Rechargeable Battery characteristics, safety, Charging and fuel gauges

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Agenda

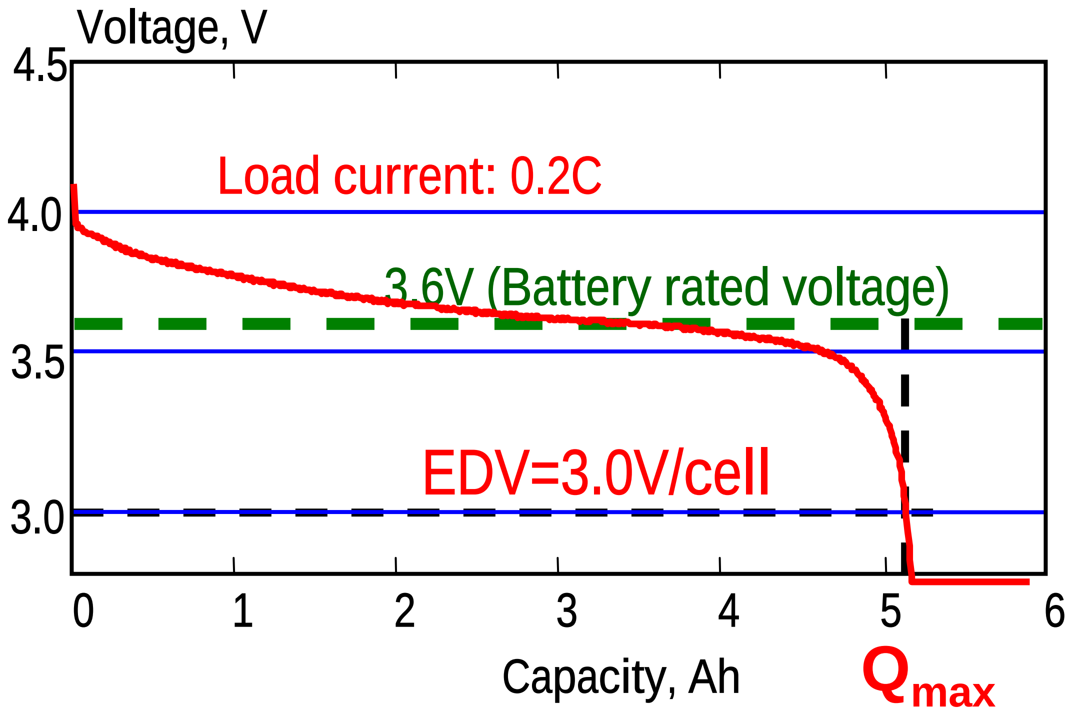
- Li-Ion and LiFePO4 Battery Characteristics
- Fuel Gauge Terminology
- Fuel gauge Fundamentals
  - ❑ Voltage Measurement Based Fuel Gauge
  - ❑ Coulomb Counting Based Fuel Gauge
  - ❑ Impedance Track Fuel Gauge
- Summary

Battery Chemistries

- Primary battery: Non-rechargeable (Alkaline)
- Secondary battery: Rechargeable
  - NiCd: 1.0V to 1.5V
  - NiMH: 1.0V to 1.5V
  - Li-Ion
    - ➢ LiCoO2 - Coke: 3.0V to 4.1V
    - ➢ LiCoO2 - Graphite: 3.0V to 4.2V
    - ➢ LiMnO4 - Graphite: 3.0V to 4.4V
    - ➢ LiFePO4 - Graphite: 2.0V to 3.6V

Li-Ion Battery Characteristics

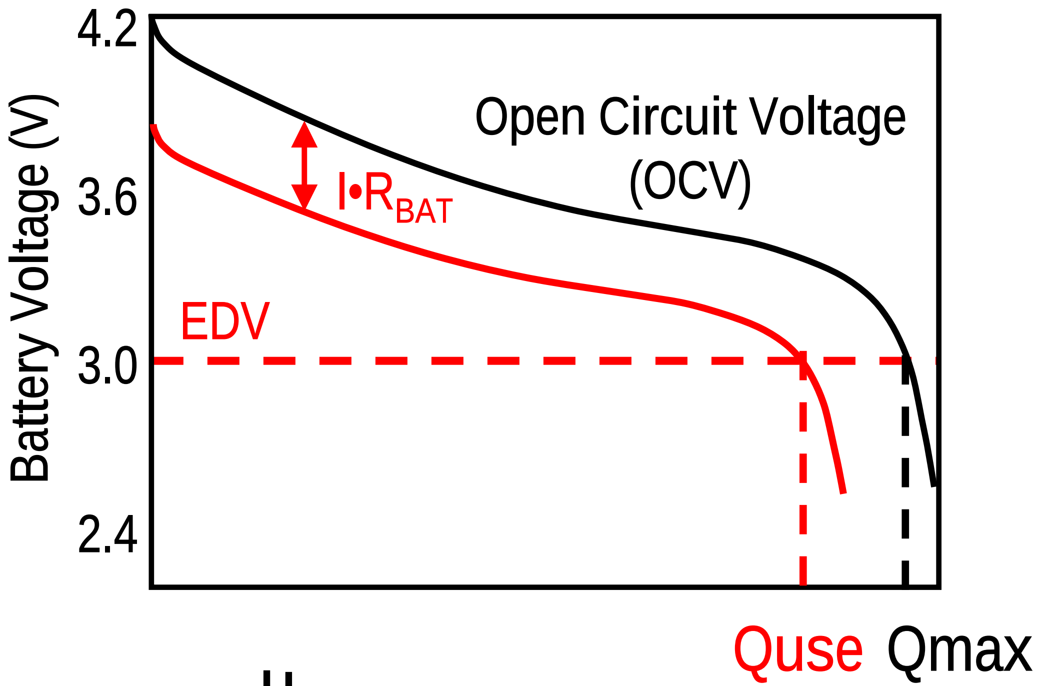
Battery Chemical Capacity

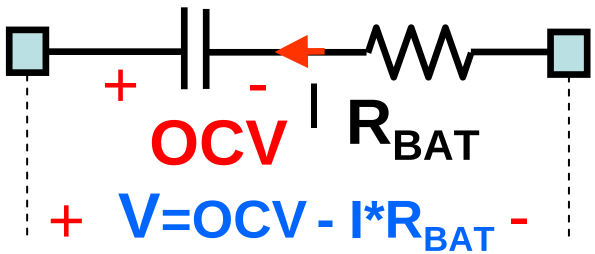


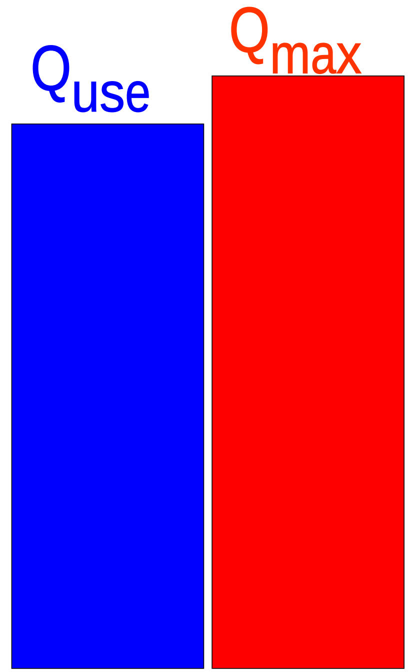
Battery Capacity: 1C
Discharge rate 1C:
Current to completely discharge a battery in one hour
Example:
2200mAh battery,
1C discharge rate: 2200mA, 1 hr
0.5C rate: 1100mA, 2hrs

- Battery capacity (Qmax) : Amount of charge can be extracted from the fully charged cell to the end of discharge voltage (EDV).
- EDV is mini. voltage acceptable for the application or for battery chemistry

Useable Capacity Quse

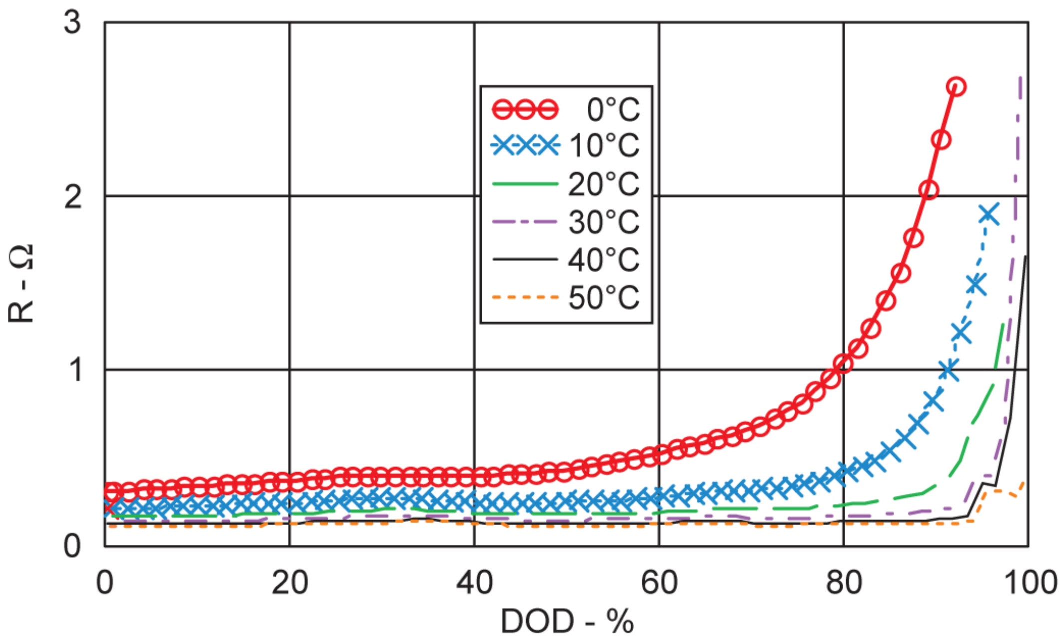






- EDV will be reached earlier for higher discharge current.
- Useable capacity $Q_{use} < Q_{max}$

