SAND2020-7243PE

Battery Management

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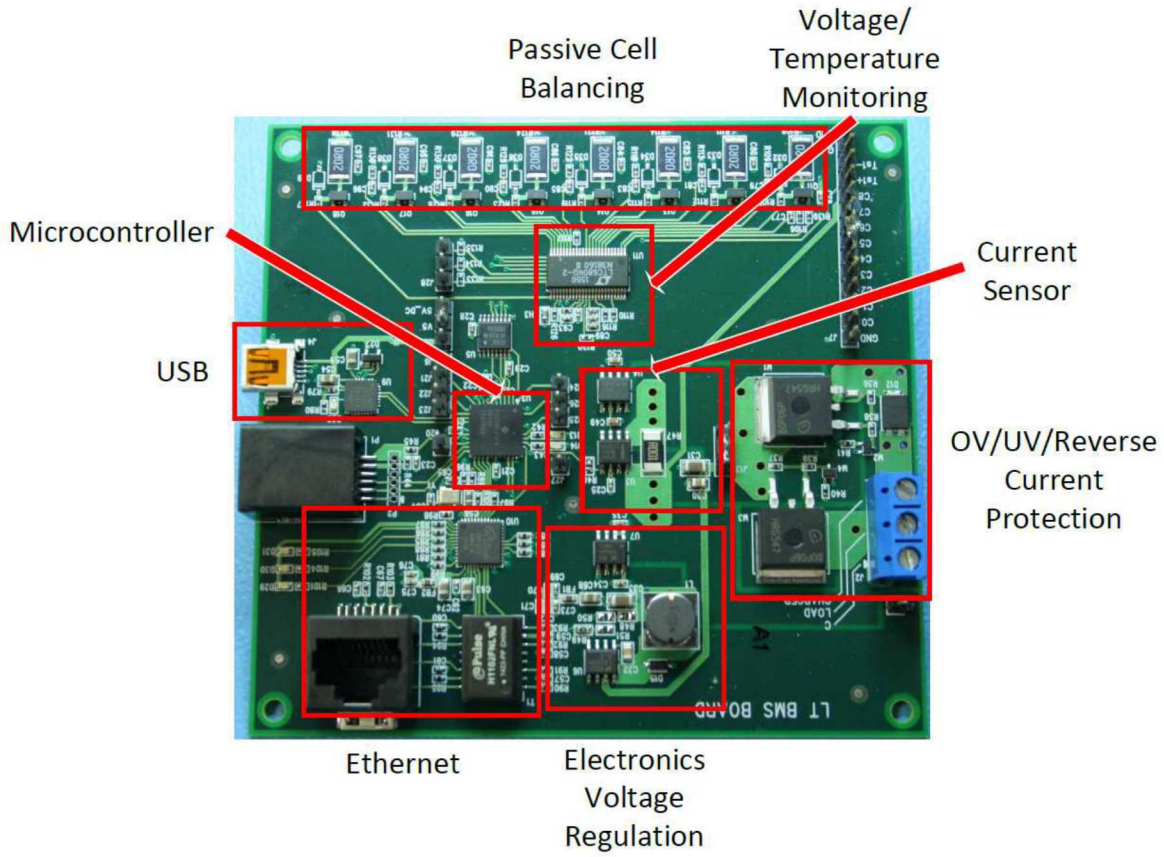
Battery Management System Goals

1. Keep cells safe
2. Keep cells balanced
3. Report capacity to host
4. Predict failures
5. Detect poor health



Generic 8 Cell Battery Management System

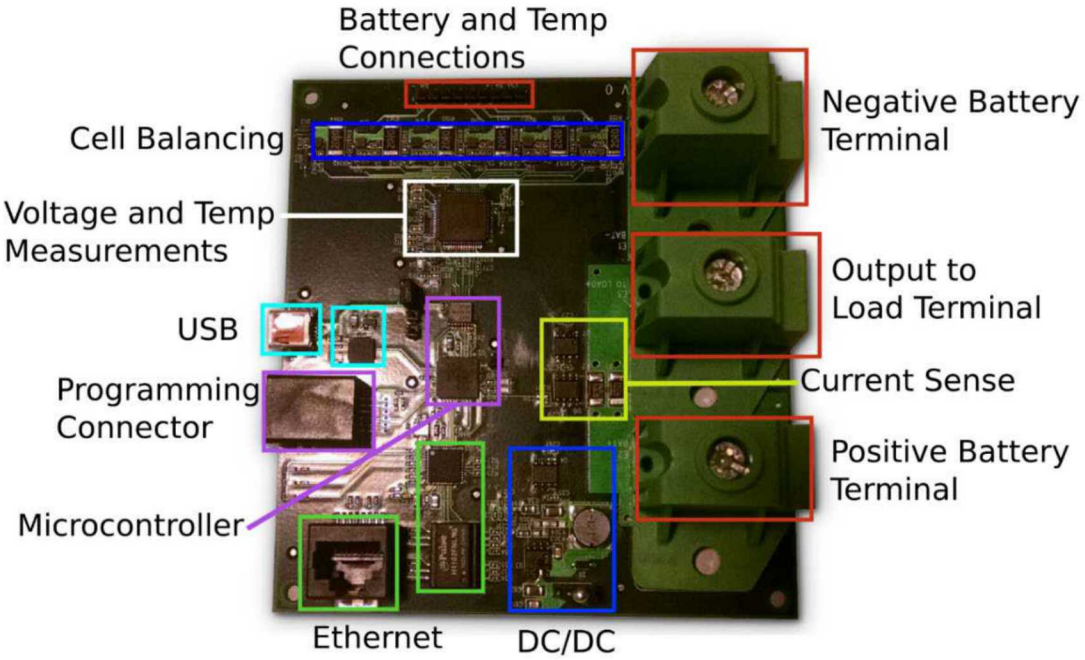
Cell Protection

Scenarios that should be prevented:

- Overvoltage
- Undervoltage
- Temperature
  - Charge/Discharge
- Overcurrent (Short Circuit)
  - Can be done in Hardware or Software
- Fast charge low voltage cells
- Reverse Current

