Introduction to Battery Fuel Gauges and Algorithms

Battery Management Deep Dive Training

October 17-19, 2017

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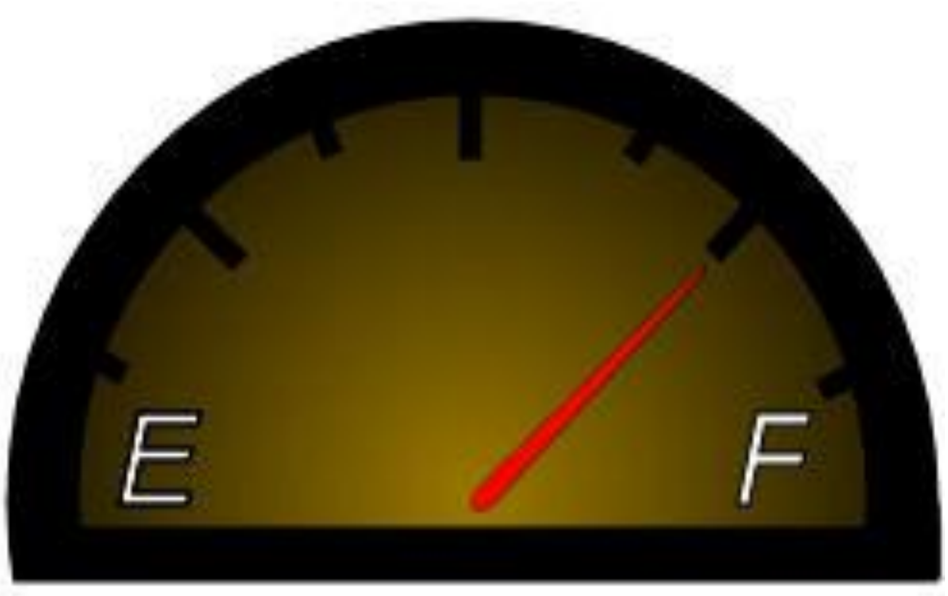
Agenda

- What is a gauge?
- Battery characteristics
- How to make a gauge
- How to use a gauge
- Multi-cell and single-cell differences



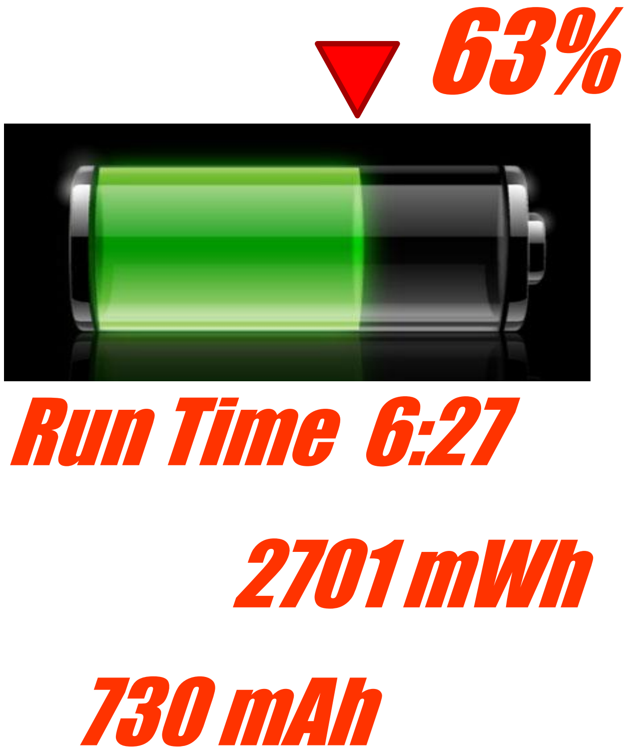
WHAT CAN A GAUGE DO?

What can a gauge do?

- Predict the future
- Enhance safety
- Be a “black box”
- Extend run-time
- Extend lifetime of a battery

What can a gauge do?

- Predict the future
    - capacity (% or mAh or mWh)
    - run-time predictions (in minutes)
    - what-if predictions
    - charge time predictions
- Enhance safety
- Be a “black box”
- Extend run-time
- Extend lifetime of a battery



What can a gauge do?

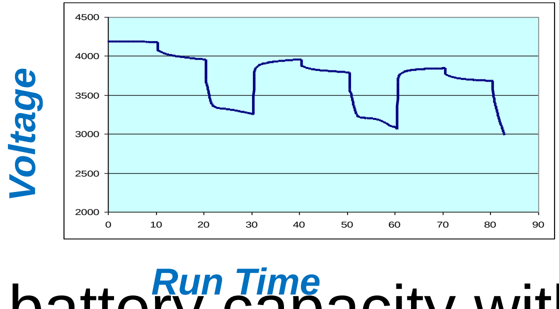
- Predict the future
- Enhance safety
  - Controls protection functions inside the battery pack
- Be a “black box”
- Extend run-time
- Extend lifetime of a battery

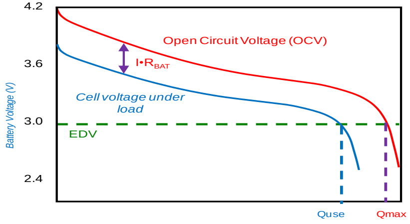
What can a gauge do?

- Predict the future
- Enhance safety
- Be a “black box”
  - record usage conditions
  - assist with warranty analysis and troubleshooting
  - assist with supplier quality improvement
- Extend run-time
- Extend lifetime of a battery

What can a gauge do?

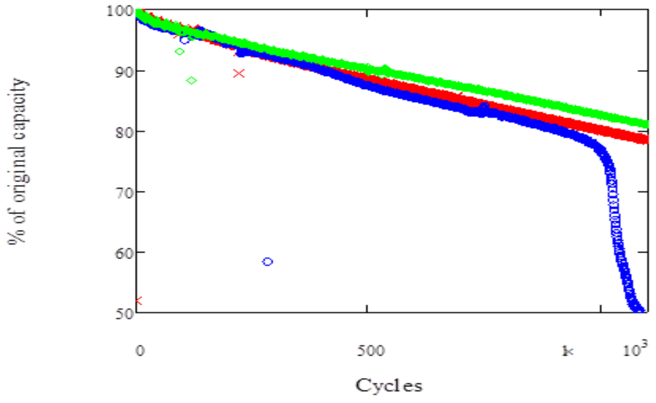
- Predict the future
- Enhance safety
- Be a “black box”
- Extend run-time
  - –confidently use all available battery capacity with no surprises
  - –no unused capacity due to over-cautious shutdown conditions
- Extend lifetime of a battery





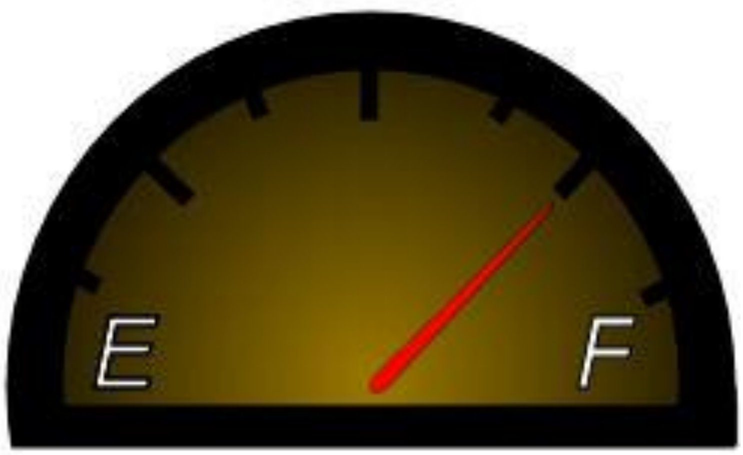
What can a gauge do?

- Predict the future
- Enhance safety
- Be a “black box”
- Extend run-time
- Extend lifetime of a battery
    - get more cycles from a battery
    - uses dynamic learning and battery modeling to control healthy, safe, and fast charging



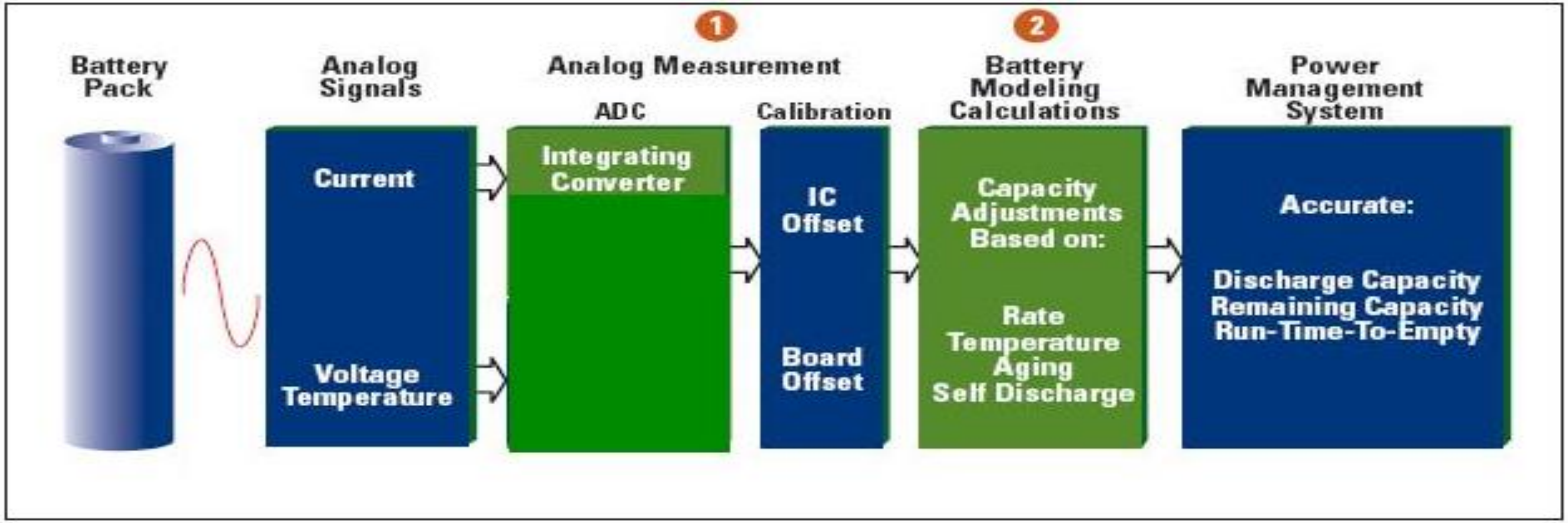
What else can a gauge do…

- Authentication
  - Ensure only safe/authorized packs are used
- State of Health
  - Objectively tell user when a battery is at end of life
- Traceability
  - Store serial numbers, production information, and more inside gauge’s flash memory
- Instrumentation in system
  - Highly accurate voltage, current, and temperature measurements
  - Useful for system characterization and production tests
- Assist with power management
  - Control charger or load
  - Recommend maximum current that won’t crash battery
  - Allow host to remain in low power state and wait for interrupts



