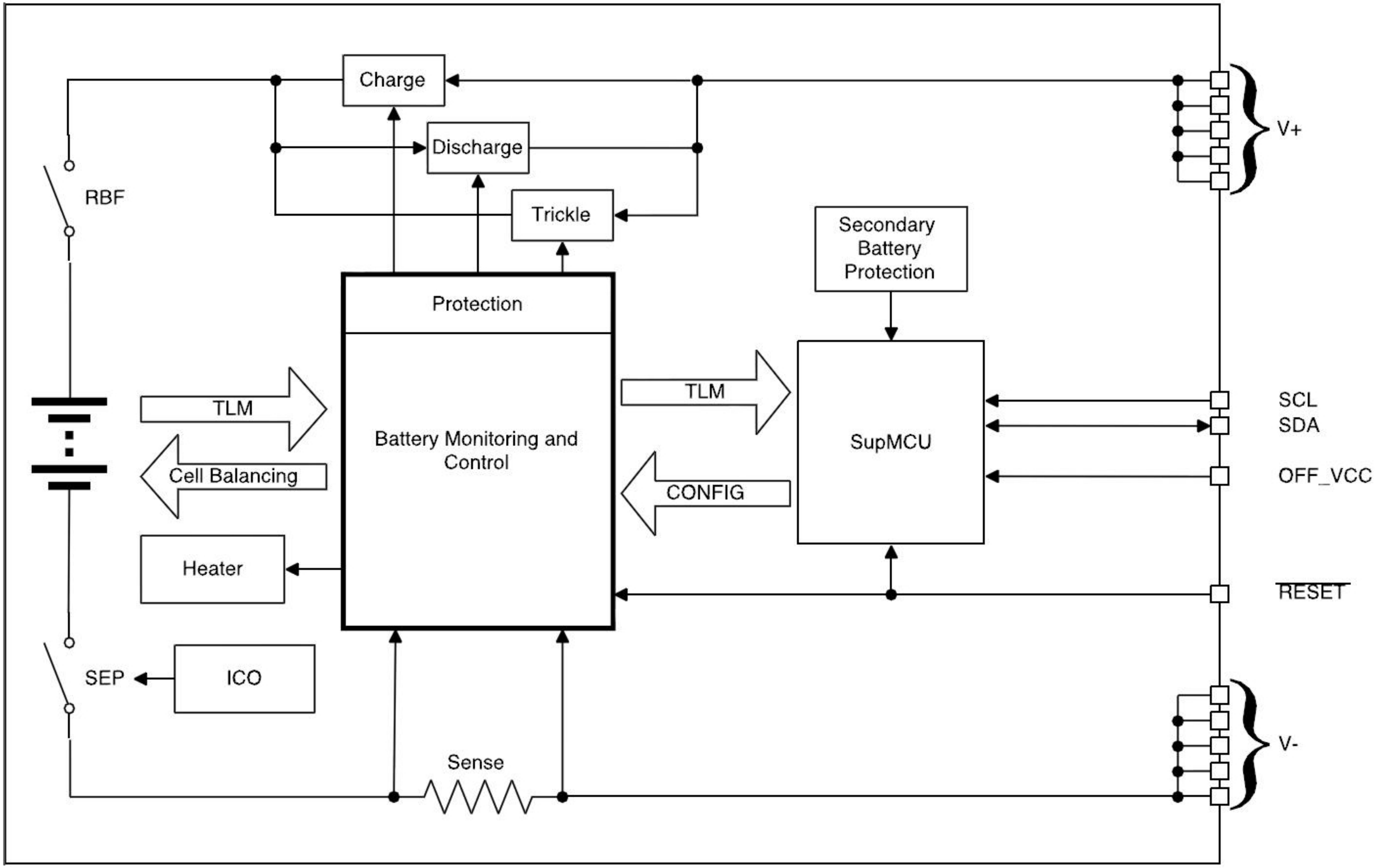
Approach Taken

- Let’s face it, batteries for space is a tiny market
- Let’s look at a small market that is uses more batteries than space, but has similar requirements: Tesla
- Tesla Model S w/85kWh battery has 7,104 18650 Li-Ion cells from Panasonic (x2E5 cars)
- What problems has Tesla solved?
  - Choice of battery cell & chemistry
  - Mechanical packaging & electrical interconnects
  - Battery management (via electronics)
  - Thermal control (in Tesla’s case, cooling)
- Lifetime, power, energy, capacity, telemetry, charging are all directly related to Tesla’s component and design decisions above
- An even bigger market is power tools, but not as sexy for this discussion …. but it also standardized on 18650 cells

But How Do We Get There?

- In 2014, 9.8GWh of battery capacity solely for electric vehicles (1 Billion 18650-cell equivalent)
- Battery protection circuits are per-cell or per-pack
- Smart battery controllers appear in more technologically advanced products (like electric vehicles)
- Consumer requirements are small in scope:
  - Gas gauge
  - Don't start a fire
  - Provide some means of clearing a (rare) fault
- More advanced requirements for space use
  - Full telemetry from the batteries
  - Automatic identification and clearing of faults
  - Seamless integration with EPS

The BM 2 Solution



The BM 2 Solution

- By choosing a smart battery controller chip and the 18650 cell form factor:
  - 2S, 3S and 4S configurations are possible (and maybe 8S in the future) – accommodate different EPS topologies
  - Can support a wide range of cells
  - Can support a wide range of chemistries
- The battery controller chip's intelligence enables:
  - Tracking the electrons moving in and out of the batteries
  - Battery aging and other environmental effects are taken into account when reporting on battery SoC
- By adding a SupMCU:
  - Local intelligence permits autonomous clearing faults
  - Easy reprogramming of battery parameter limits on-orbit
  - Additional functionality (e.g., heat batteries to 60C on purpose)