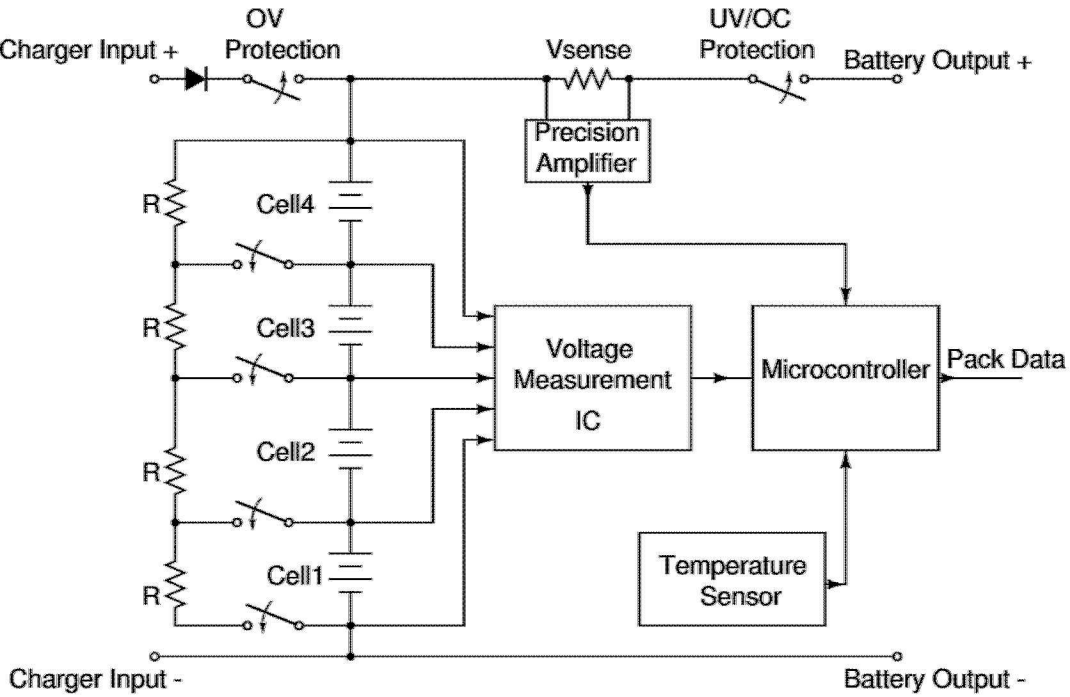
Methods

- FETs if systems allows
- Relays in some cases
- Diodes



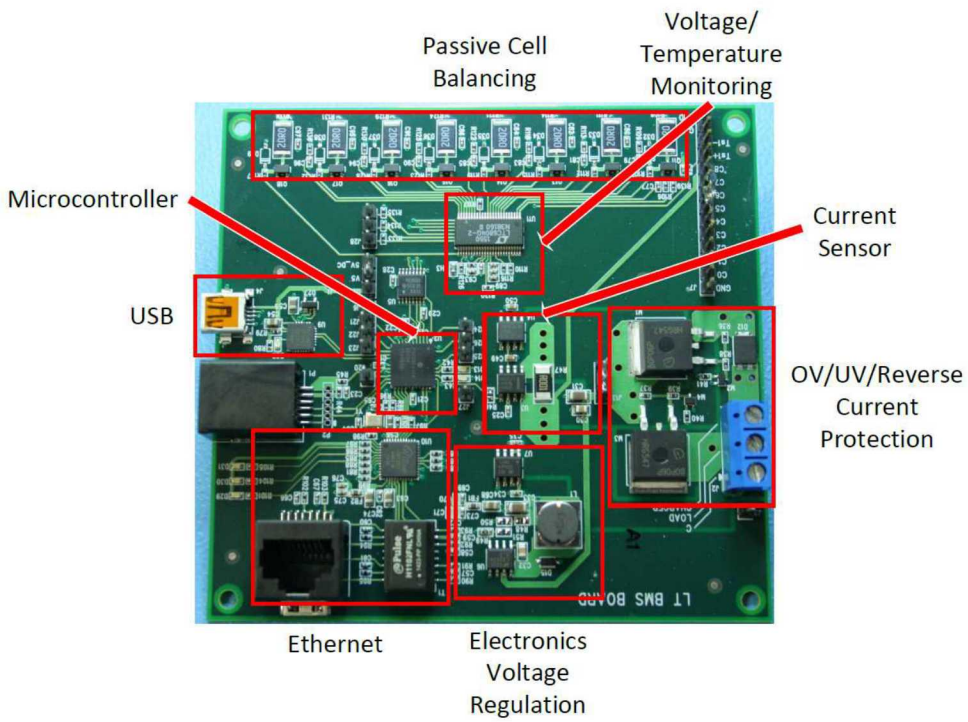
Generic 6 Cell Battery Management System