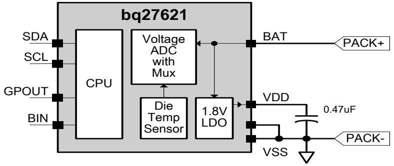
WHAT IS A GAUGE

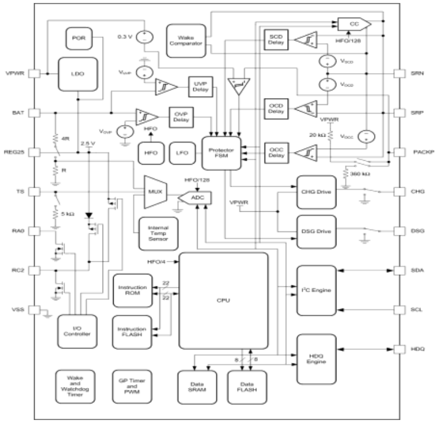
Gauging concept



Hardware features (minimum)

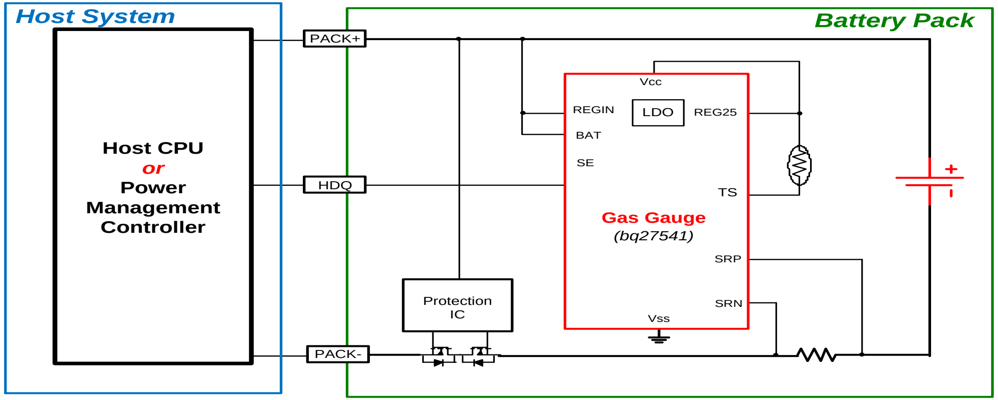
- Optimized hardware for
  - Low power consumption (battery powered and all that…)
  - ADC for
    - voltage measurements (1mV accuracy target)
    - temperature measurements
  - Coulomb counter (integrating ADC)
    - accumulating passed charge
    - current measurements
  - CPU/RAM
  - Non-volatile Memory
    - Flash or EEPROM and/or ROM