Impedance Dependent on Temperature and DOD



Full Charged

Fully Discharged

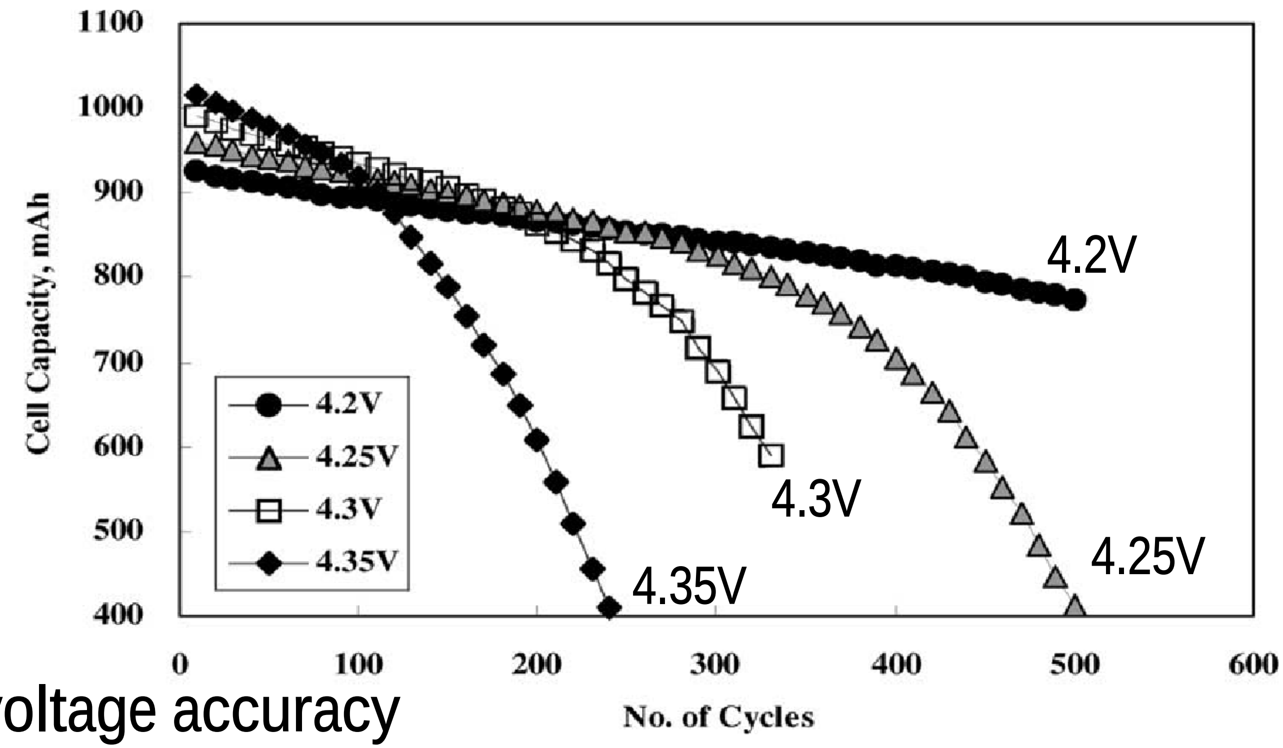
Impedance is strongly dependent on temperature, State of charge and aging

$$SOC = \frac{Q}{Q_{max}}$$

DOD=1-SOC (State of Charge)
SOC=1 (Full charged battery)
SOC=0 (Full discharged battery)

SOC: State of Charge
DOD: Depth of Discharge

Battery Capacity, Cycle Life vs Charge Voltage



Low charge voltage accuracy

Overcharging

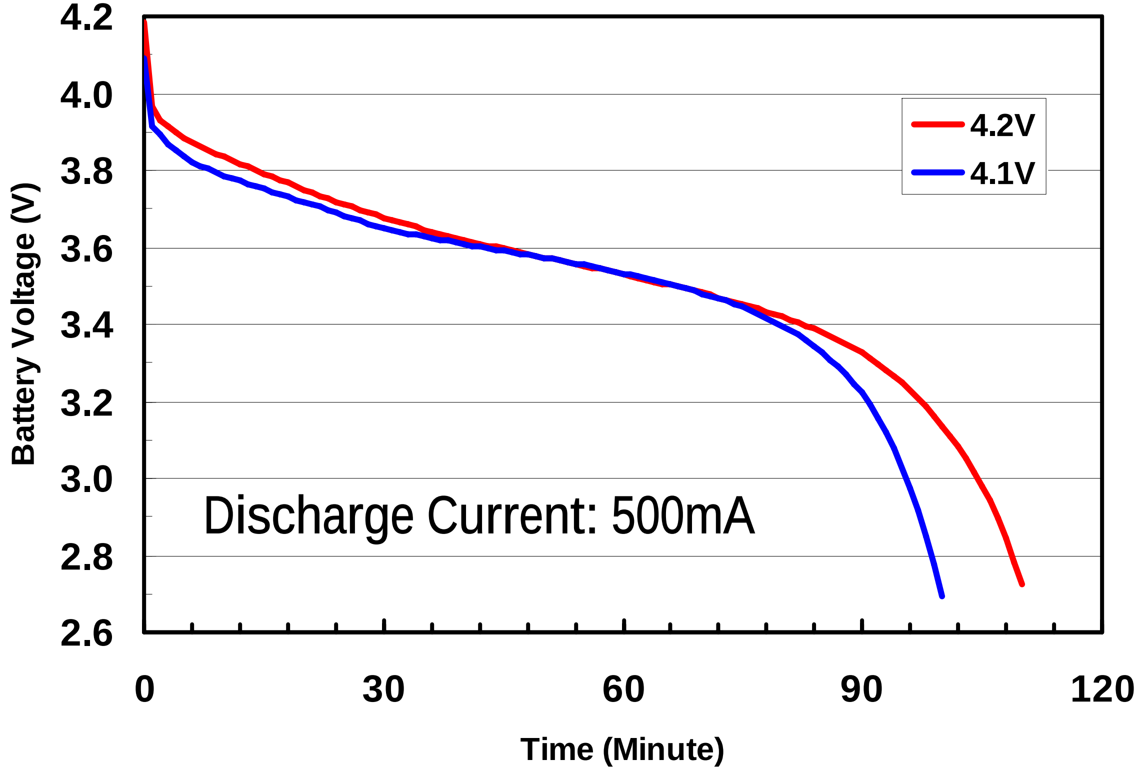
- Increase the battery initial capacity;
- Shorten battery cycle life

Undercharging

- Low capacity and short run-time

Accurate Charge Voltage: Maximize Capacity and Cycle Life

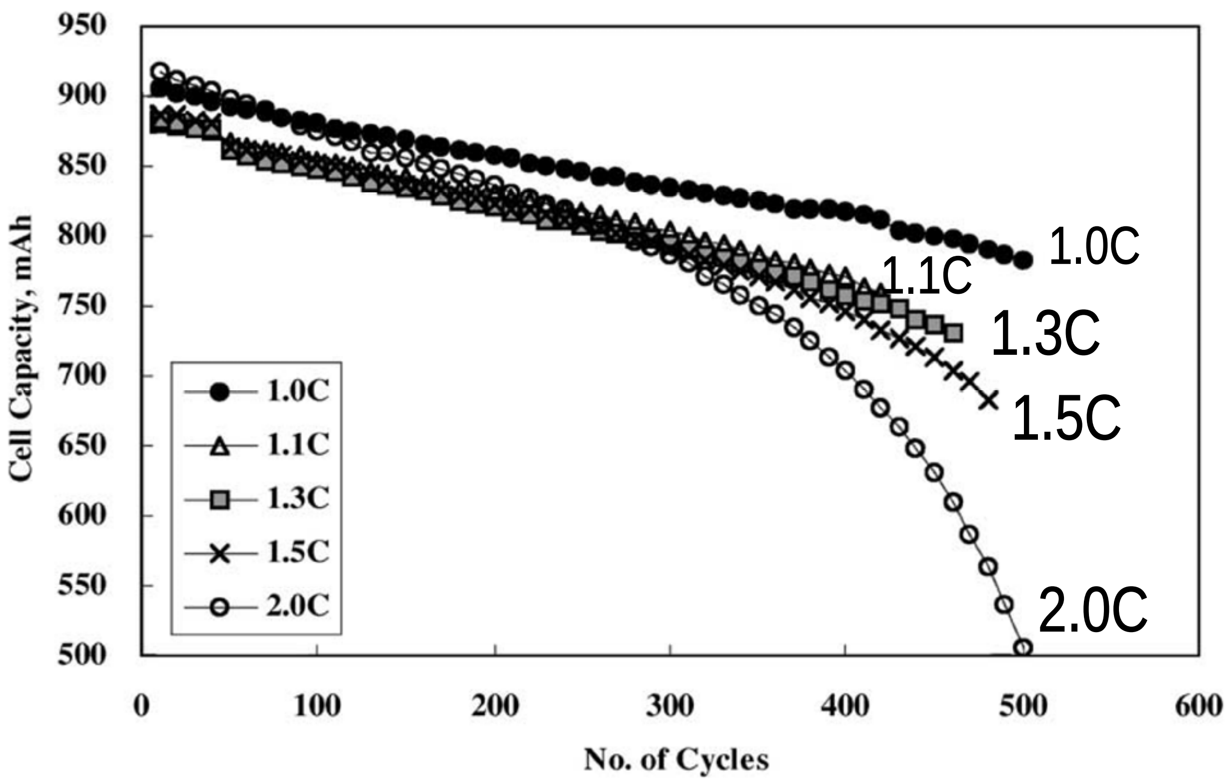
Battery Capacity at Different Charge Voltage



- 800mAh @4.1V, 10% less than @4.2V
- 875mAh @ 4.2V

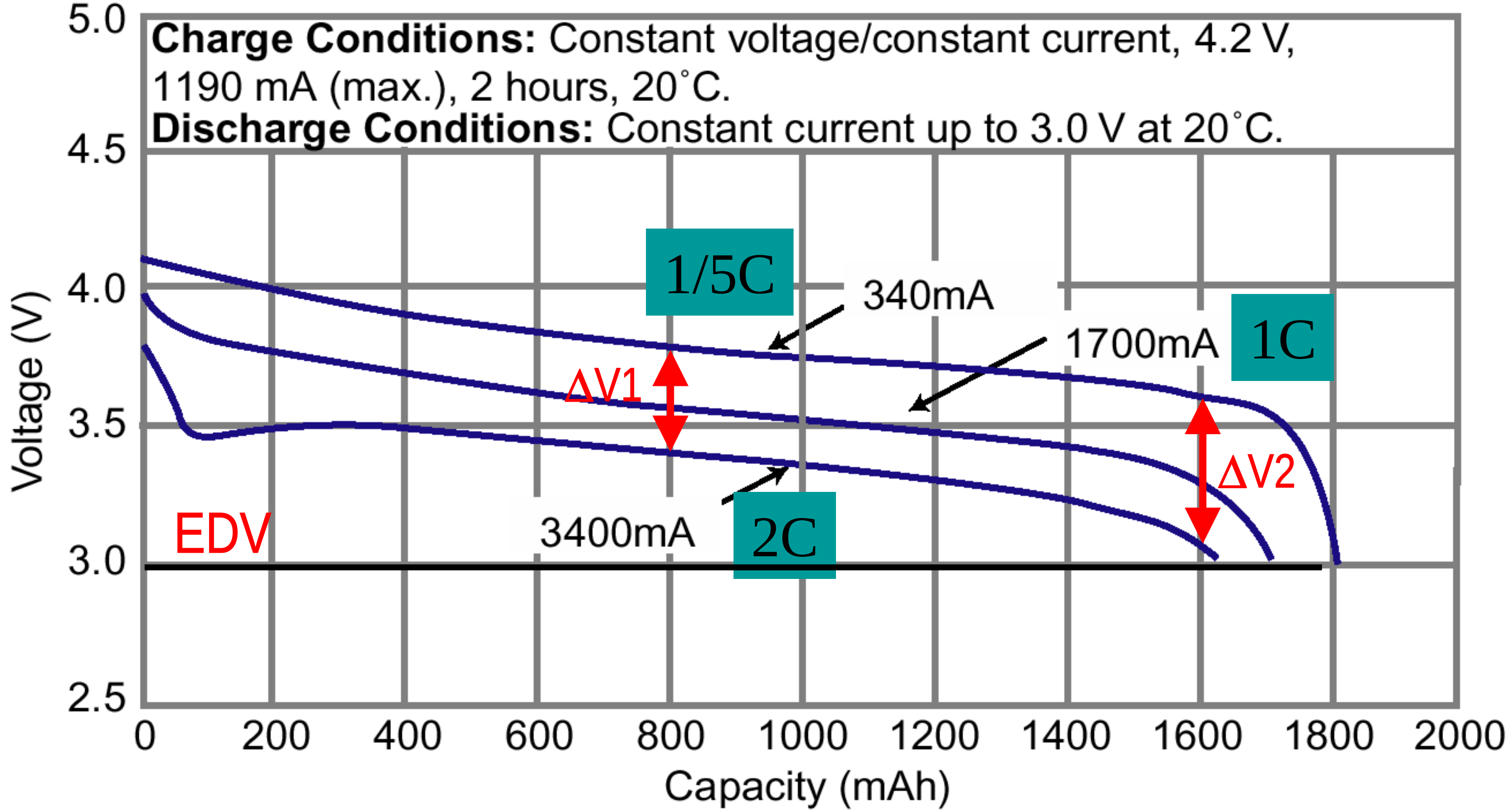
Charge Current vs Battery Degradation

- < 1C rate to prevent overheating and resulting accelerated degradation.