Passive Battery Management System

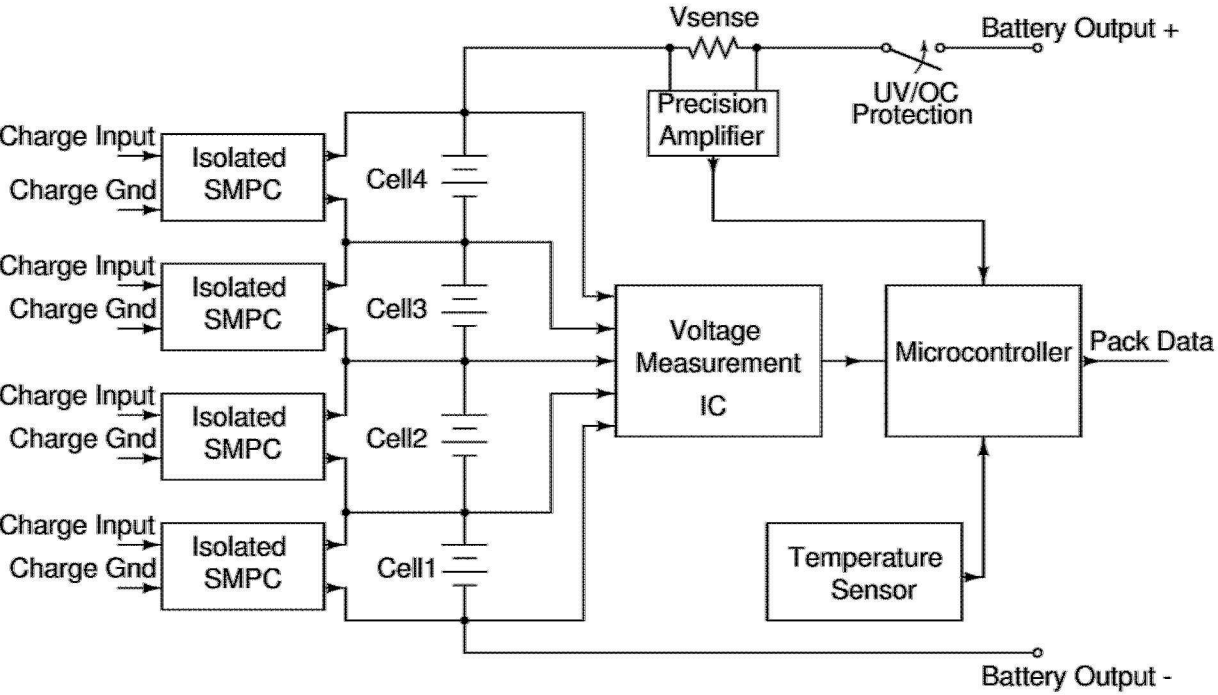


- ✓ Easy to implement
- ✓ Easy to control
- ✓ Cheap
- X High heat dissipation
- X Slow charging
- X Inefficient

LT Passive Board

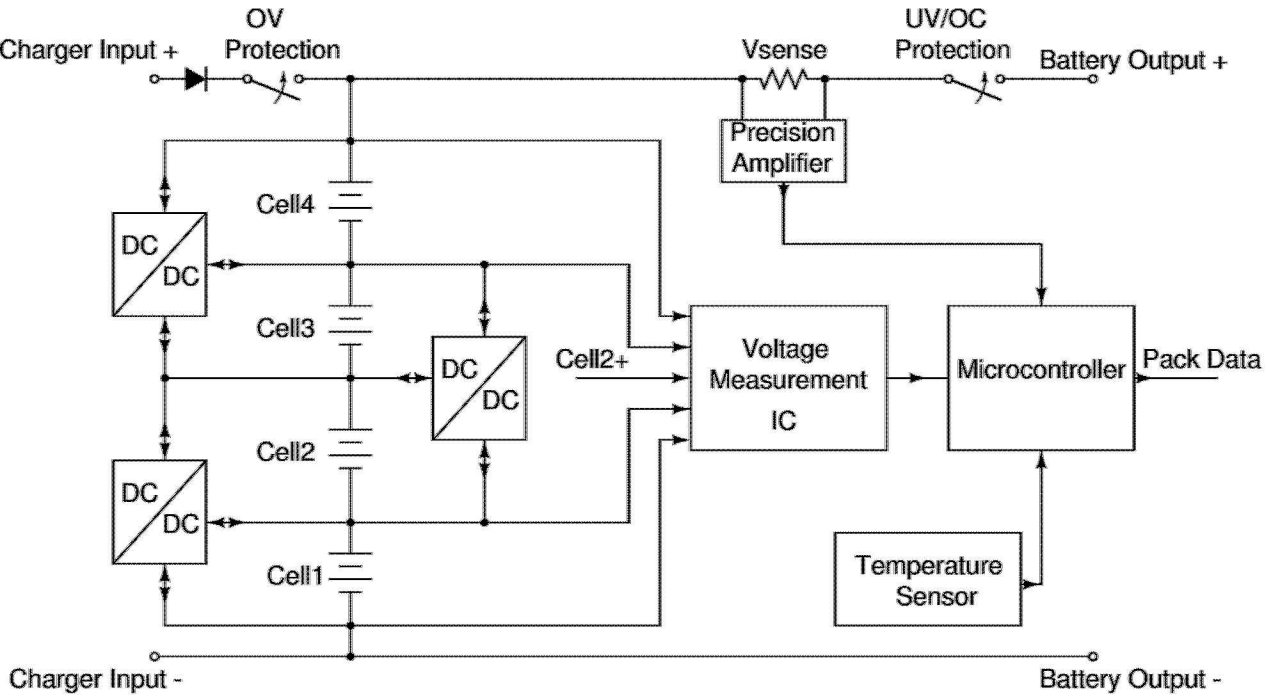


Charge every battery cell directly from isolated power supplies.



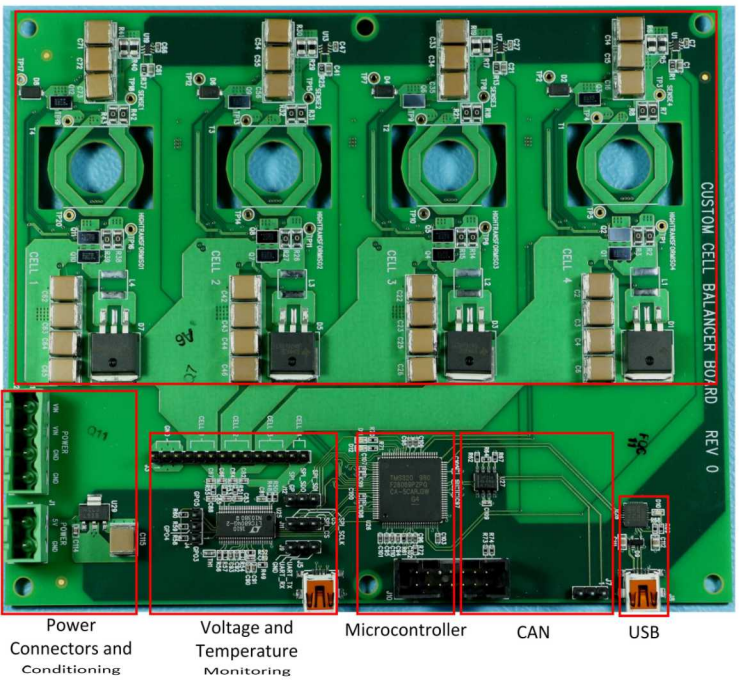
- ✓ Extremely fast charging
- ✓ Easy to control
- ▪ Moderate heat dissipation
- ▪ Moderately inefficient
- X Complex SMPC
- X Single point failure