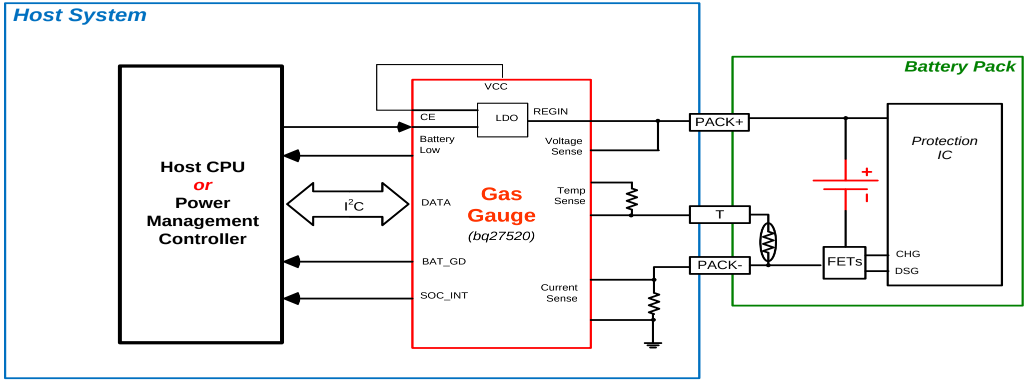




Gas gauge placement

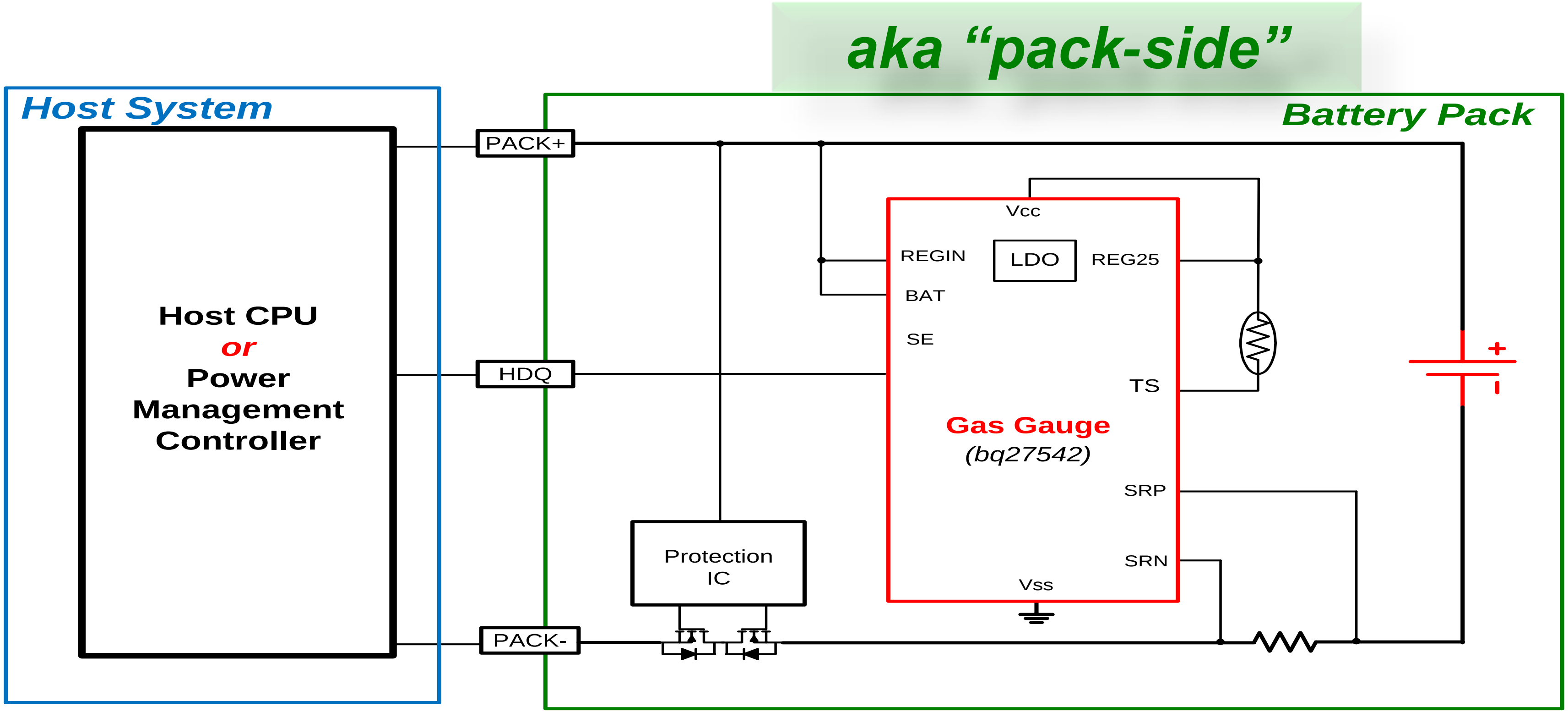
Pack-side





System-side

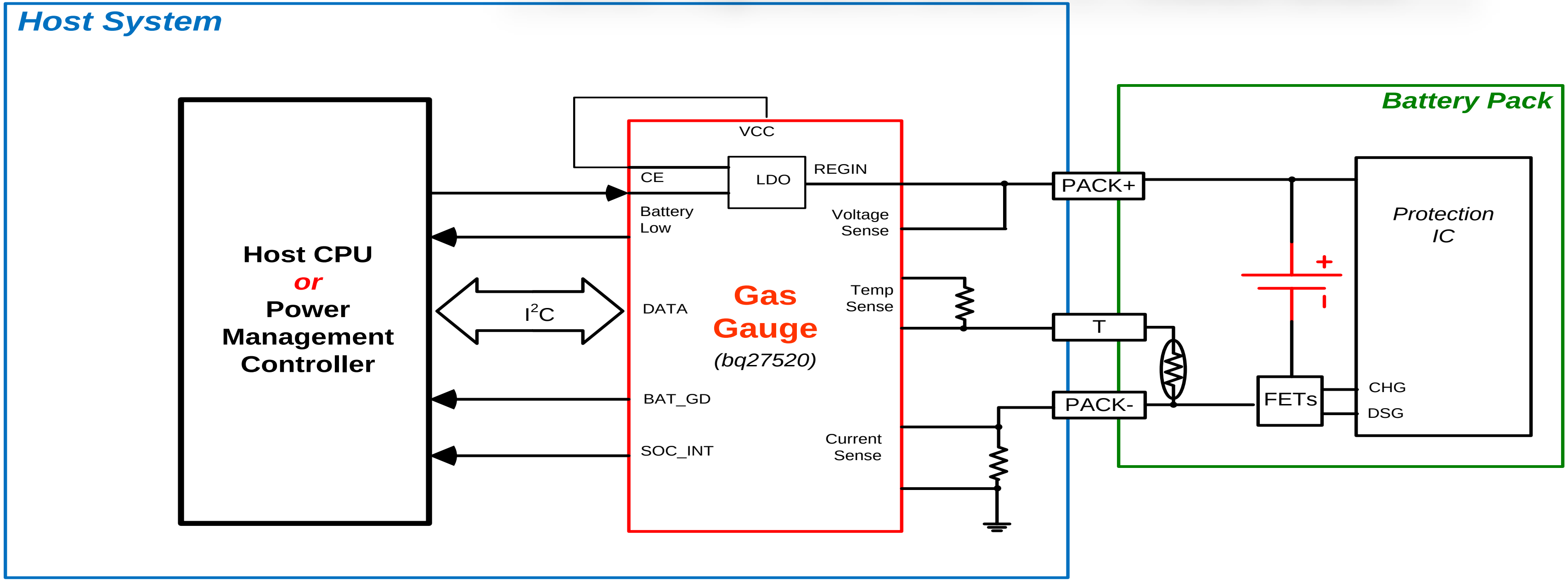
Single-cell gauge in the pack



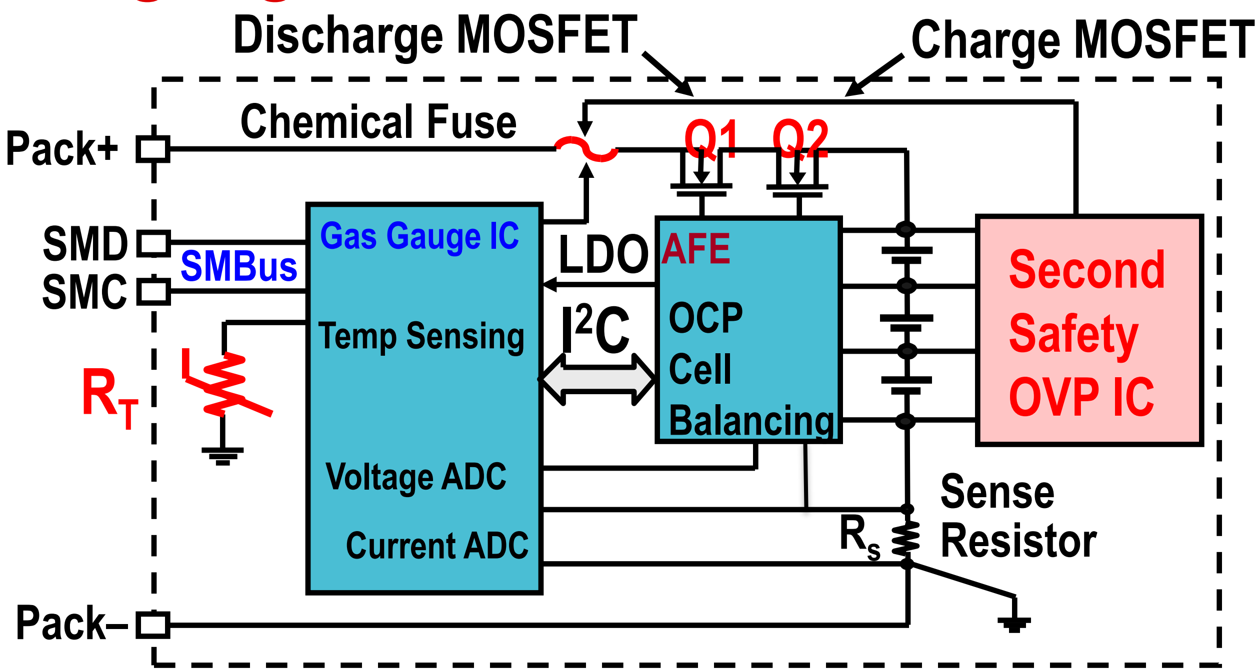
bq27742 and bq27750 combine gauge+protector

Single-cell gauge in the system

aka "system-side" / "host-side"



Multi-cell gauge



bq40z50-R2 gas gauge : Remaining capacity, run time, health condition, balancing, protection, lifetime, authentication

LI-ION BATTERY CHARACTERISTICS

Treatment of Li-ion Battery

Healthy habits:

- Most stable in 50% charged state.
- High voltages accelerate corrosion and electrolyte decomposing. Charging should be limited to maximal voltage specified by manufacturer (4.1 or 4.2 V)
- Short deep discharge is not detrimental, but long storage in discharge state results in dissolution of protective layer and resulting capacity loss.
- High temperature is main killer. Provide appropriate cooling and place battery far from heat-generating circuits. Take battery out of equipment if long term AC powered to prevent pack exposure to high temperatures.
- Use battery soon after manufacturing. Discharge capacity degrades even if not used
- Storage at low temperatures increases shelf life
- If used in stand-by application, charger should terminate charging and not resume until state of charge drops below ~95%. Trickle charging is not recommended.
- Unnecessary charging or discharging should be avoided, different from NiCd and NiMh there is no benefit from "exercising" the battery.

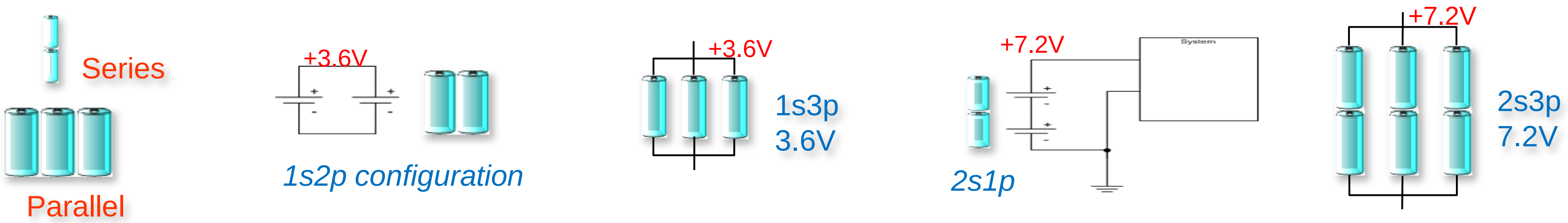
Degradation mechanisms:

- Reaction of Li-carbon compound with electrolyte. Despite protective layer, this reaction is always ongoing and is accelerated by high voltage and high temperature.
- Electrode corrosion. Very thin Al and Cu foils are used as current collectors. They are prone to corrosion, particularly at high states of charge. For this reason and electrolyte decomposition it is recommended to store batteries at 50% state of charge

Terminology

- XsYp
  - “X” number of cells in series
    - Voltage of pack is “X”*Vcell
  - “Y” number of cells in parallel
    - Capacity of pack is “Y”*Capacitycell

Pack Configurations



Types of cells

prismatic

cylindrical

coin cell

laminate / “pouch”

Terminology – Design Capacity

- Battery label says: 3200/3300mAh (min/typ)

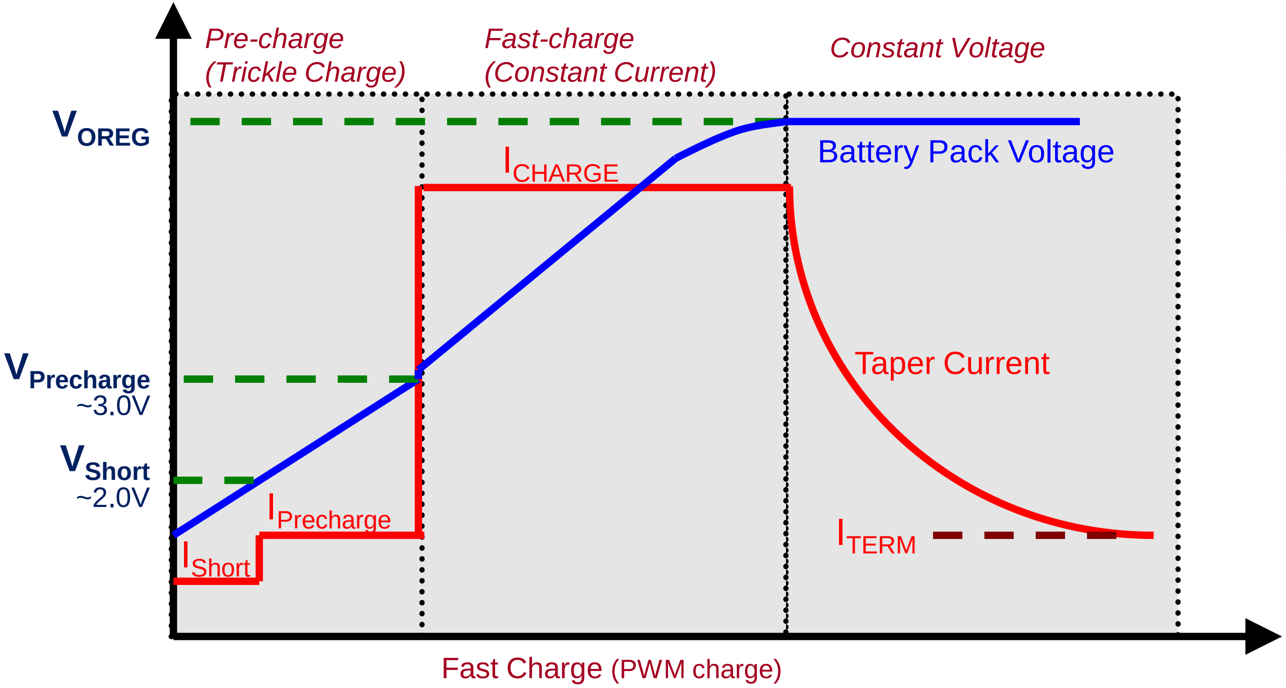
- We say “Design Capacity = 3300mAh”

Terminology – “C-rate” or “Hour rate”

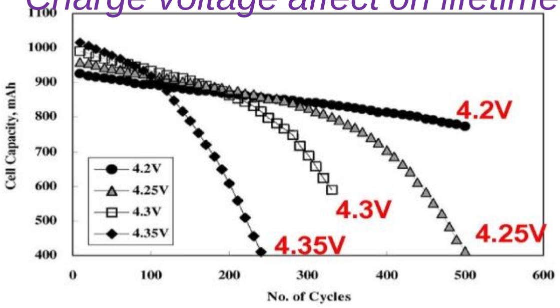
- “C-rate” or “Hour rate” is a way of expressing current relative to nominal battery capacity.
- If nominal capacity is 3300mAh…
  - A discharge rate of “1C” means use a current of 3300mA.
    - In theory, it would take 1 hour to discharge at this rate, but actually it will probably be shorter.
  - A charge rate of “C/2” means use a current of 1650mA.
    - This is also considered a “2-hour rate”.