"Factors that affect cycle-life and possible degradation mechanisms of a Li-ion cell based on LiCoO2", Journal of Power Sources 111 (2002) 130-136

Li-Ion 18650 Discharge Characteristics

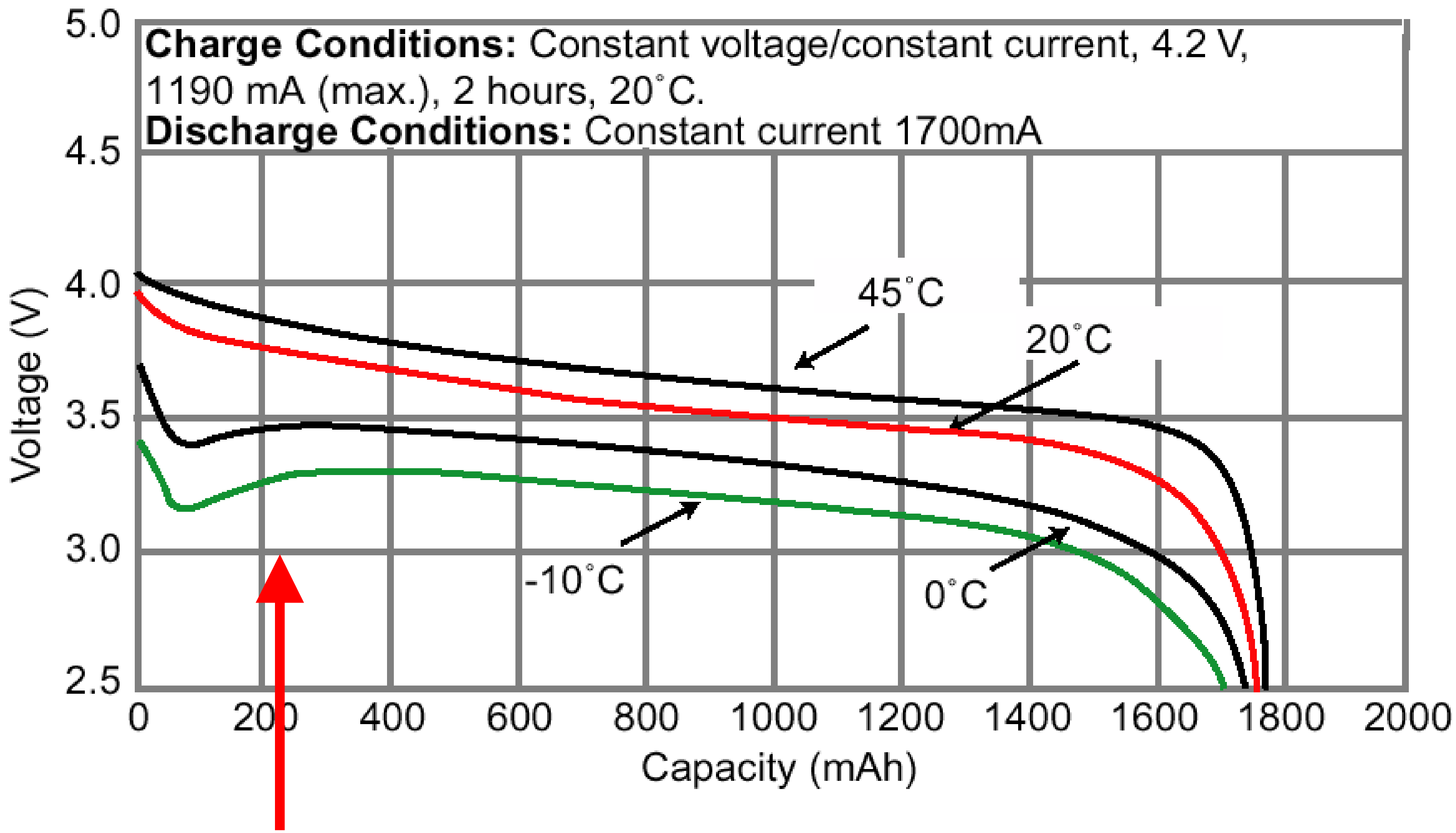


What's battery DC impedance at SOC=50%?

$\Delta V = \Delta I\, R_{BAT}$

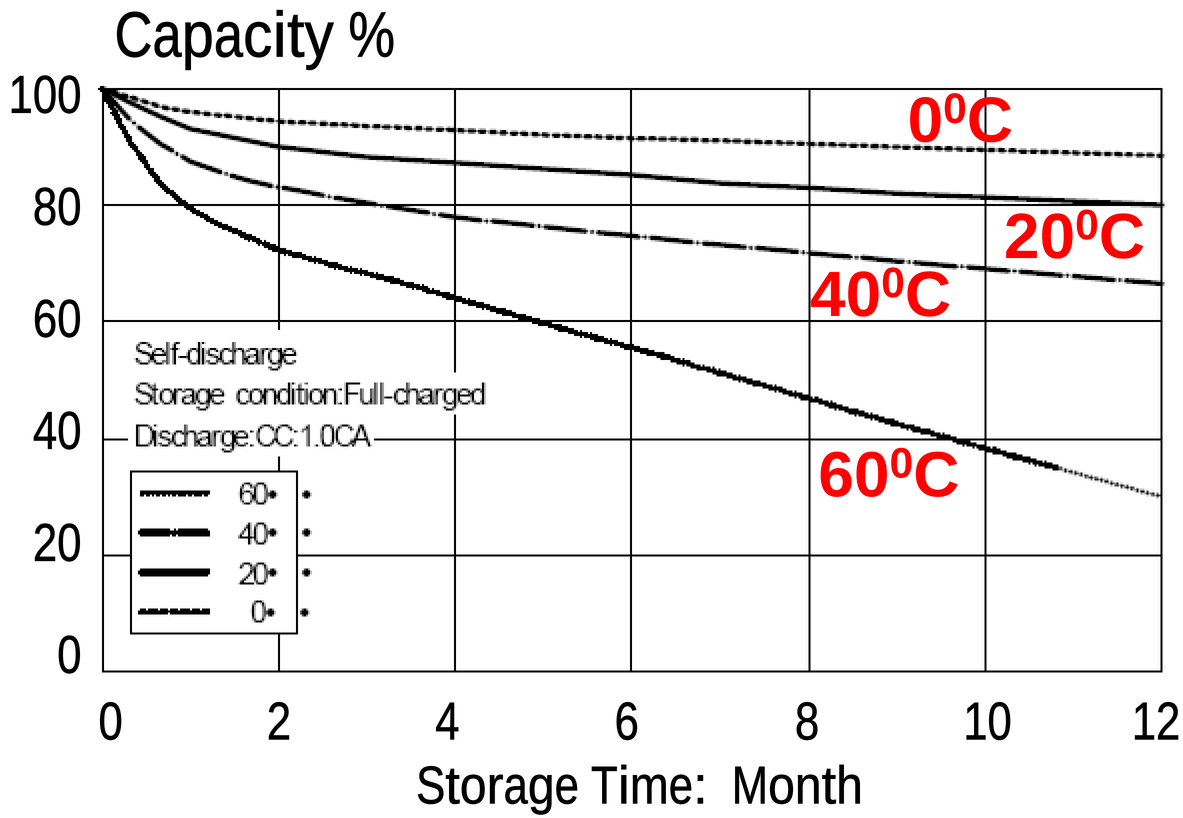
(3.8V-3.4V)/3A=130mΩ

Li-Ion 18650 Temperature Discharge Profile



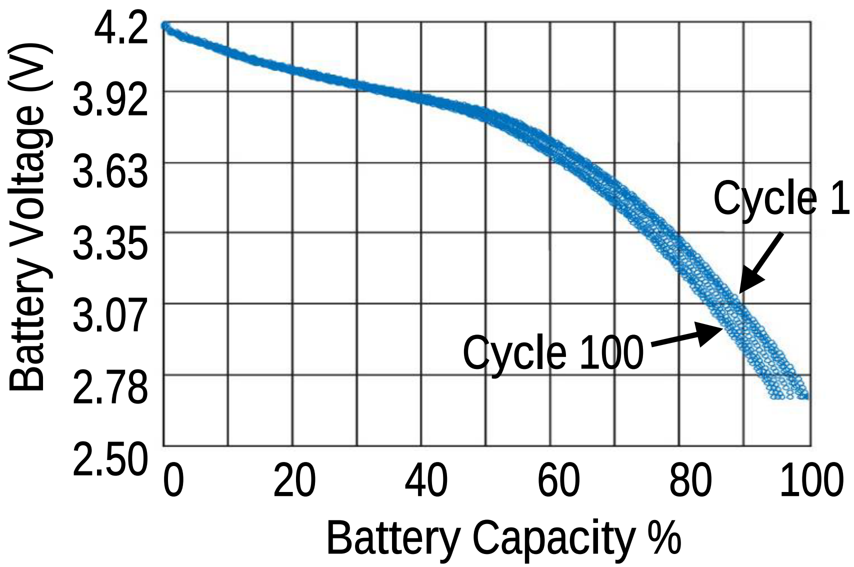
Self-heat Effect (Internal impedance decrease when T increase)