Differential Power Processing - Battery Cell to Battery Cell (Switched Capacitor or Inductor)

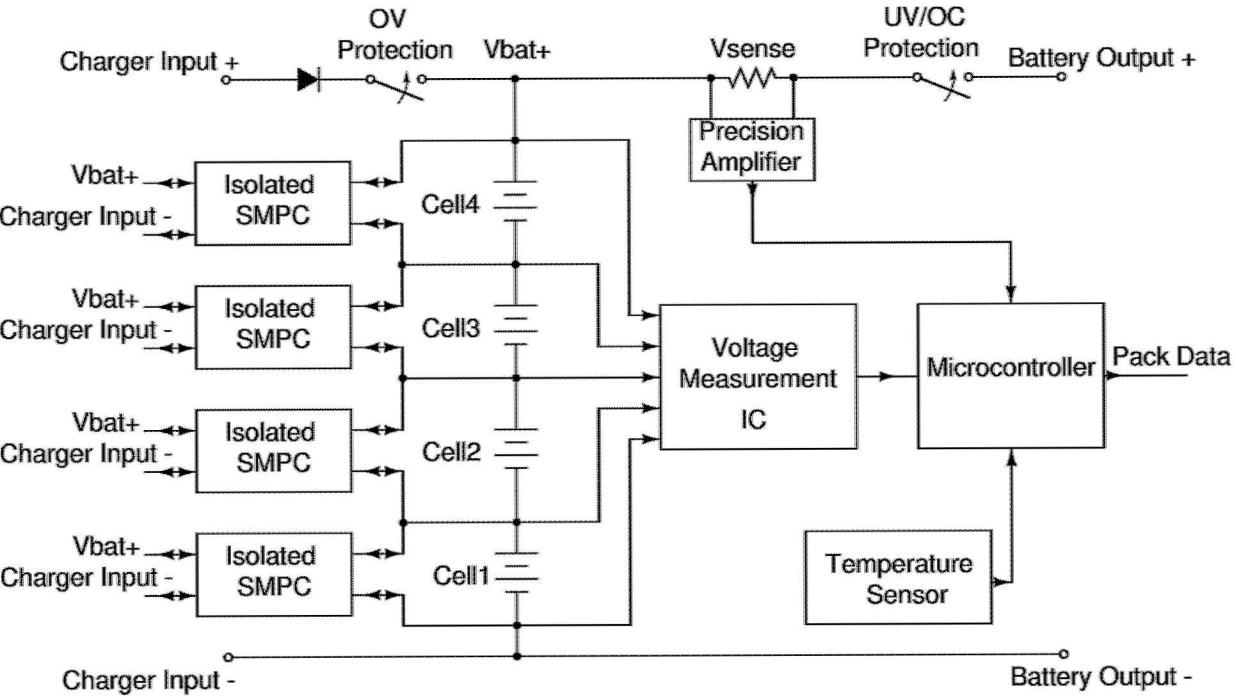


- ✓ Extremely efficient
- ✓ Little heat dissipation
- ✓ Can relocate energy without applied charger
- ✓ Non-Isolated SMPC
- ▪ Fast charging
- X Complex SMPC
- X Complex control
- X Isolated Communication

Active Board - Custom Controller



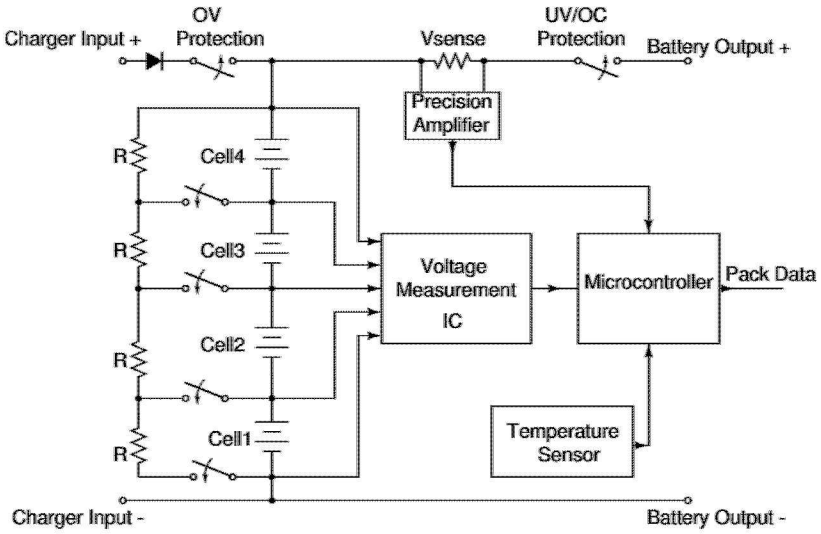
Differential Power Processing - Battery to pack (Unidirectional or Bidirectional)