Charging

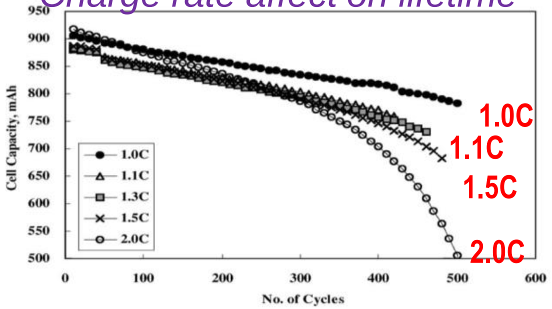
Li-Ion Charge Profile



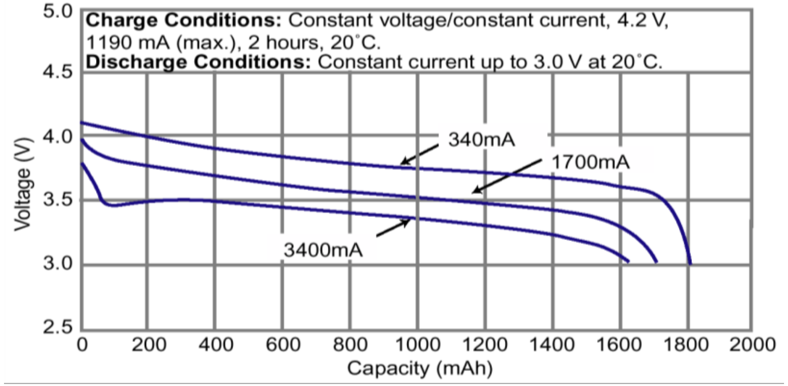
Charge voltage affect on lifetime

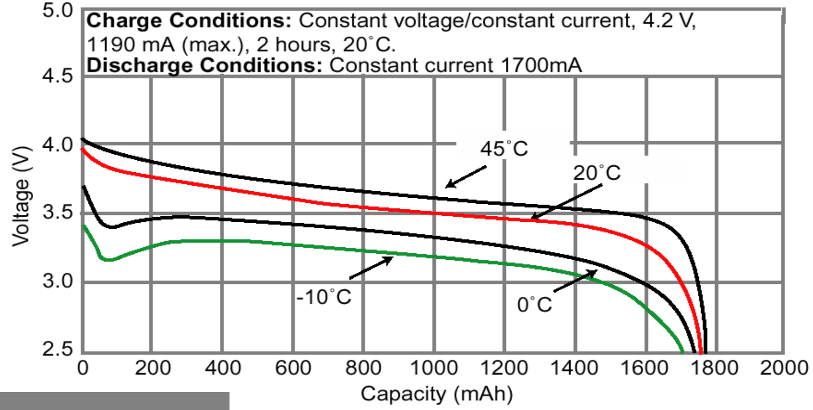


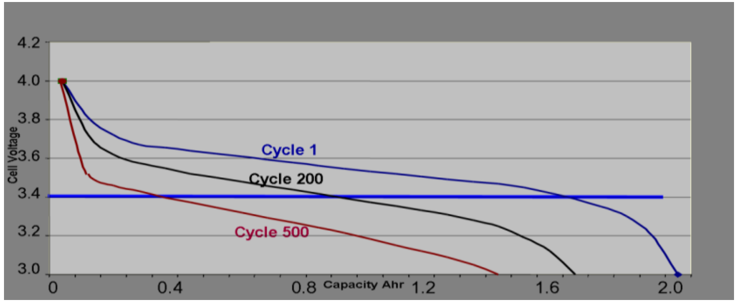
Charge rate affect on lifetime



Battery curves



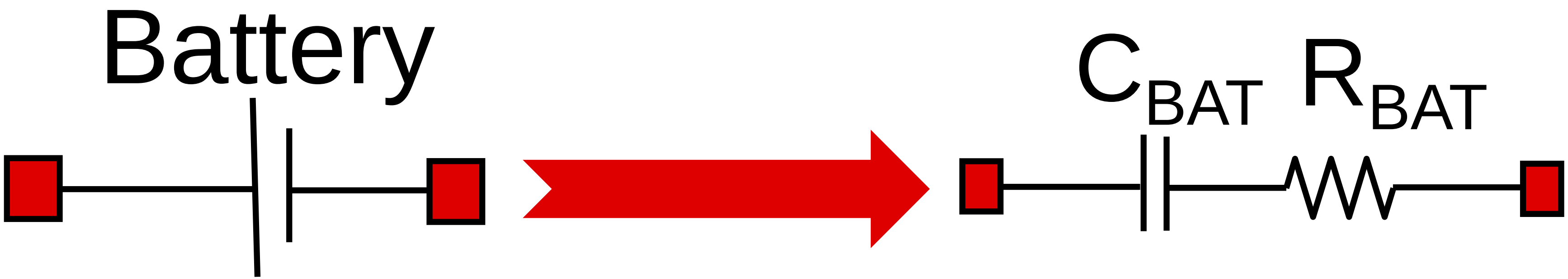




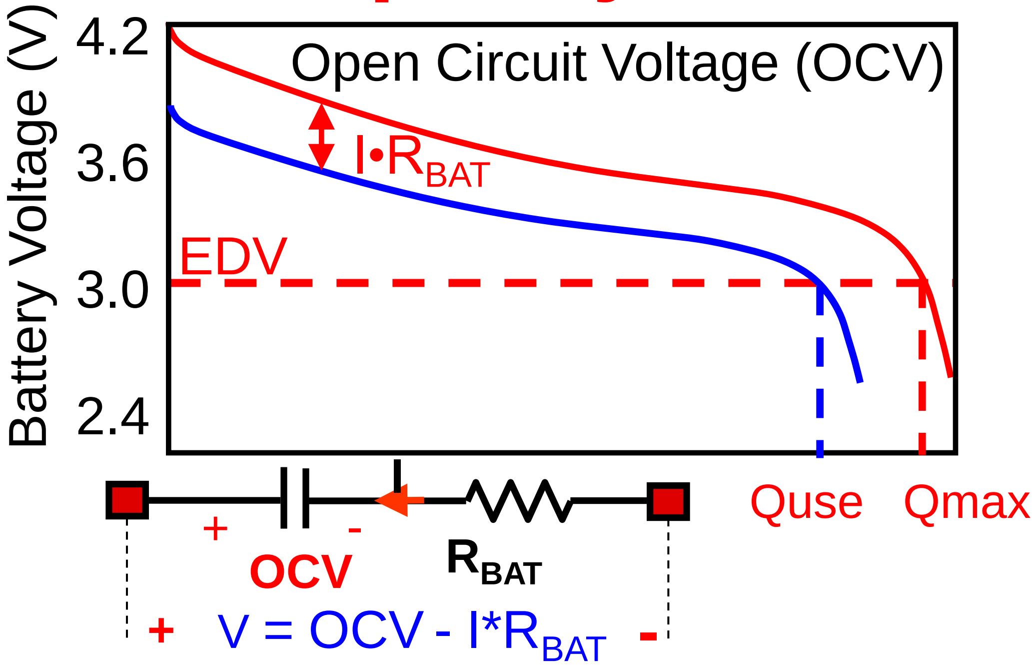
Varying shutdown voltage with discharge rate, temperature, and age provides the longest possible run time

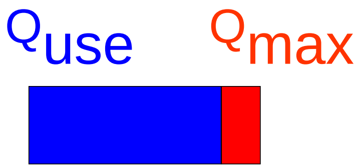
Simple battery model

- A battery is a complex electro-chemical system, but let's start with a simplistic model…



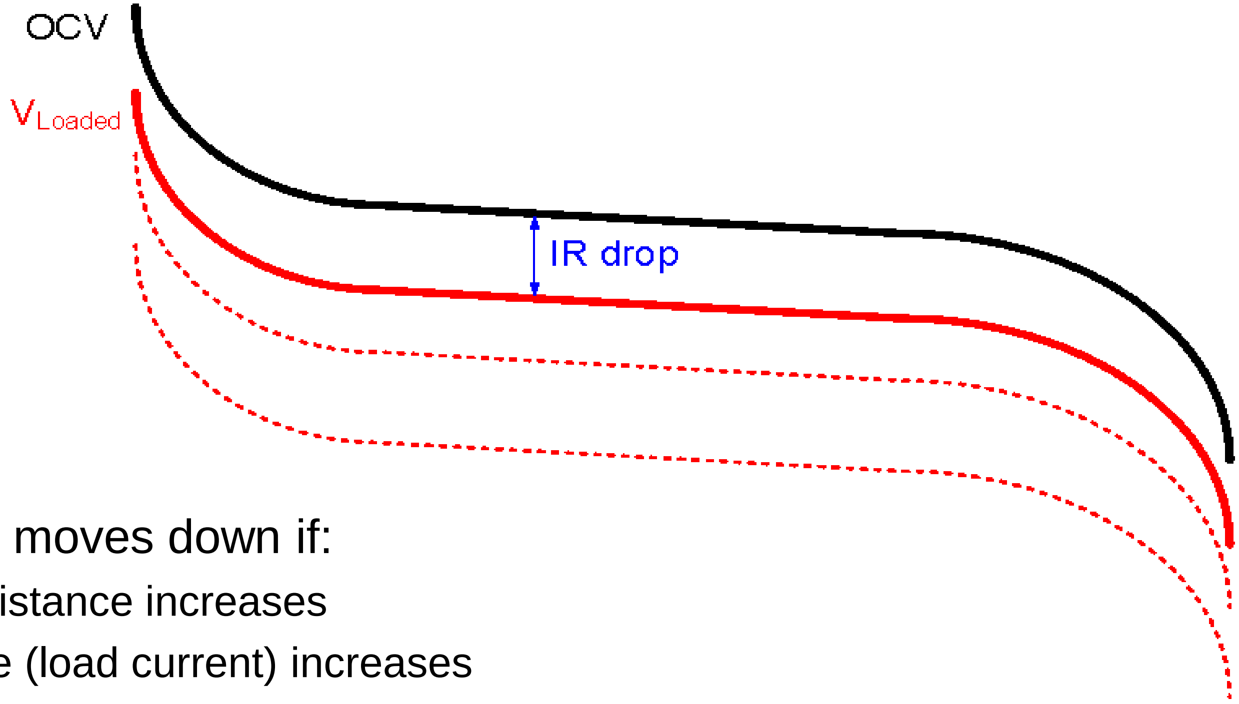
Usable capacity





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

IR drop: different usable capacities

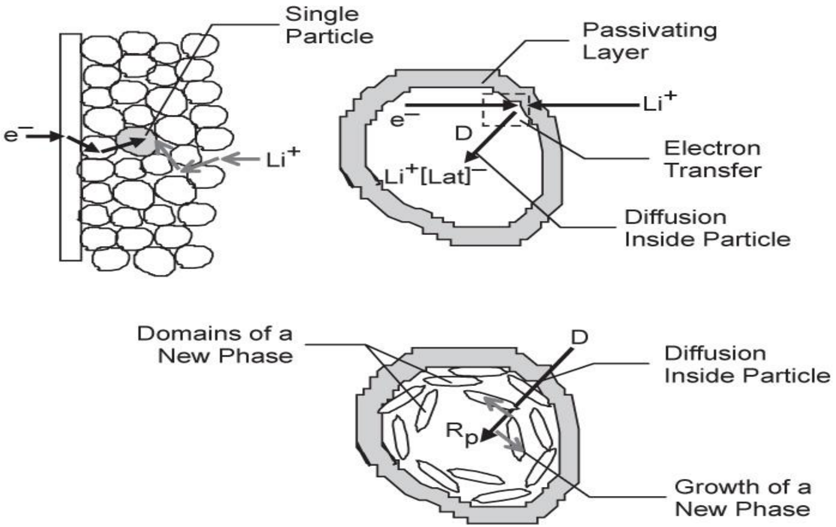


- V_{Loaded} moves down if:
  - – Resistance increases
  - – Rate (load current) increases
  - – Temperature decreases

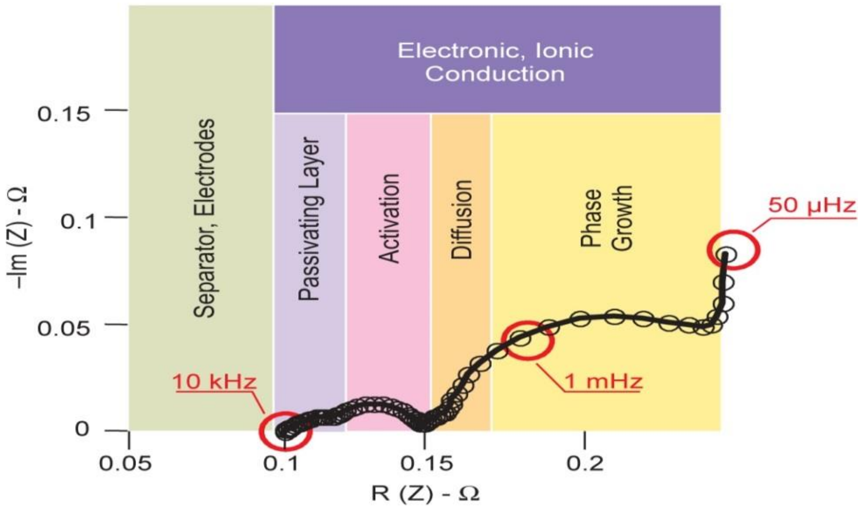
Electro-chemical system

Battery Impedance Spectrum corresponds to a complex impedance function Z(s)