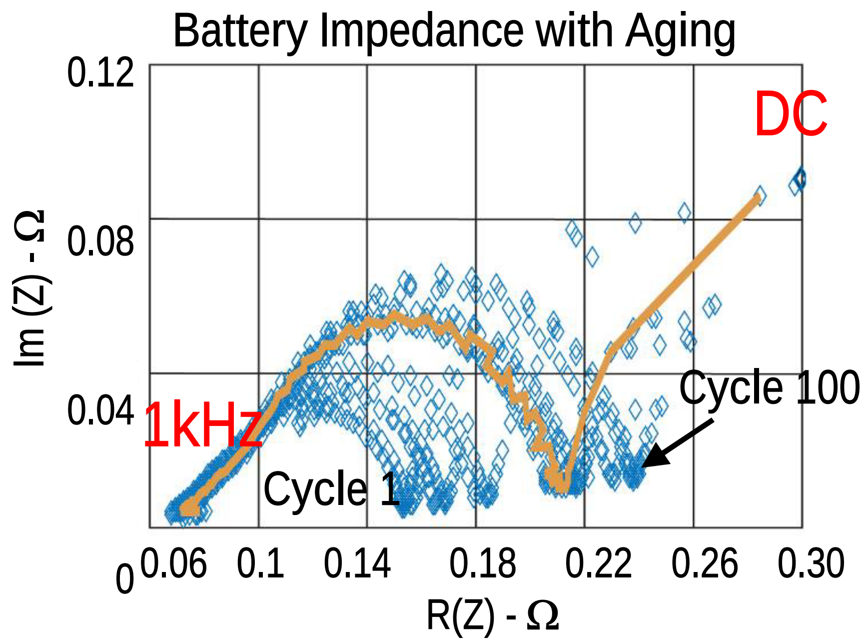
Li-Ion Storage Characteristics



- 2-3% Self-discharge per month at 20^0C
- Self-discharge rate doubles for every 10^0C

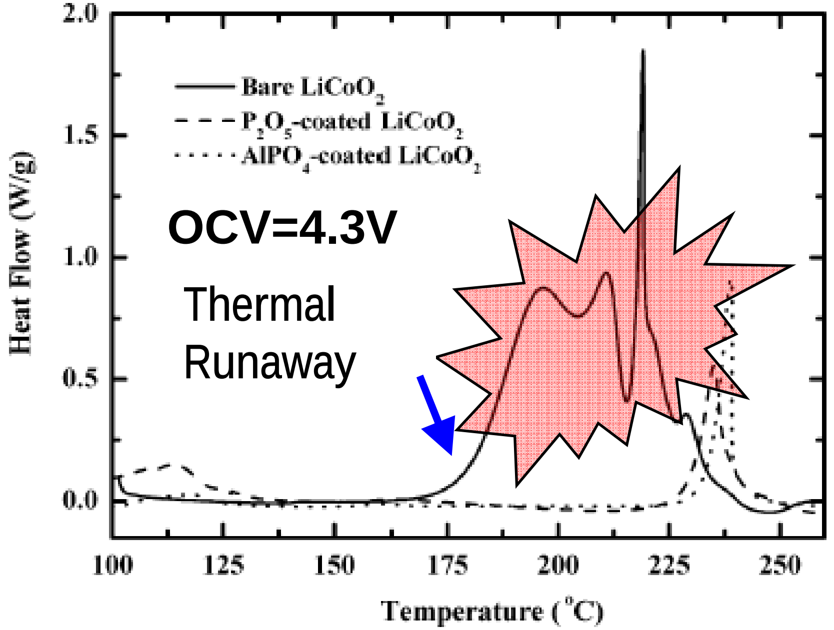
Impedance and Capacity Change with Aging





- Battery impedance increase with aging
- Impedance almost doubles after 100 cycles .
- Chemical capacity reduces by 3-5% after 100 cycles

Safety and Thermal Stability



- Active metallic lithium is deposited on anode @ overcharged.
- Rapid temperature increase can happen @ overcharged or shorted
- Increased temperature can accelerate degradation, cause thermal run-away, and battery explosion

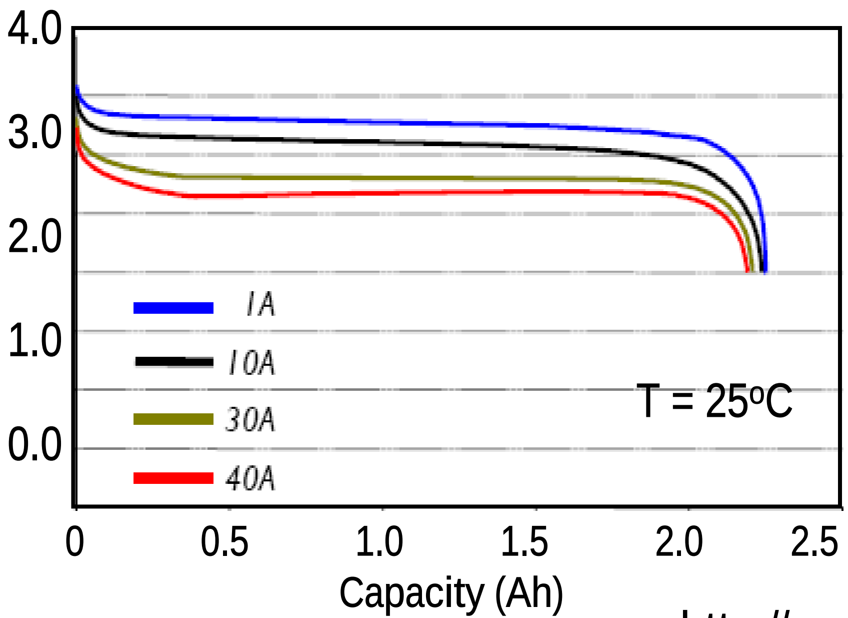
3192 *Chem. Mater., Vol. 15, No. 16, 2003* Cho et al.

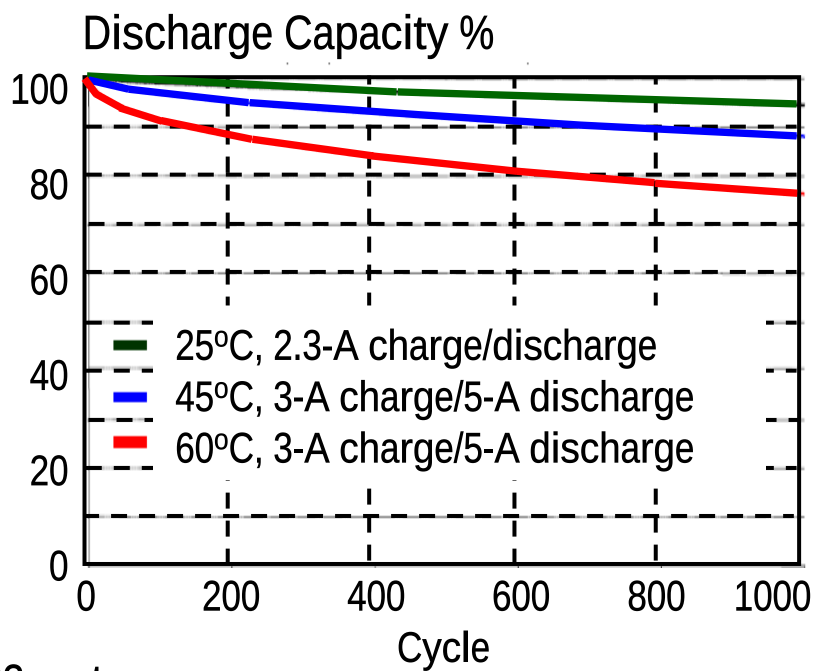
LiFePO4 Battery Characteristics

LiFePO4 Battery

– High Safety: 350° C Thermal Runaway
– 10 mΩ at 1 Hz, suitable for high discharge rate applications
– 2 times longer cycle life
– 60% lower energy density (Volumetric density)

26650A LiFePO4

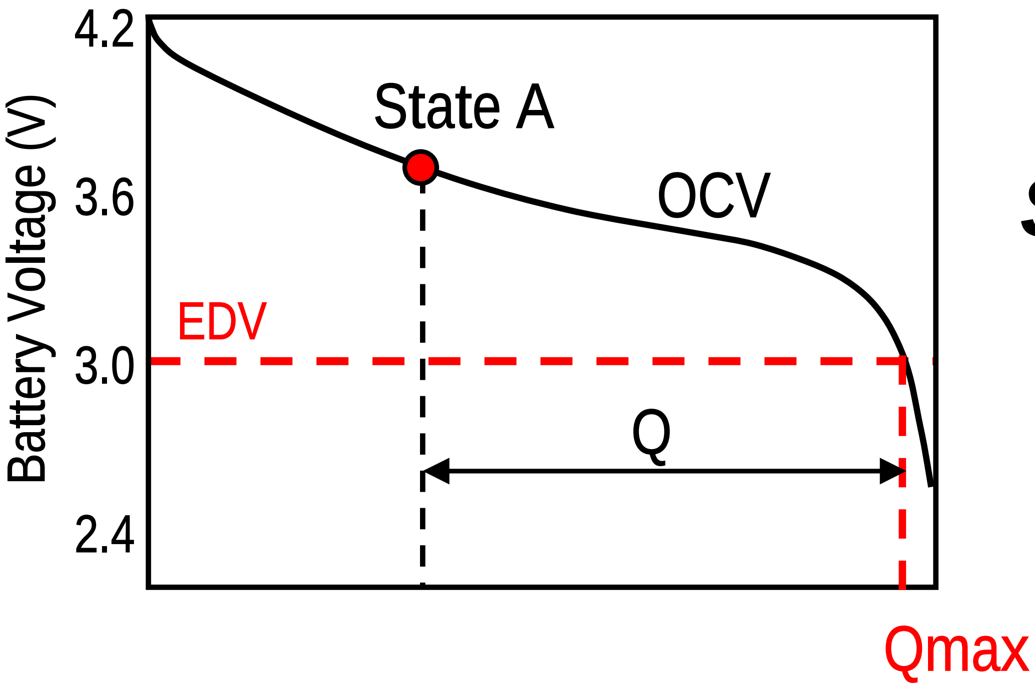




http://www.a123systems.com

Battery Fuel Gauge Terminology

State of Charge (SOC)