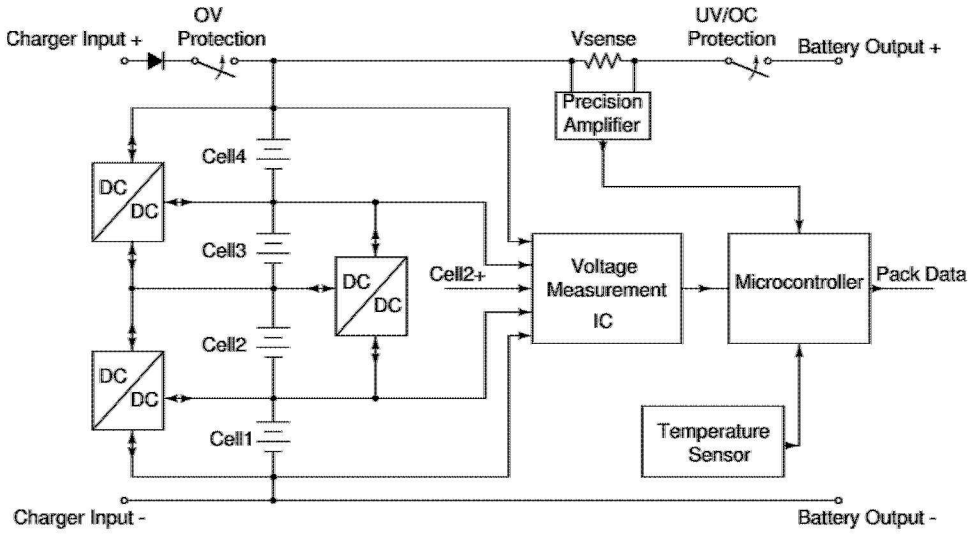
- ✓ Extremely fast charging
- ✓ Extremely efficient
- ✓ Little heat dissipation
- ✓ Can relocate energy without applied charger
- X Complex SMPC
- X Very complex control