Kinetic Steps in Li-Ion Battery

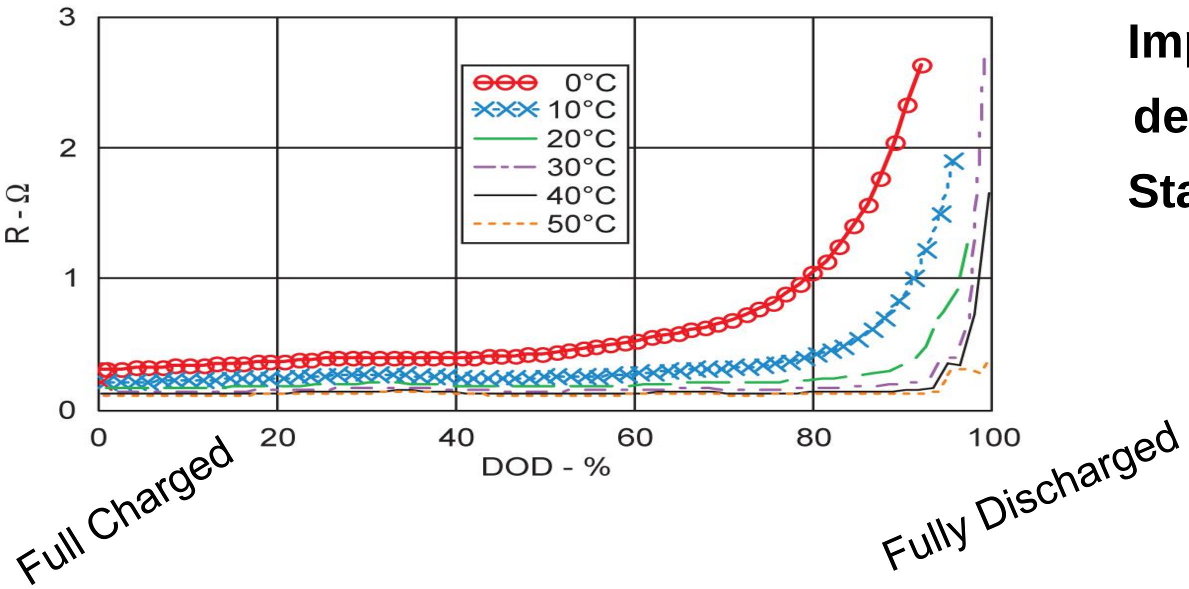


Corresponding Impedance Spectrum



***E. Barsoukov et al., J. New Materials for Electrochem. Sys., 3, (2000) 301**

Resistance curves



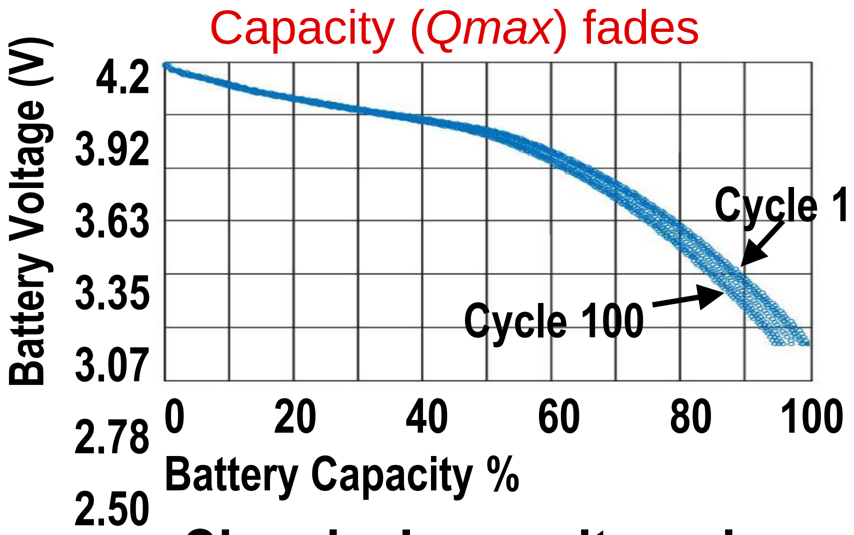
Impedance is strongly dependent on temperature, State of Charge and aging

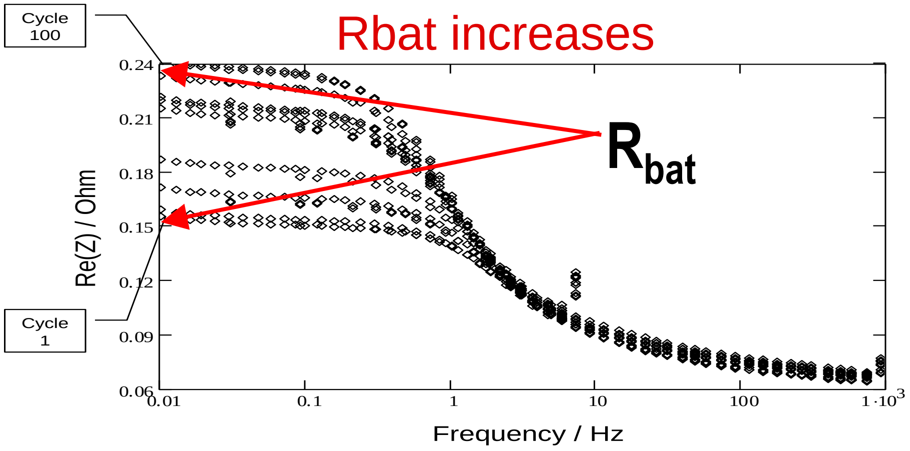
$$SOC = \frac{Q}{Q_{max}}$$

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

SOC: State of Charge
DOD: Depth of Discharge

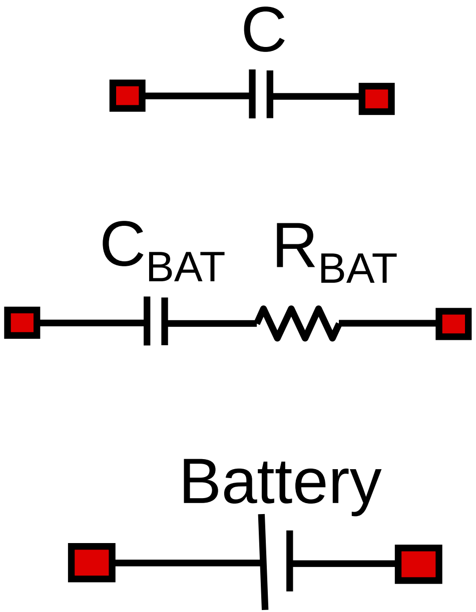
Battery aging: capacity and resistance

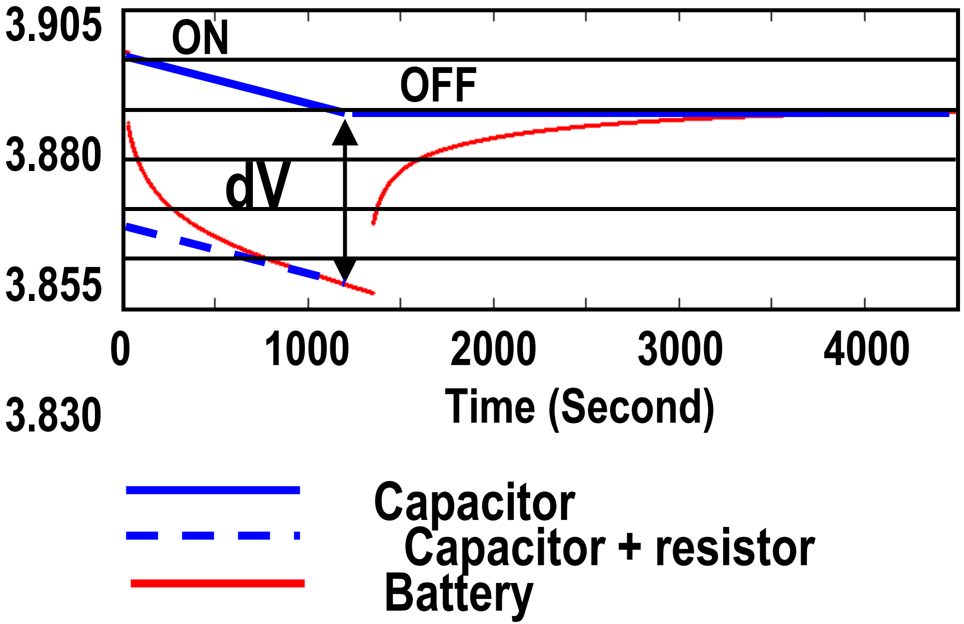




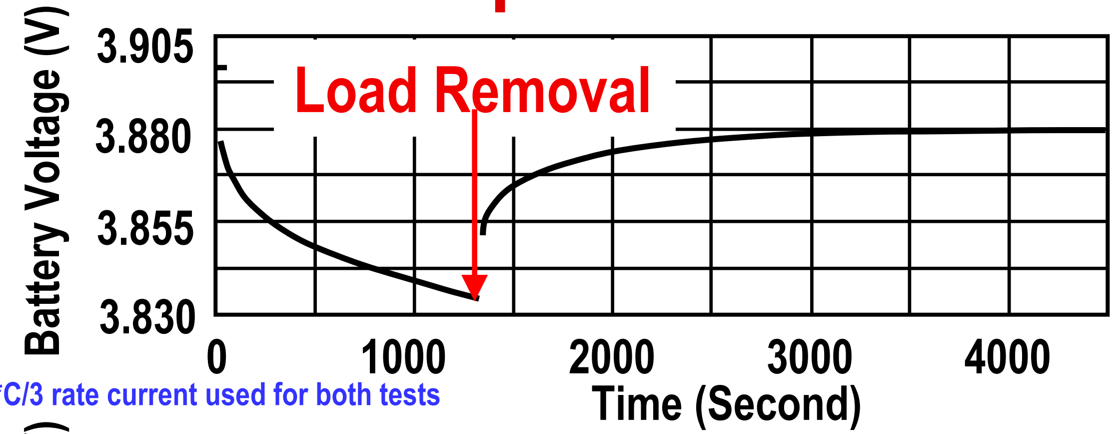
- Chemical capacity reduces by 3-5% after 100 cycles
- Battery impedance increases with aging
- Impedance almost doubles after 100 cycles .