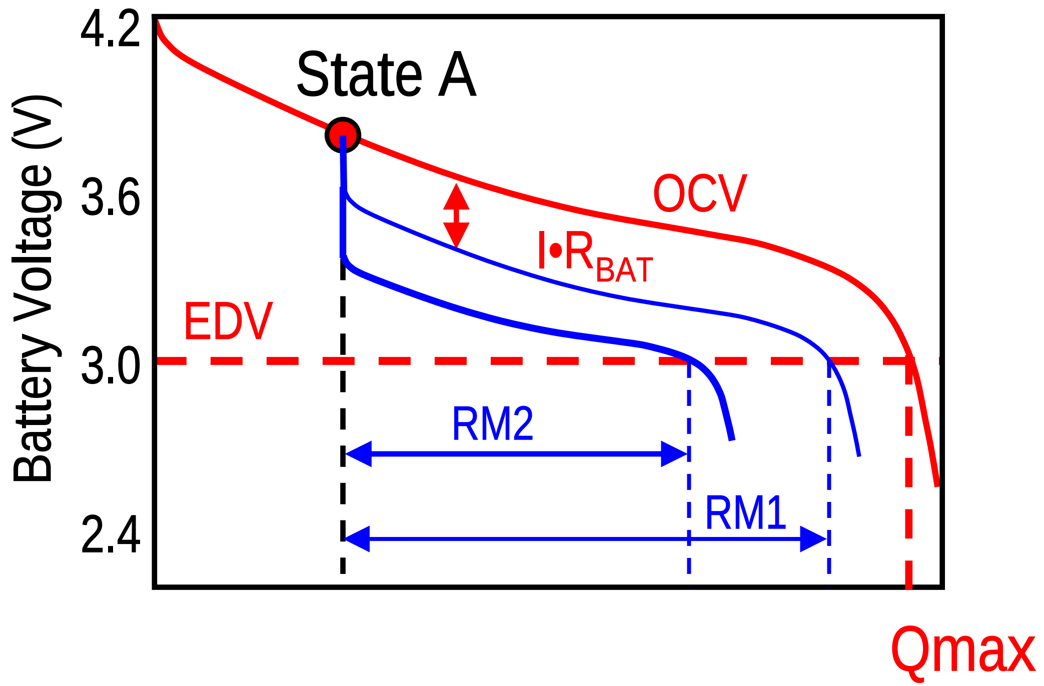
$$SOC = \frac{Q}{Q_{max}}$$

- SOC = 1 (DOD=0) for a fully charged battery
- SOC = 0 (DOD= 1) for a fully discharged battery

DOD= Depth of Discharge

Battery Remaining Capacity RM

RM: Battery capacity from the current state to EDV

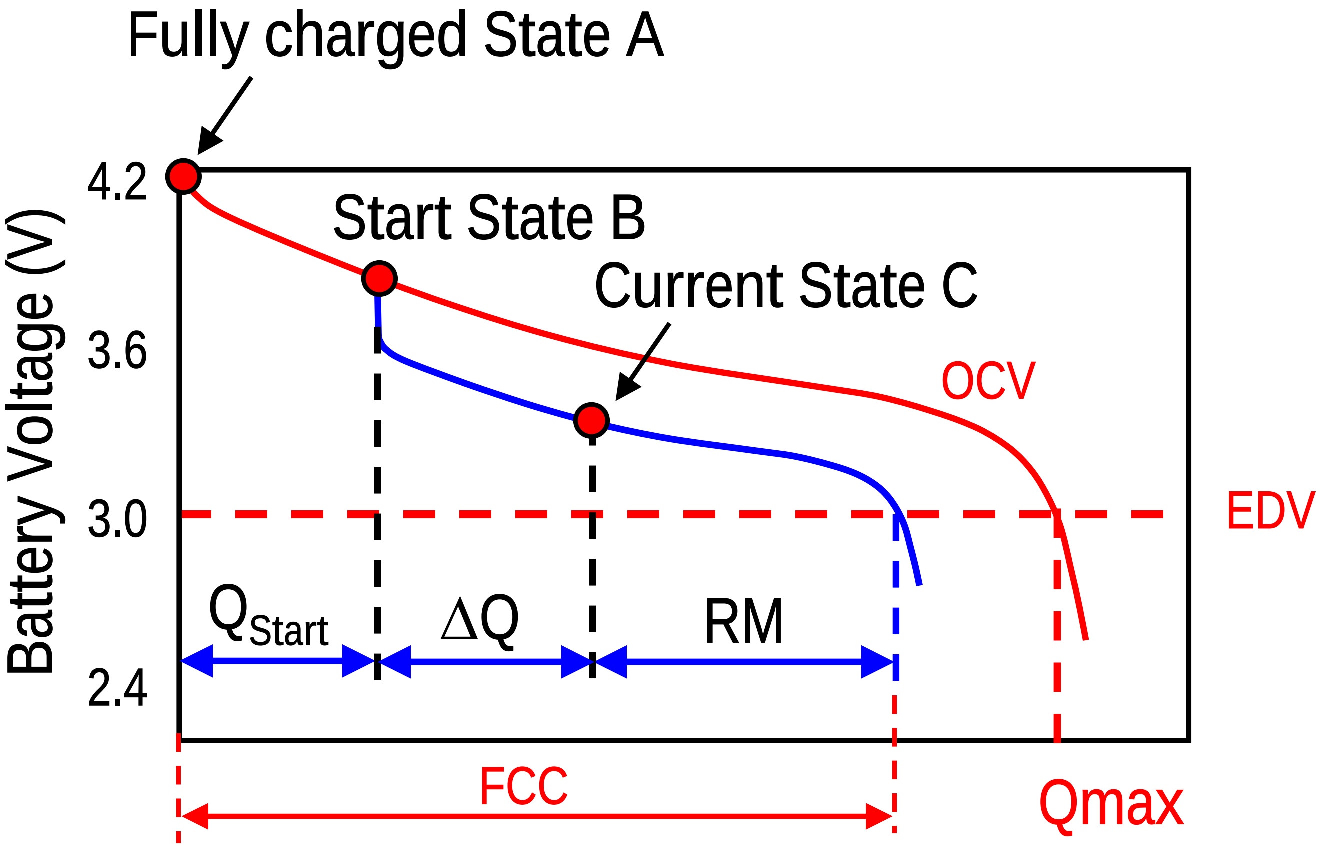


- RM is different @ different discharge Rate

Full Charge Capacity (FCC)

FCC: The amount of charge passed from a fully charged state until EDV is reached at a given discharge rate

$$FCC = Q_{start} + \Delta Q + RM$$



Battery Fuel Gauge Fundamentals

What does the Battery Fuel Gauge do?

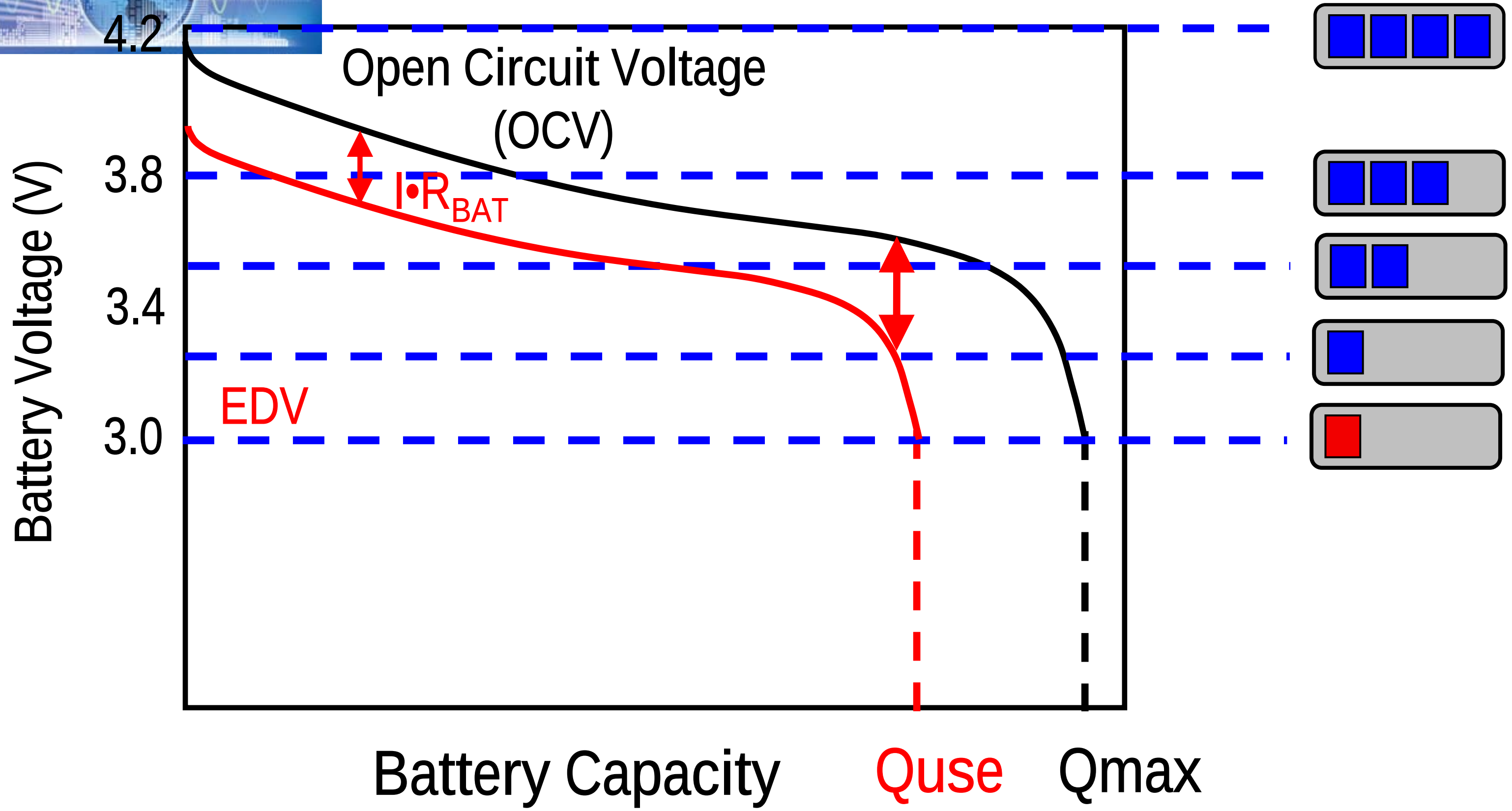
- Communication between battery and user
- Measurement:
  - Battery voltage
  - Charging or discharging current
  - Temperature
- Provide:
  - Battery Run Time (Time to Empty) and Remaining Capacity
  - Battery health information
  - Overall battery power management (Operation mode)

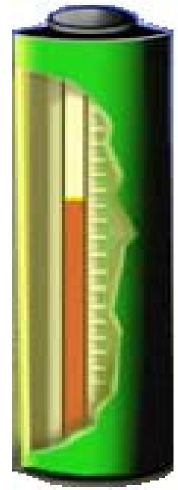
How to Implement Fuel Gauge?