Cell Balancing

Keeping cell voltages equal increases the battery capacity

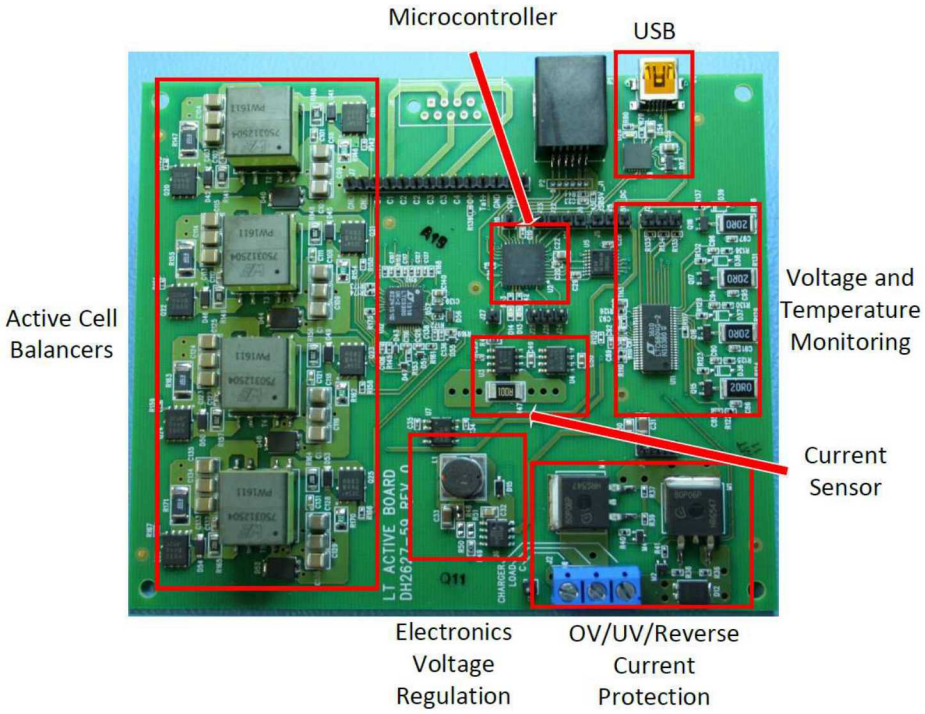


Passive Cell Balancing



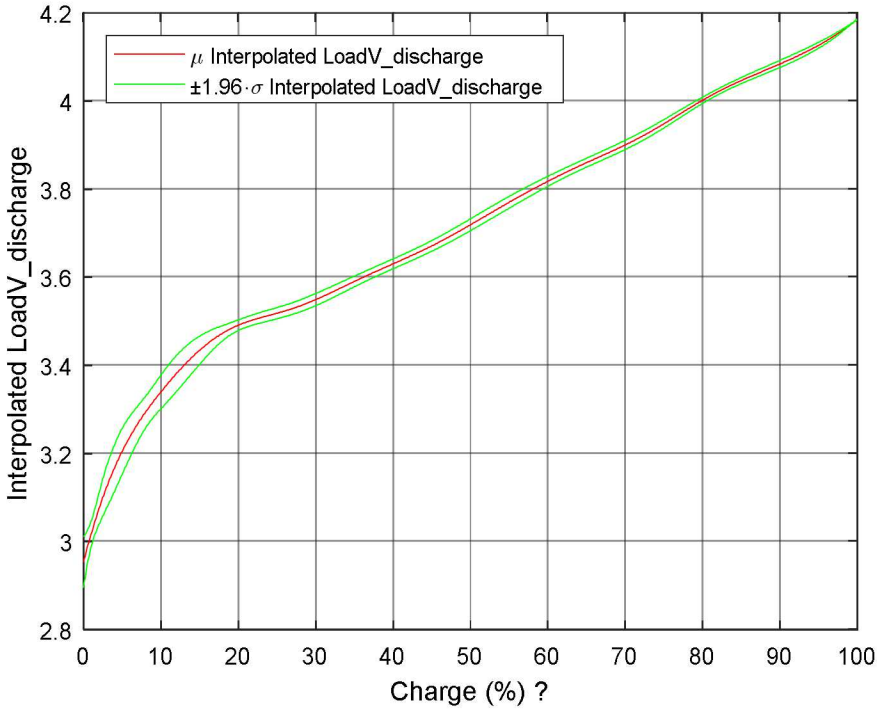
Active Cell Balancing

Active Board – LT Controller

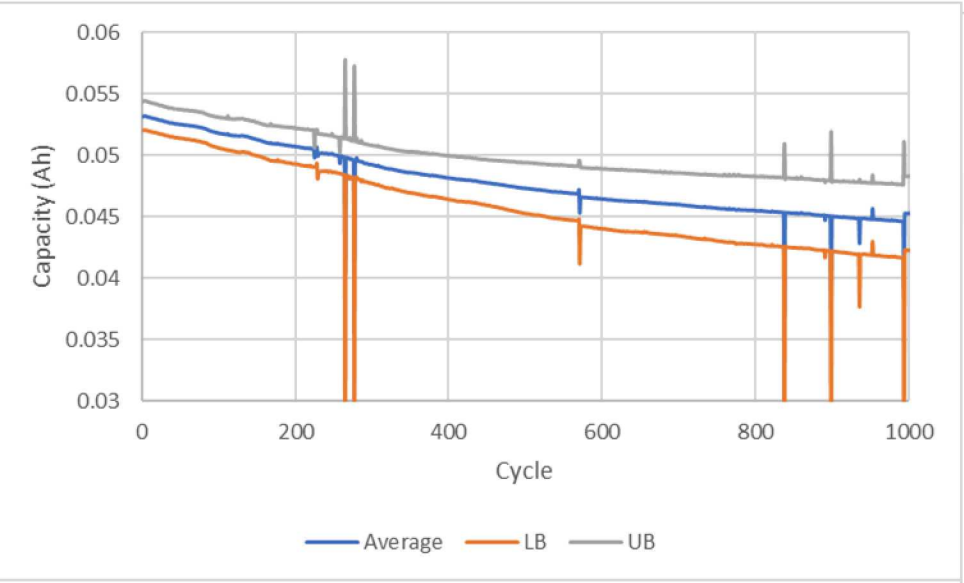


Why do cell balancing?

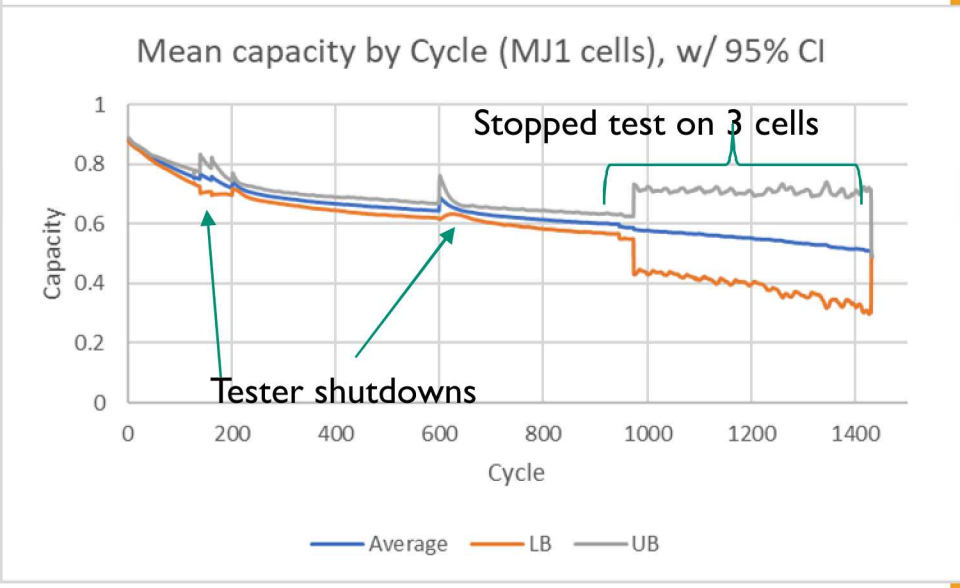
- If all cells in series have the same capacity, but are different states of charge, the highest SOC cell will reach max safe voltage first during charge, and the lowest SOC cell will reach min safe voltage first during discharge
- Battery capacity will be set by the difference between maximum and minimum cell capacity for cells in series



So, how much drift should we expect? Small cell measurements.



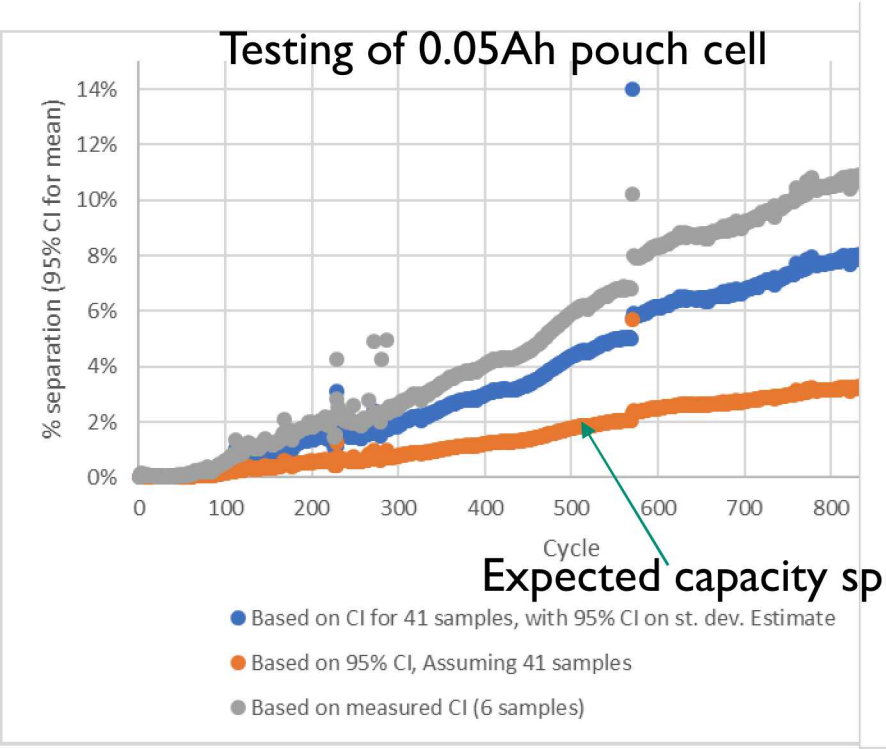
Average performance for 6 pouch cells (NMC cathode, 0.05 Ah)
1C charge/ discharge, 4.2 to 3.0V