Transient response

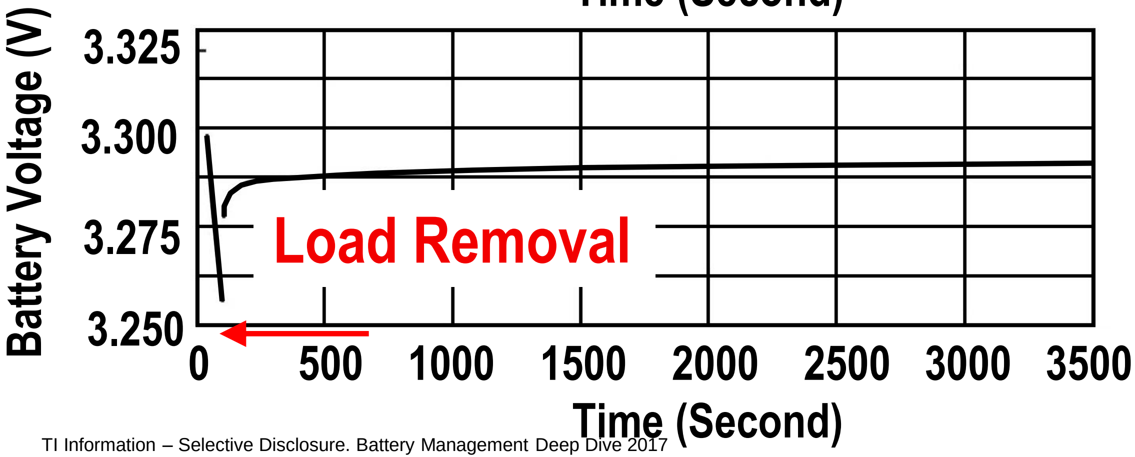




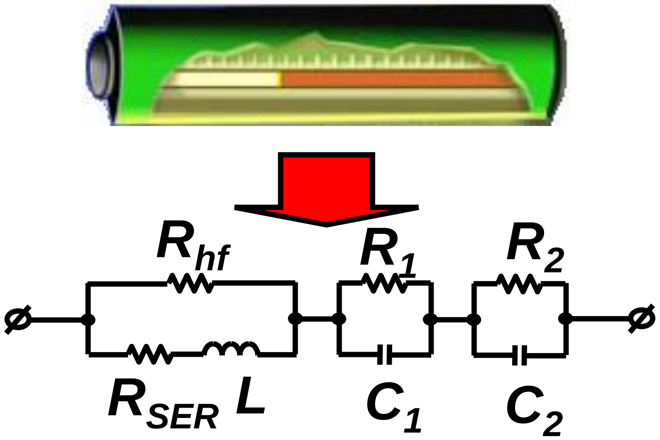
Transient response



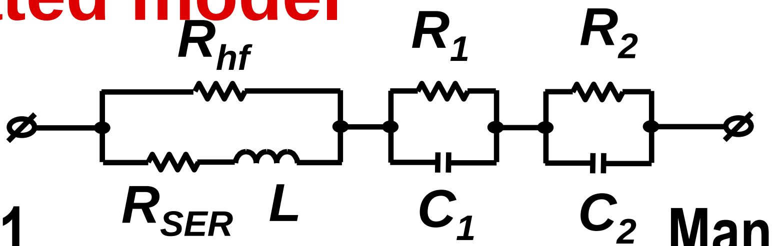
*C/3 rate current used for both tests



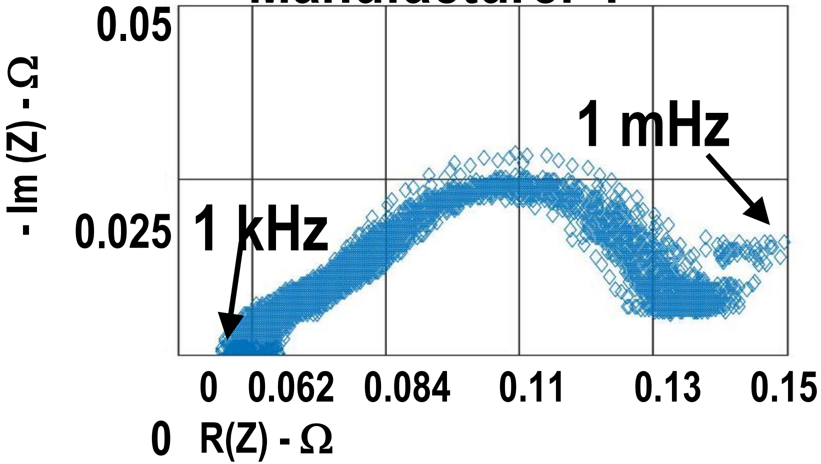
- Complete relaxation takes about 2000 seconds
- Different voltage at different instants
- Voltage difference between 20 and 3000 seconds is over 20 mV



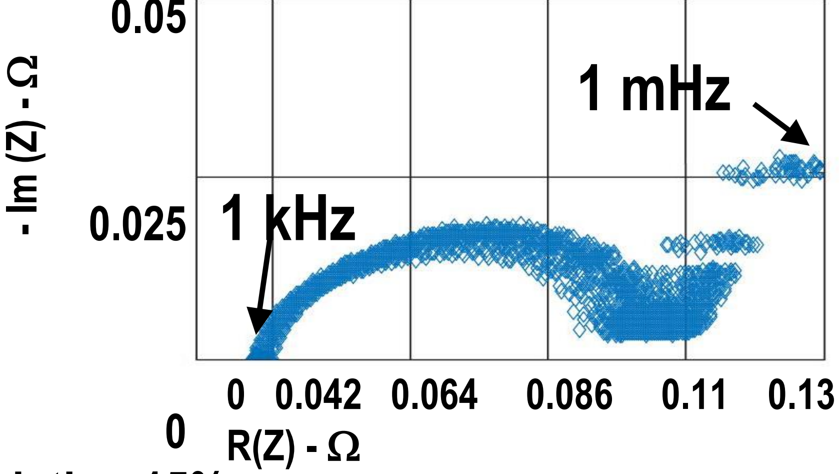
More sophisticated model



Manufacturer 1



Manufacturer 2



- Low-frequency (1 mHz) impedance variation 15%
- At 1C rate discharge, 40-mV difference, causes maximum SOC error of ±26%

Battery chemistry summary

- Qmax = battery chemical capacity (no load)
- Quse = usable capacity (load dependent)
- Battery resistance results in I-R drop with load
- SOC = State of Charge (% depends on OCV)
- RM = Remaining capacity (depends on load)
- Battery aging affects impedance and capacity

HOW TO MAKE A GAUGE

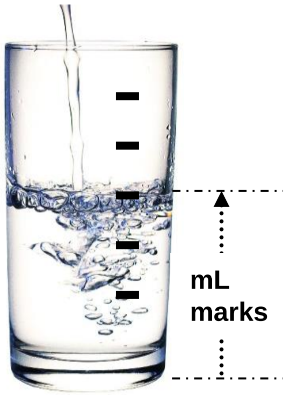
How to estimate battery capacity?

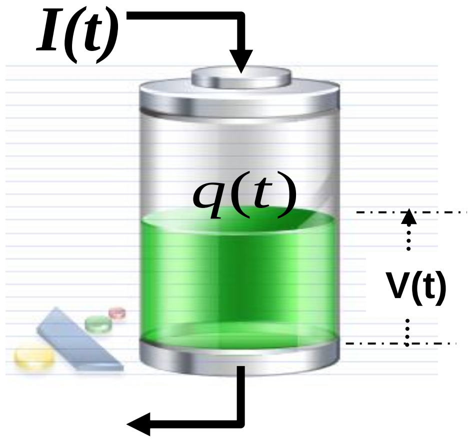
- Measure change in capacity
  - Voltage lookup
  - Coulomb counting

- Develop a cell model
  - Circuit model
  - Table Lookup

Voltage lookup

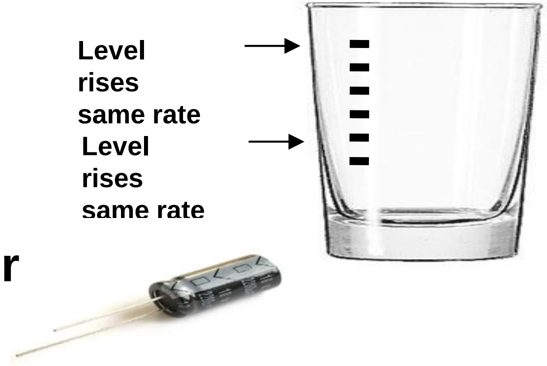
- One can tell how much water is in a glass by reading the water level
  - Accurate water level reading should only be made after the water settles (no ripple, etc)
- One can tell how much charge is in a battery by reading well-rested cell voltage
  - Accurate voltage should only be made after the battery is well rested (stops charging or discharging)

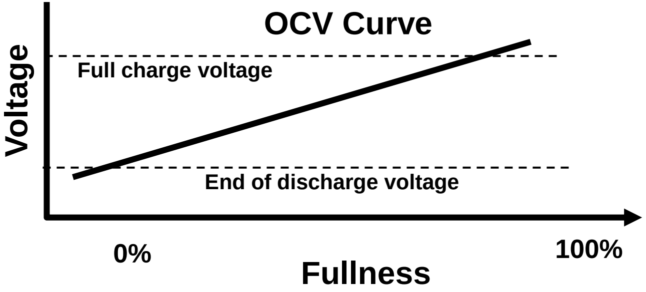




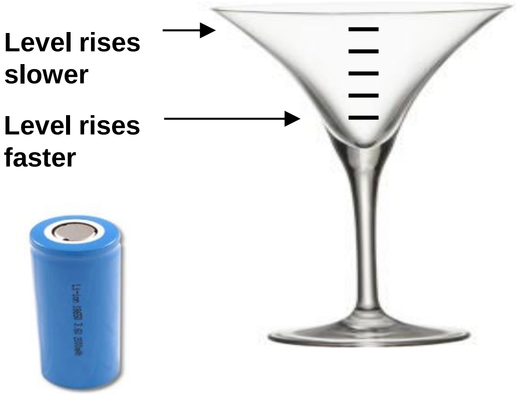
OCV curve

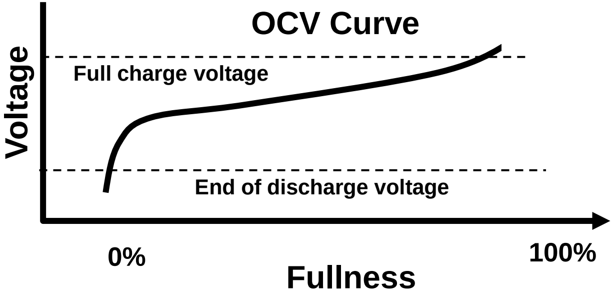
Capacitor





Battery





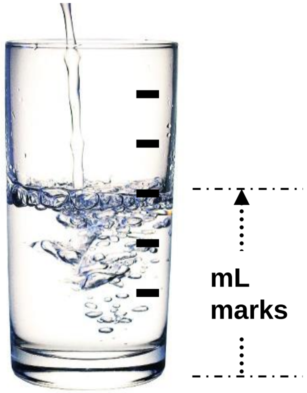
Current integration

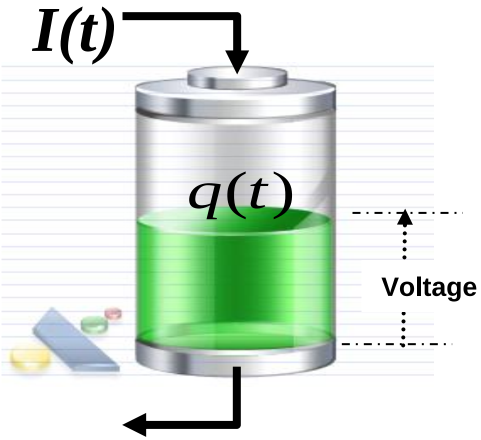
- One can also measure how much water goes in and out
- In batteries, battery capacity *changes* can be monitored by tracking the amount of electrical charges going in/out