- Voltage Based: SOC = f (VBAT)
- Coulomb Counting: $\boldsymbol{Q = \int i\, dt}$
- Impedance Track: Real time resistance measurement $\boldsymbol{V = V_{OCV} - I \cdot R_{BAT}}$

Voltage Measurement Based Fuel Gauge

Voltage Based Fuel Gauge

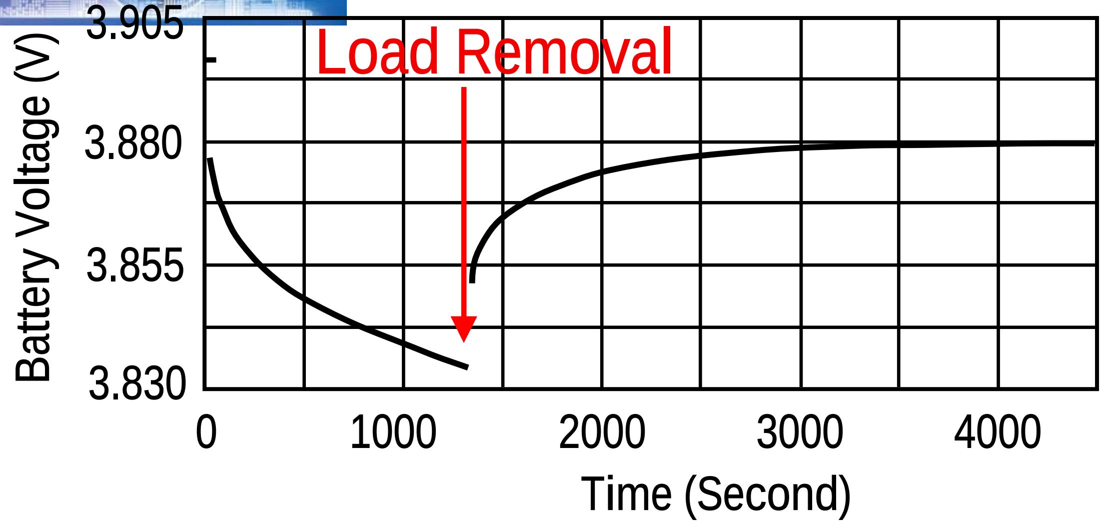


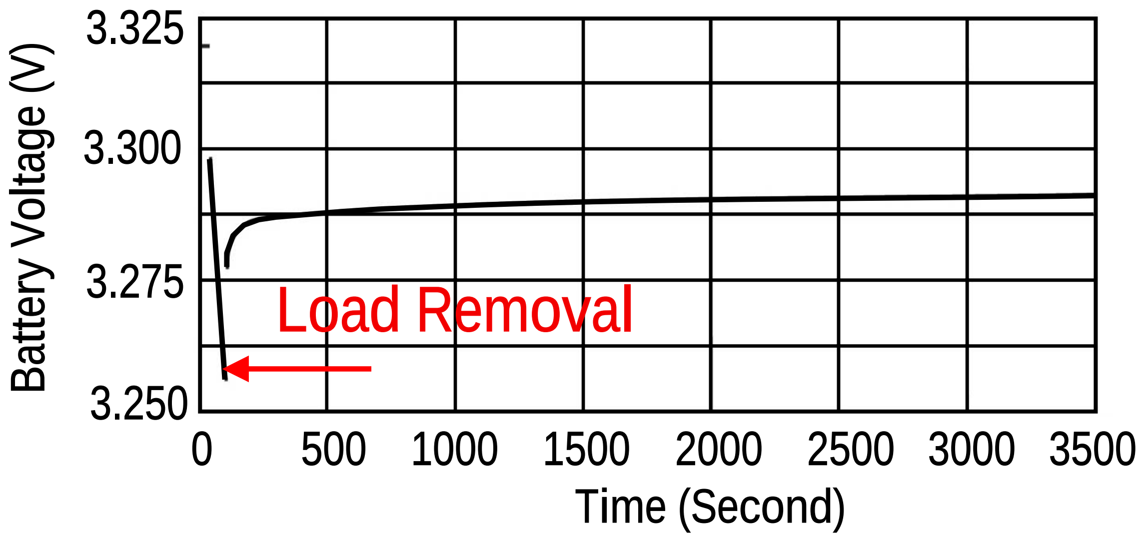


- Applications: low end cellular phone, DSC,…
- One bar represents over 50% capacity between 3.8V and 3.4V
- Pulsating load causes capacity bar up and down
- Accurate ONLY at very low current

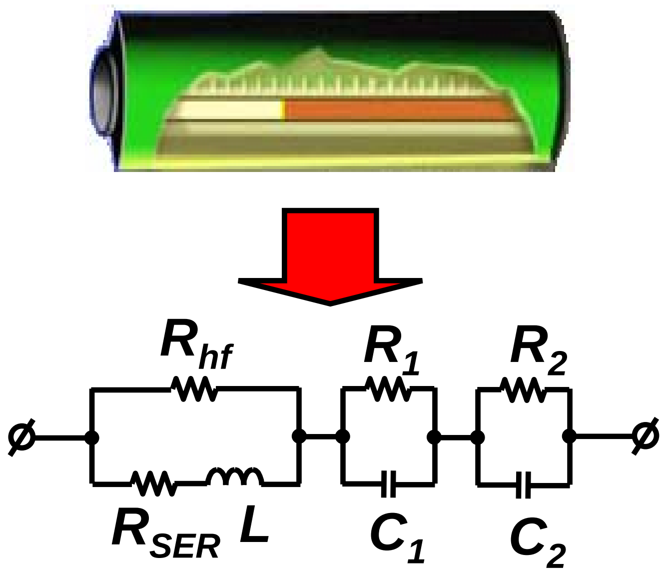
$$V = V_{OCV} - I \cdot R_{BAT} ?$$

Battery Relaxation



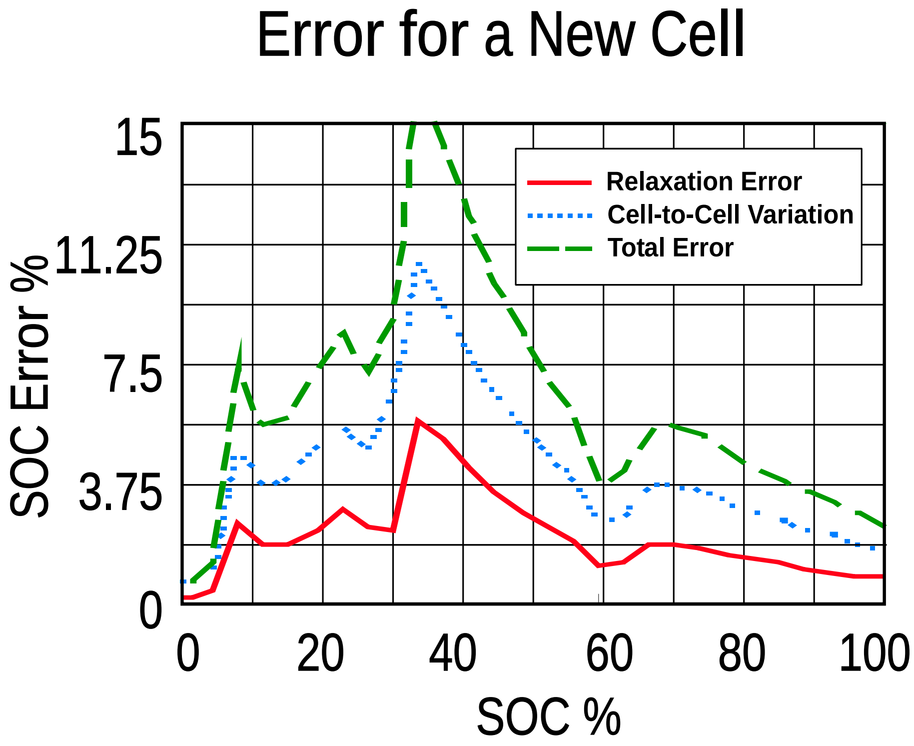


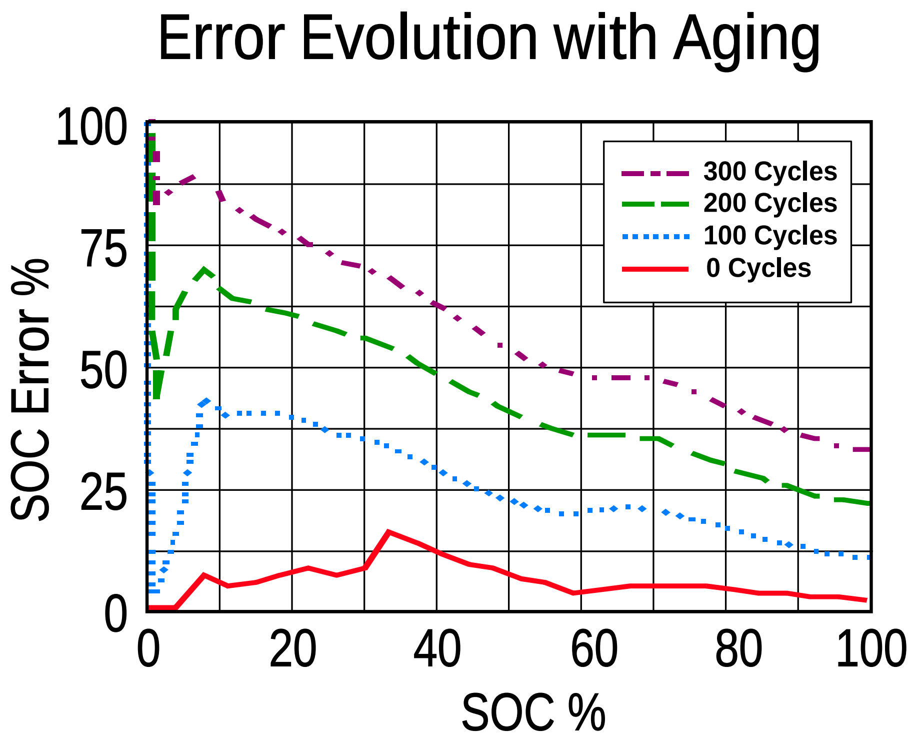
- Complete relaxation takes about 2000 seconds
- Different voltage at different instants
- Voltage difference between 20 and 3000 seconds is over 20 mV



*C/3 rate current used for both tests

SOC Error of Voltage-Based Fuel Gauging





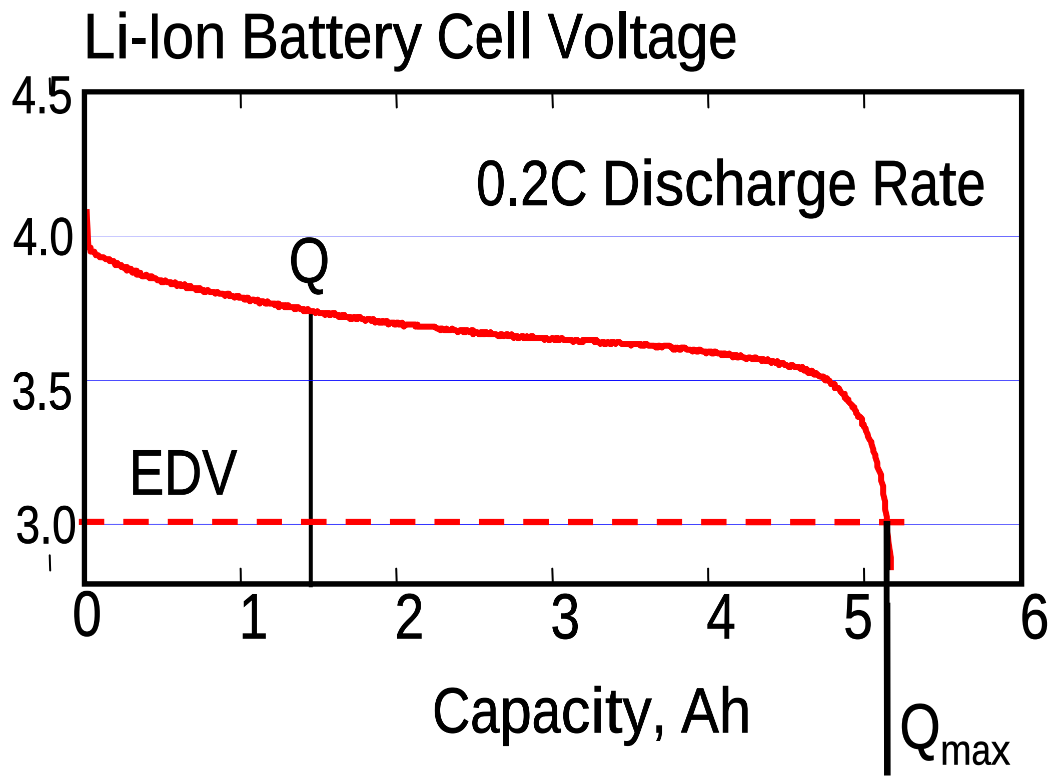
$$V = V_{OCV} - I \cdot R_{BAT} \; ?$$

- 20-mV relaxation measurement error
- 15% cell-to-cell resistance tolerance
- Battery resistance doubles every 100 cycles