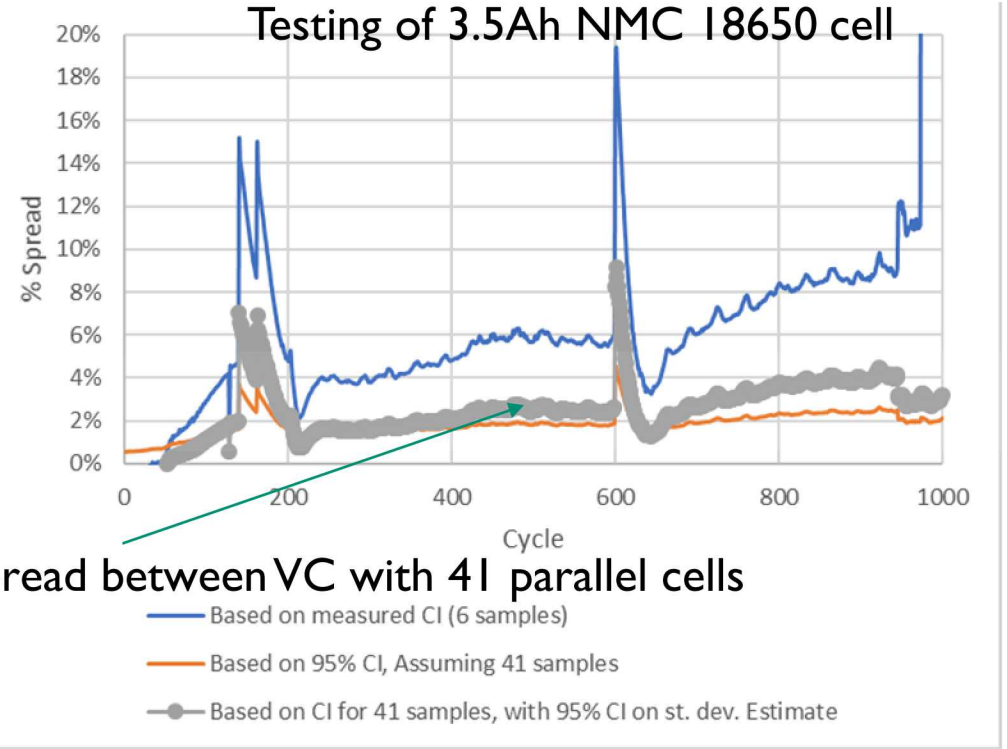


Average performance for 6 18650 cells (NMC cathode, 3.5 Ah)
1C charge/ discharge, 4.2 to 3.0V

The spread in performance with cycle is not very high even for for small cells- only about 6% over 500 cycles

Extrapolation to larger cells





Expected capacity spread between VC with 41 parallel cells

- This is further reduced when considering a multi-parallel virtual cell (VC). The performance of a VC is the average of the individual cells, so drift is reduced. For 41 cells (example), the expected spread will drop by half.
- Grid storage batteries will be much large- hundreds of cells- and therefore spread will be less.

Cell capacity changes are likely less than a 3% over 500 cycles

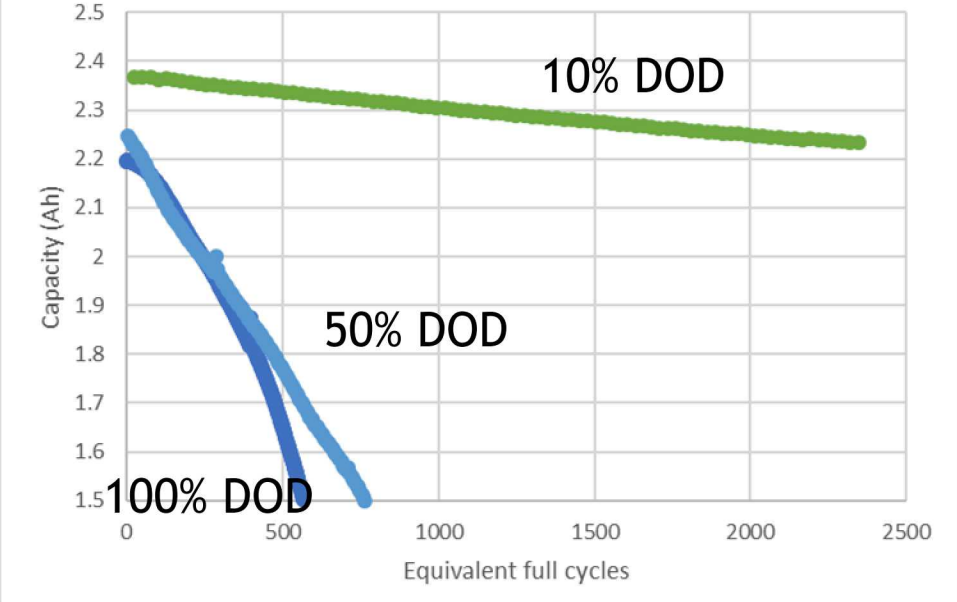
Does 3% in cell capacity make any difference?

For a standalone power application, the battery can never come close to running out of capacity.

- 25% margin would be a minimum safety factor, so 3% is in the noise for battery sizing.

Battery lifetime is improved by narrowing the voltage window (e.g. doing 50% SOC cycles).

- The decision on how large to make the voltage swings is far more consequential to battery sizing than 3% from spread



1C charge/discharge to different SOC levels, 4.2V charge

Does 3% in cell capacity make any difference?

The efficiency of the BMS is critical to maximizing energy storage

- In a passive BMS, all the extra energy is burned off, so the system gains nothing by cell balancing. Any benefit at the end of discharge cycling was lost during the end of charge

In an active BMS, the parasitic current draw of the complex circuitry reduces efficiency.