$$q(t) = q_0 + \int I(t) \cdot dt$$

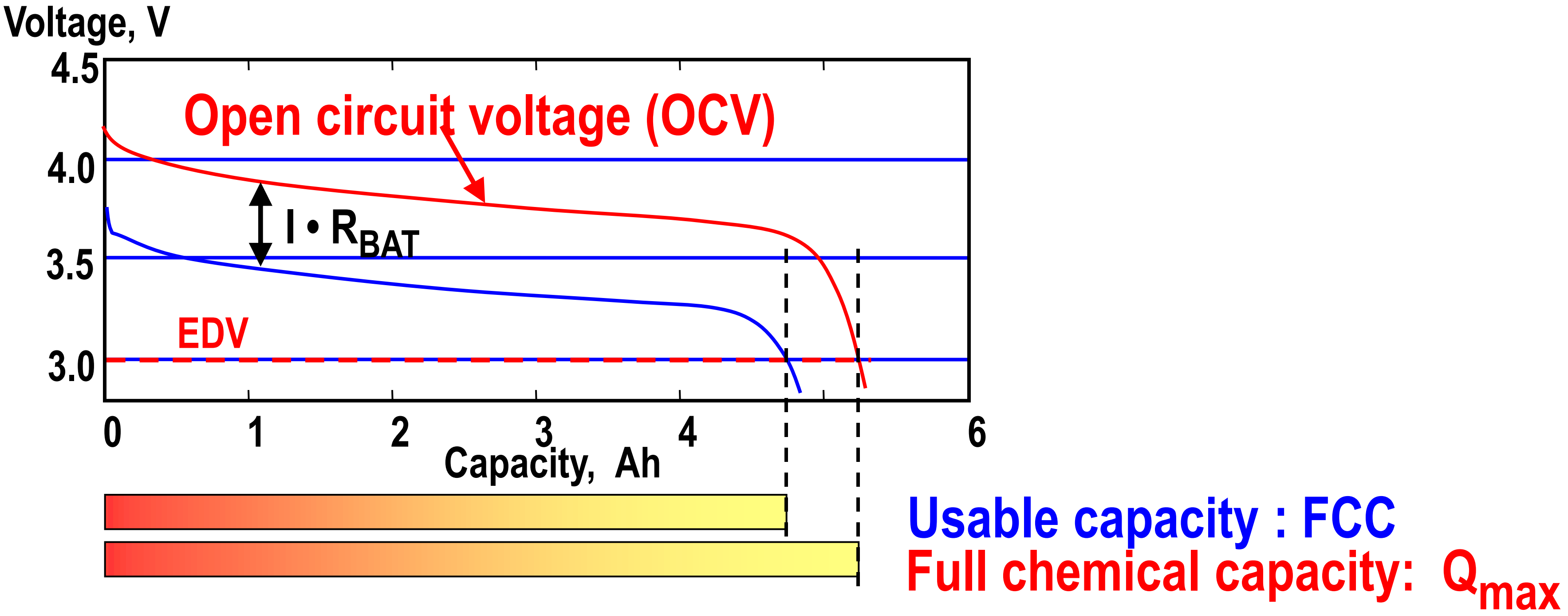
$$q_k = q_0 + \Delta t \cdot \sum_k I_k$$

- But how do you know the amount of charge, q_0 , already in the battery at the start?
- How do you count charges accurately?



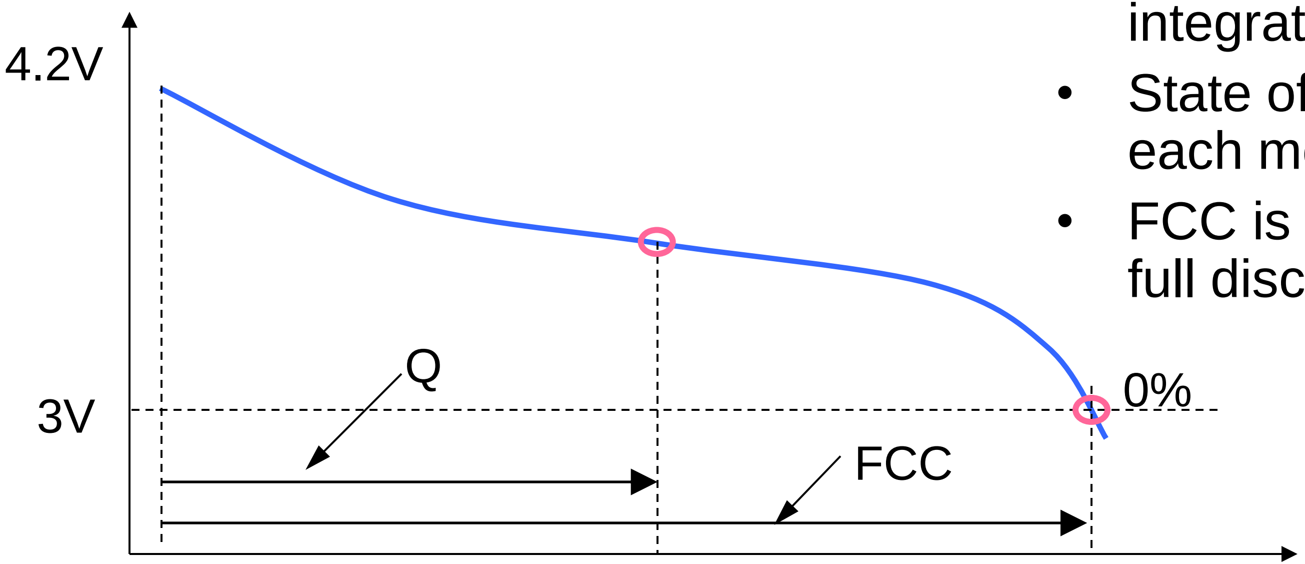


How Much Capacity is Really Available?



- External battery voltage (blue curve) $V = V_{0CV} - I \cdot R_{BAT}$
- Higher C-rate →EDV is reached earlier (higher $I \cdot R_{BAT}$)

Current Integration Based Fuel-gauging



- Battery is fully charged
- During discharge capacity is integrated
- State of charge (SOC) at each moment is RM/FCC
- FCC is updated every time full discharge occurs

RM = FCC - Q

SOC = RM/FCC

Gauging Algorithm Options

- Impedance Track
  - Consumer applications, allows system-side gauging, increased gauging accuracy
- Compensated-End-of-Discharge
  - Industrial applications with highly pulsed loads, applications that do not allow rest periods.
- End-of-Service
  - Rarely discharged applications, Li-primary cells, system-side gauging

IMPEDANCE TRACK (IT)

Fuel Gauging – Impedance Track™

Cell Voltage Measurement

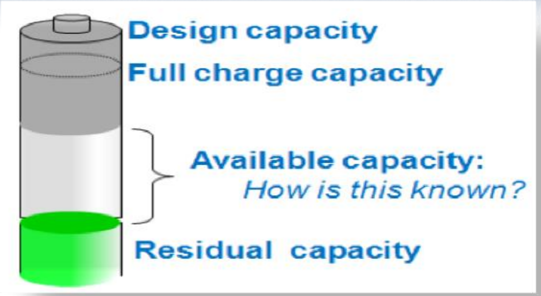
- Measures cell voltage
- Advantage: Simple
- Not accurate over load conditions

Coulomb Counting

- Measures and integrates current over time
- Affected by cell impedance
- Affected by cell self discharge
- Standby current
- Cell Aging
- Must have *full to empty* learning cycles
- Must develop cell models that will vary with cell maker
- Can count the charge leaving the battery, but won't know remaining charge without complex models
- Models will become less accurate with age

Impedance Track™

- **Directly measures effect of discharge rate, temp, age and other factors by learning cell impedance**
- **Calculates effect on remaining capacity and full charge capacity**
- **No learning cycles needed**
- **No host algorithms or calculations**



What is Impedance Track?

1. Chemistry table in Data Flash:

$$OCV = f\,(dod)$$

$$dod = g\,(OCV)$$

2. *Impedance learning* during discharge:

$$R = \frac{OCV - V}{I}$$

3. Update Max Chemical Capacity for each cell

$$Qmax = PassedCharge / (SOC1 - SOC2)$$

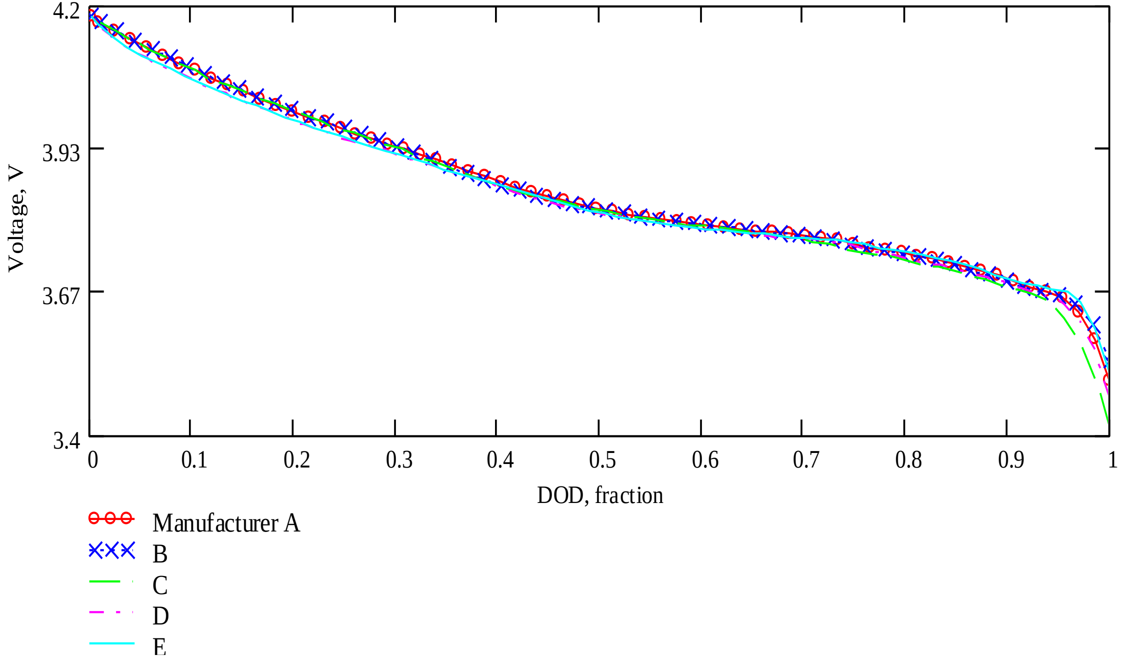
4. Run periodic *simulations* to update predictions of Remaining and Full Capacity