Coulomb Counting Based Fuel Gauge

Coulomb Counting: Current Integration

- Battery is fully charged
- During discharge capacity is integrated
- Q_{max} is updated every time full discharge occurs

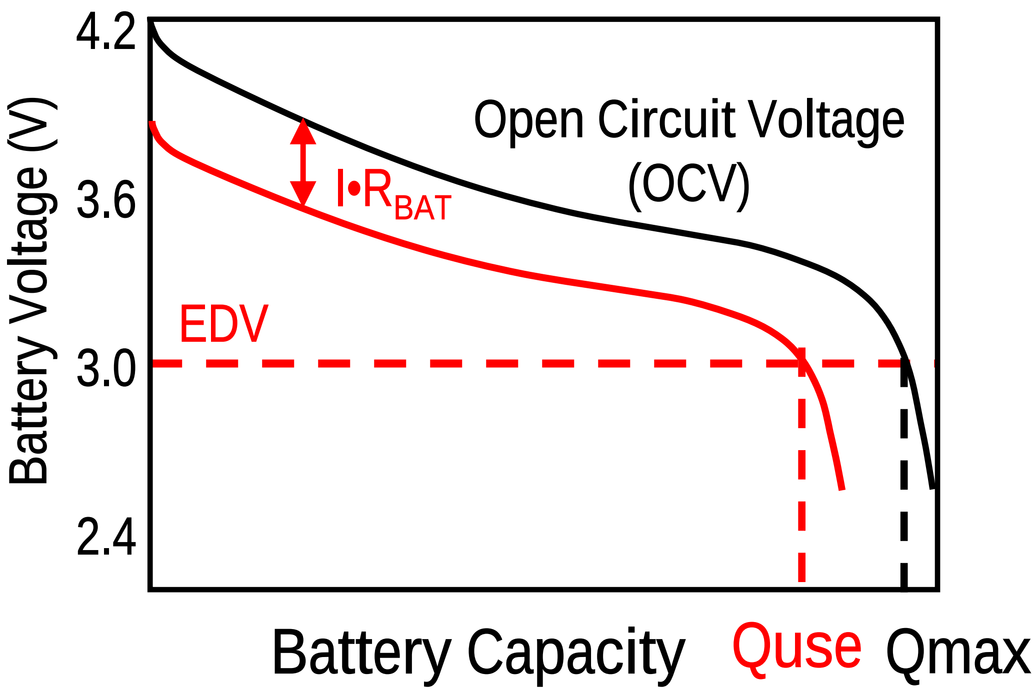


$$Q = \int i \, dt$$

EDV: End of Discharge Voltage

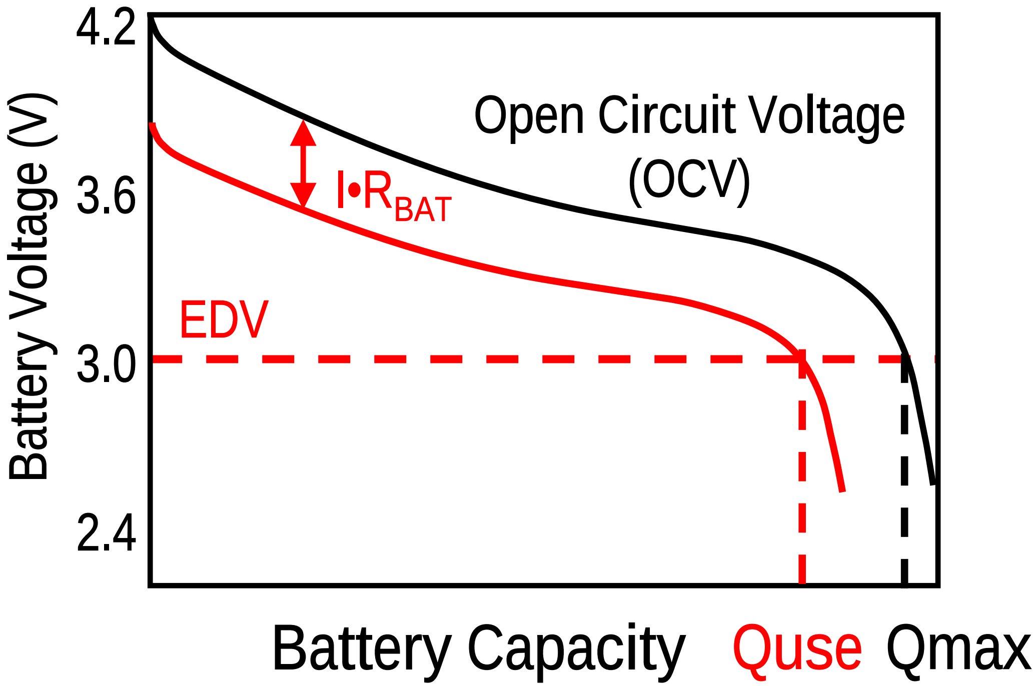
Impedance Track™ Fuel Gauge Technology

Advantages for Existing Fuel Gauge



- Very accurate gauging from OCV without load (relaxation)
- Very accurate gauging with Coulomb Counting with load

Issue Review



- Voltage Based Fuel Gauge: V = OCV(T,SOC) - I×R(T,SOC, Aging)
- Current integration Fuel gauge: CEDV = OCV(T,SOC) - I×R(T,SOC, Aging)

Problem: Battery Impedance

Impedance Track™ Fuel Gauge

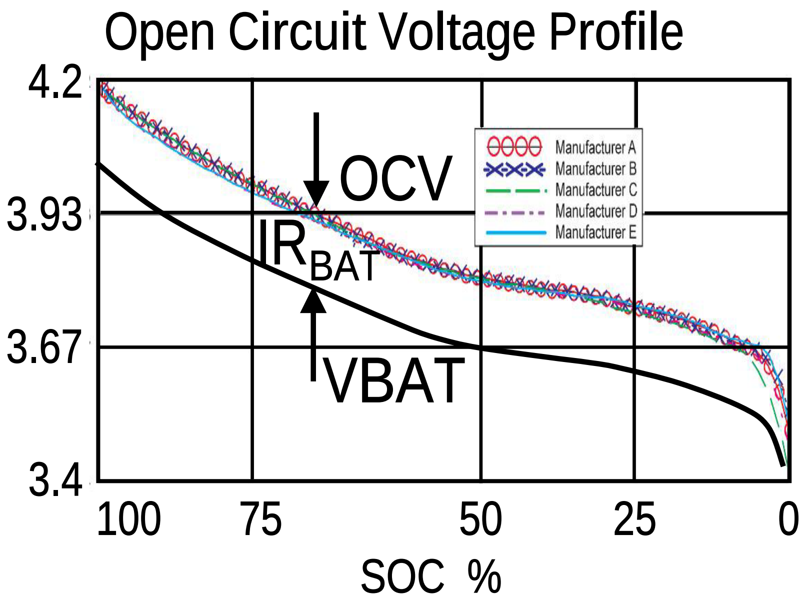
- Voltage based Fuel gauge: Accurate gauging under no load
- Coulomb counting based gauging: Accurate gauging under load
- Combine advantages of voltage and current based methods
- Real Time Measuring impedance
- Calculate remaining run-time at given average load using both open circuit voltage and impedance information.

$$V = OCV(T,SOC) - I*R(T,SOC, Aging)$$

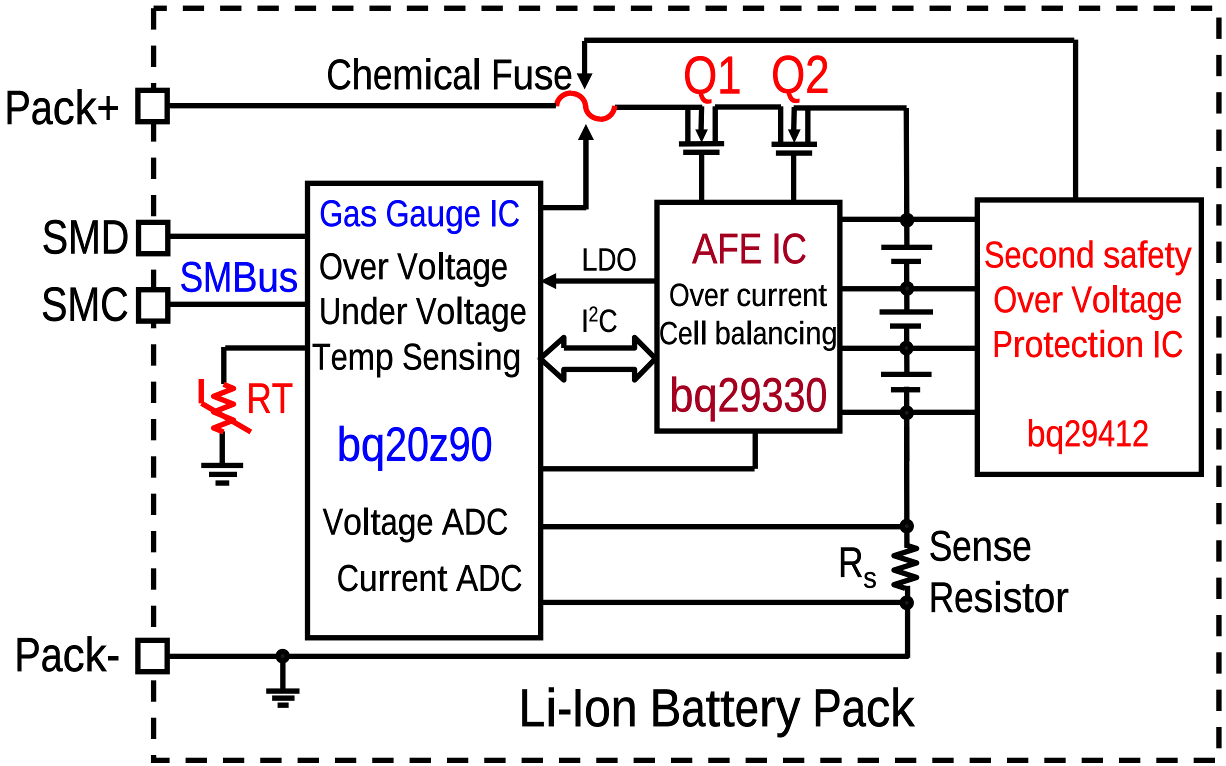
How to Measure Impedance ?