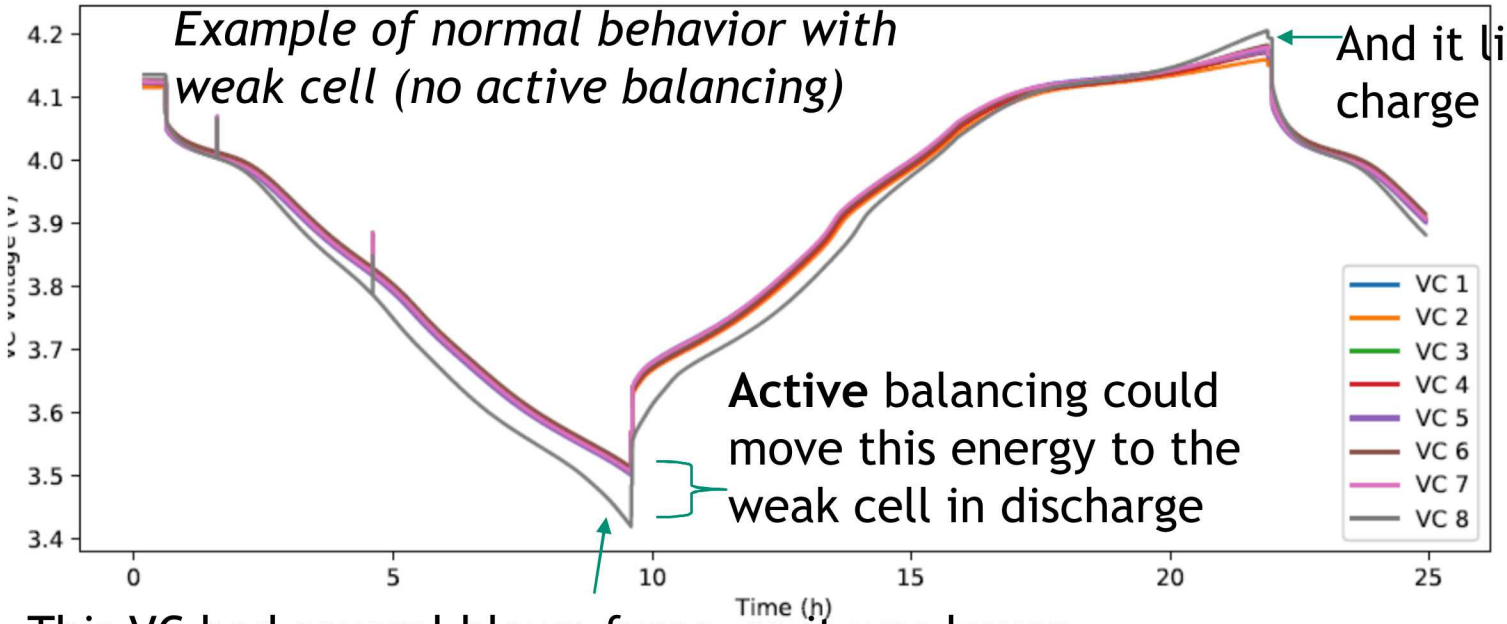
- Our active BMS draws 170 mW continuously *while off*, or 1.4 kWh/yr. For our application (~50 cycles/year on a 4 kWh battery), that is a 1% capacity hit.
- Scale up to MWh batteries will also scale up parasitic currents, so circuitry must be efficient
- DC/DC conversion can be >80% efficient, so the actual power movement is OK

How does active balancing help?

In large parallel cell arrays, individual cells can become disconnected (CID opening, bad welds). This reduces the VC capacity, and therefore the entire battery capacity.

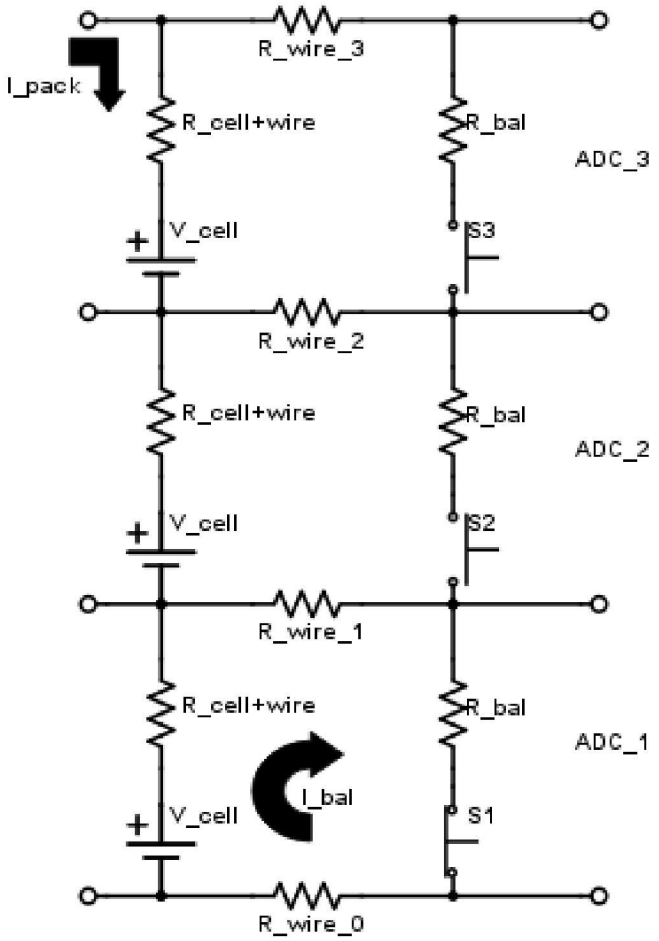
- Active balancing during discharge can move energy from high capacity cells to the weak cell, making the total battery capacity the average of all series cell capacities rather than being limited by the capacity of the weakest cell.
- Active balancing during charge must bypass the weak cell.

Any capacity gain is reduced by the 80-90% efficiency of the DC conversion



This VC had several blown fuses, so it was lower capacity. It limited overall pack capacity during discharge.

Using balancing to assess state of health



- Passing current through the balancing resistor changes the voltage observed on the cell
- By sequentially switching balancing resistors, the resistance of the cell and wiring can be determined
- This is enough to indicate if the pack is deteriorated, though not how (could be cell capacity fade, or broken welds in a parallel cell)

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System Modes

Four Levels to Define Battery State of Health

- Nominal Level
  - Every part of the battery power module is good
- Warning Level
  - Something is broken but it is not critical
  - Send out a warning message
- Critical Level
  - Keep the load switch closed but shut down as soon as possible. Non-critical functions like cell balancing and charging will be disabled.
- Catastrophic Level
  - Disable all functions and shut down