  - Extreme attention to system power management

The BM 2 Solution

BM 2 Features

- Can support any 18650 cell+chemistry in 2S4P, 3S2P and 4S2P configurations
- 1st- and 2nd-level safeties independent of SupMCU
- Independent charge & discharge paths & limits
- Intelligent gas gauge with over 100 telemetry point that take temperature, cycles etc. into account when reporting SoC
- Active cell balancing on charge and discharge
- Integrated heaters in robust thermal design
- VBATT of 6-8.4Vdc, 9-12.6Vdc or 12-16.8Vdc
- 10A in/out baseline config
- 72-100Wh using typical cells
- 84-168W using typical cells
- 70A MOSFETs – currents are connector/harness-limited
- Rapid charging, too!
- Very low (<5μA) sleep mode guarantees battery health – integrated storage ca. 2yrs
- Intelligent Charge Override (ICO) to top off after integration

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SPACE SYSTEMS

Q&A Session

Appendix

- **Acknowledgements**

  - Dr. Eric Swenson and his team at the Air Force Institute of Technology (AFIT), for the partnership in developing, analyzing and testing SUPERNOVA.

- **Speaker information**
  - David Wright is a systems engineer at Pumpkin, and is responsible for much of the BM 2's electronics, analog design and firmware. Contact David at david@pumpkininc.com.
  - Dr. Kalman is Pumpkin's president and chief technology architect. He entered the embedded programming world in the mid-1980's. After co-founding Euphonix, Inc – the pioneering Silicon Valley high-tech pro-audio company – he founded Pumpkin, Inc. to explore the feasibility of applying high-level programming paradigms to severely memory-constrained embedded architectures. He is the creator of the Salvo RTOS, the CubeSat Kit and the SUPERNOVA architecture. He holds several United States patents. He is a consulting professor in the Department of Aeronautics & Astronautics at Stanford University and directs the department's Space Systems Development Laboratory (SSDL). Contact Andrew at aek@pumpkininc.com.
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