- Data flash contains a fixed table: *OCV = f (SOC, T)*
- IT algorithm performs real-time measurements and calculations during charge and discharge cycles.

$$R_{BAT} = \frac{OCV - V_{BAT}}{I_{AVG}}$$



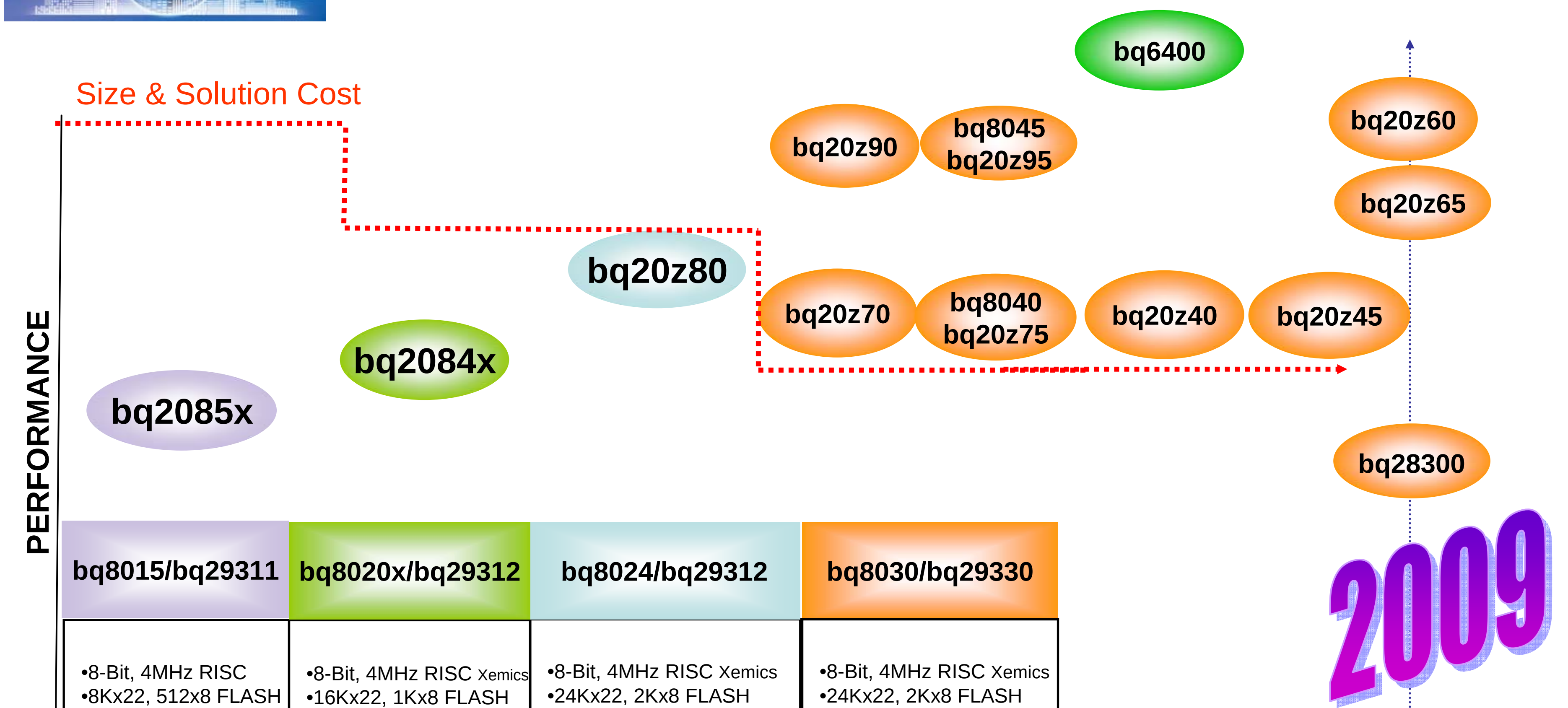
Multi-Cell Battery Pack Electronics



Chipset: bq20z90-bq29330:
Gas gauge accuracy 1% over battery life

- Over Charge (or over-voltage)
  - 1st : Gas gauge IC firmware
  - 2nd: Protection IC
- Over Current
  - Gas gauge IC firmware
    - 1st level (chg or dsg)
    - 2nd level, Safety
  - AFE hardware
    - 3rd level, discharge only
- Short Circuit – AFE hardware.
- Over-Discharge
- Over temperature

2-4 Cells Fuel Gauges

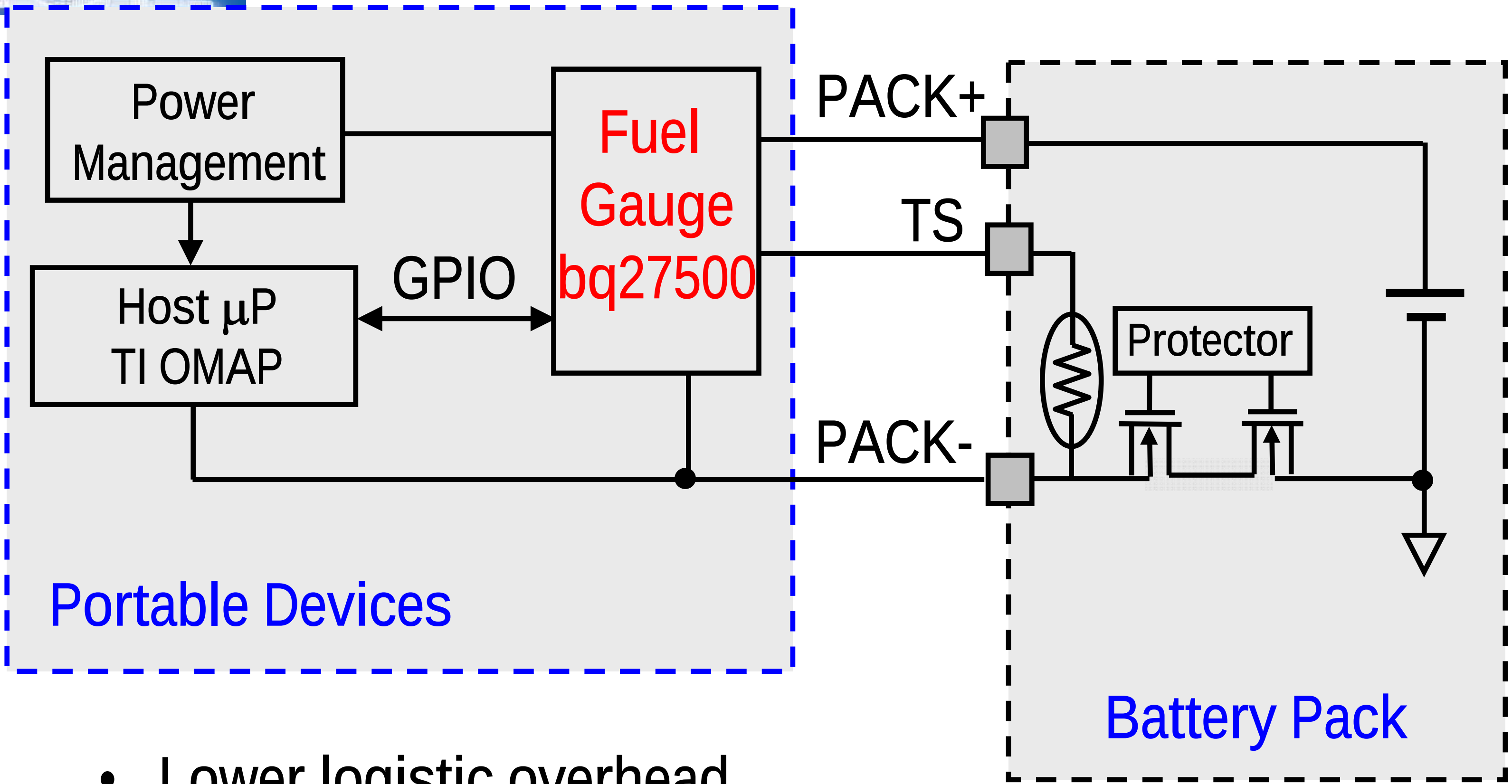


bq8015/bq29311	bq8020x/bq29312	bq8024/bq29312	bq8030/bq29330
•8-Bit, 4MHz RISC •8Kx22, 512x8 FLASH •4Kx22 ROM, •512x8 SRAM •Delta Sigma ADC, CC •RC Oscillator, PLL •SMBus, HDQ •24 GPIO •38 TSSOP	•8-Bit, 4MHz RISC Xemics •16Kx22, 1Kx8 FLASH •4Kx22 ROM •768x8 SRAM •Delta Sigma ADC, CC •Crystal Oscillator, RC, PLL •SMBus, HDQ •24 GPIO •38 TSSOP	•8-Bit, 4MHz RISC Xemics •24Kx22, 2Kx8 FLASH •4Kx22 ROM •1kx8 SRAM •Delta Sigma ADC, CC •Crystal Oscillator, RC, PLL •SMBus •24 GPIO •38 TSSOP	•8-Bit, 4MHz RISC Xemics •24Kx22, 2Kx8 FLASH •6Kx22 ROM •2Kx8 SRAM •Delta Sigma ADC, CC •Integrated RC, DCO •SMBus •24 GPIO or 10 GPIO •30 TSSOP or 20 TSSOP

time

today

System-Side Impedance Track Fuel Gauge



- Lower logistic overhead
- Common batteries: Lower cost
- OEM/ODM total control
- Movement toward total on board battery management

Single-Cell Fuel Gauges

bqJunior Family — Coulomb Counting

bq27210 / bq27010
- Compensated EDV termination
- HDQ and I2C options
- 10 pin, 3x4 mm QFN

bq27200 / bq27000
- Fixed EDV termination
- HDQ and I2C options
- 10 pin, 3x4 mm QFN

bq27500 Family — Impedance Track

Host Side

released **bq27500**

released **bq27501**
- ID Resistor option
- 12 pin, 2.5x4 mm QFN

released **bq27510**
- Integrated LDO
- 12 pin, 2.5x4 mm QFN

released **bq27500**
- Small CSP package
- 2mm x 2.5mm

Q409 **bq27520**
- Integrated LDO
- Small CSP package
- 2mm x 2.7mm

Pack Side

released **bq27541**
- I2C, HDQ, SDQ options
- SHA-1 Security integrated
- 12 pin, 2.5x4 mm QFN

Q4 09 **bq27550**
- SDQ, HDQ options
- integrated protector
- SHA-1 Security integrated
- 12 pin, 2.5x4 mm QFN

Thank you!

Q & A