10,000 foot View

Definitions (part 1)

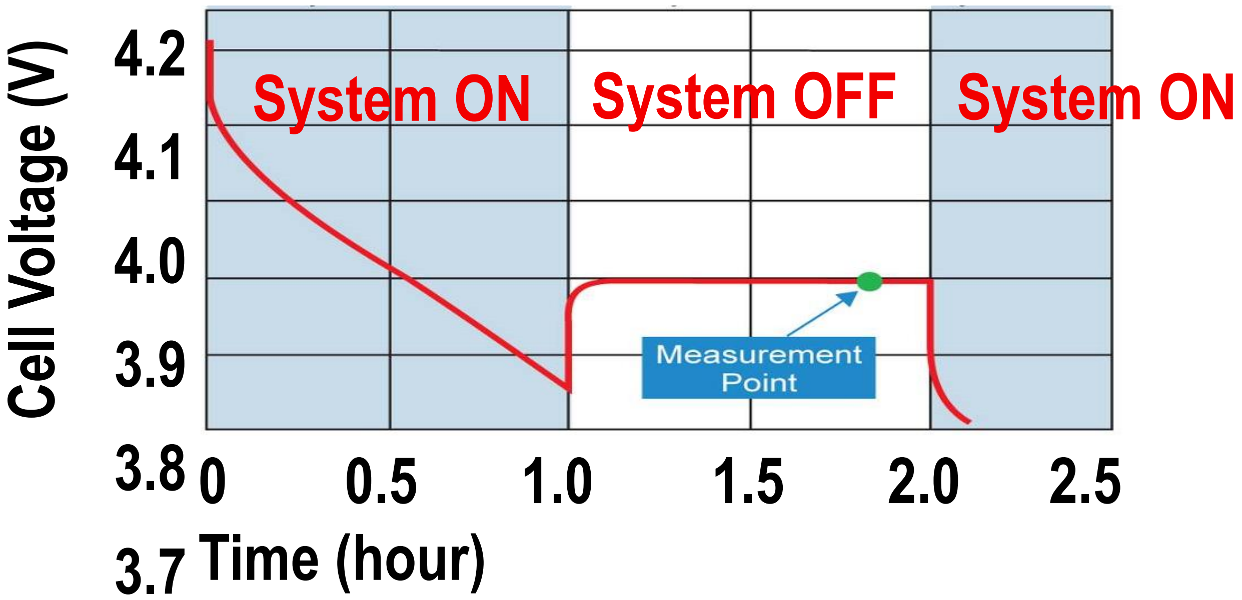
- OCV – open circuit voltage
  - relaxed or predicted voltage with no load
- DOD – depth of discharge
  - 0% is charged to the brim, 100% is completely empty of energy
  - Does not depend on load or temperature or system characteristics
- RM – Remaining Capacity in mAh
  - Usable capacity of the battery from current DOD to empty
- FCC – Full Charge Capacity in mAh
  - Usable capacity of the battery from full to empty
- SOC – state of charge, 0% - 100%
  - Full and empty points depend on the system
  - Can change with load and temperature
  - SOC = RM / FCC

OCV (open circuit voltage)



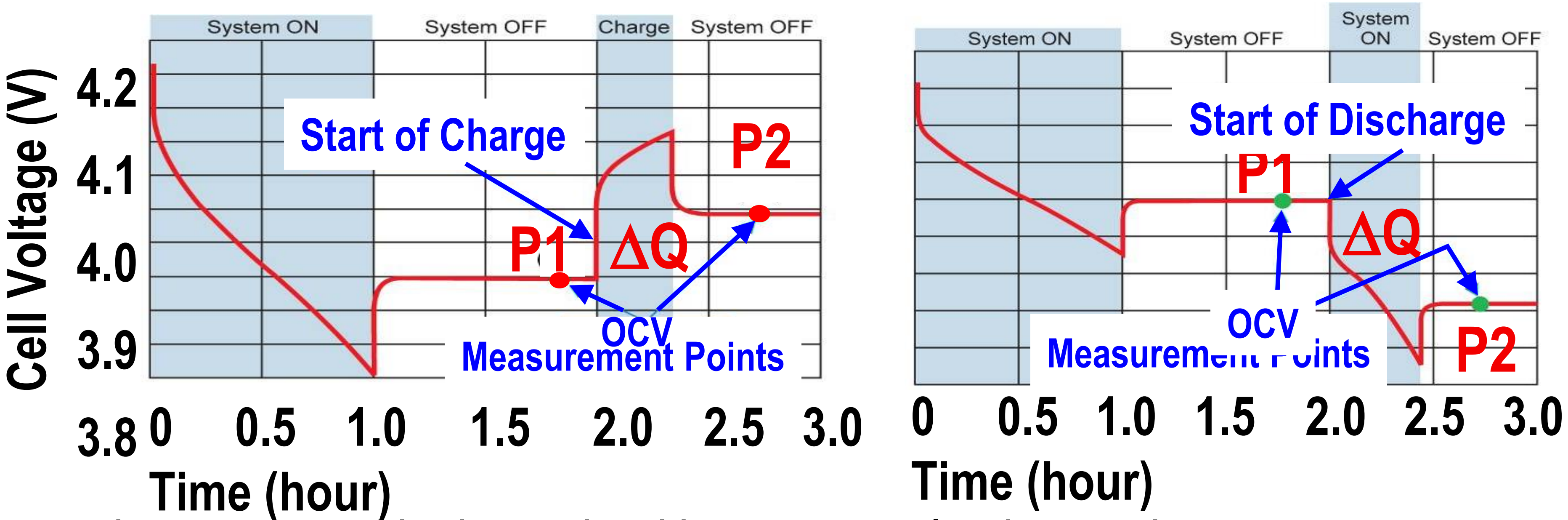
- OCV profiles can be very consistent if base electrode chemistry is the same
- Most voltage deviations from average are below 5mV
- Average DOD prediction error based on average voltage/DOD dependence is below 1.5%
- Same OCV database can be used with batteries produced by different manufacturers as long as base chemistry is same
- Generic database allows significant simplification of fuel-gauge implementation at user side

Measuring OCV



- OCV measurement allows SOC with 0.1% max error
- Self-discharge estimation is eliminated

Qmax updating



- Charge passed is determined by exact coulomb counting
- SOC1 and SOC2 measured by its OCV
- Method works for both charge or discharge exposure

$$Q_{max} = \frac{\Delta Q}{SOC1 - SOC2}$$

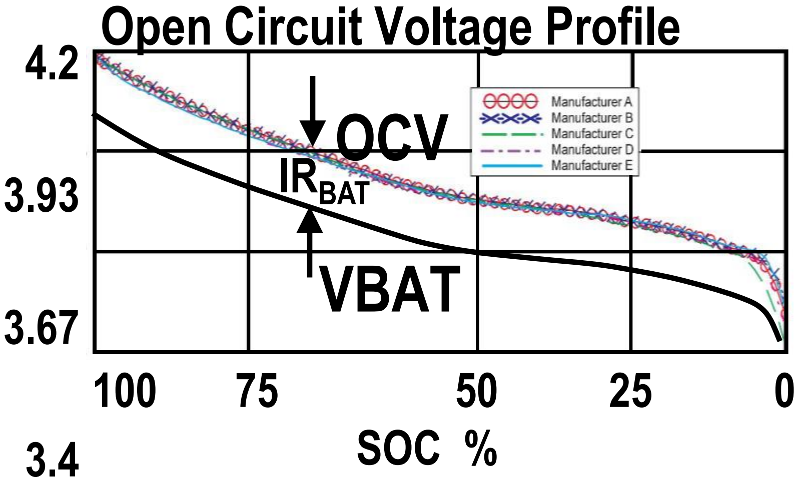
Measuring resistance

- Data flash contains a fixed table: *OCV* = *f (SOC, T)*
- IT algorithm: Real-time measurements and calculations

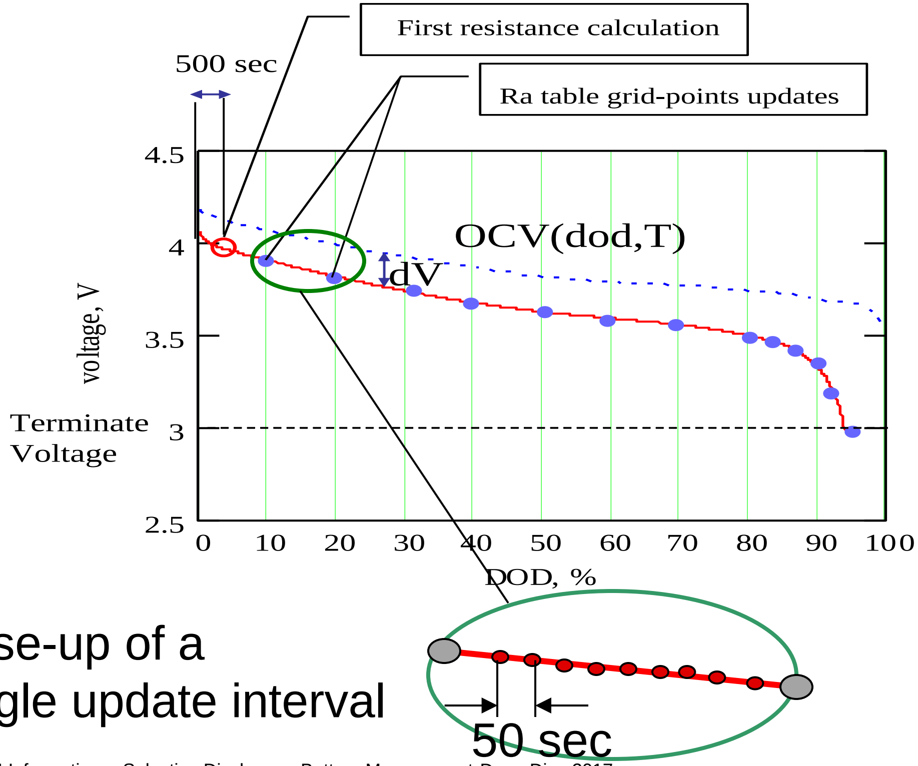
during charge and discharge.

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

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



Resistance update process

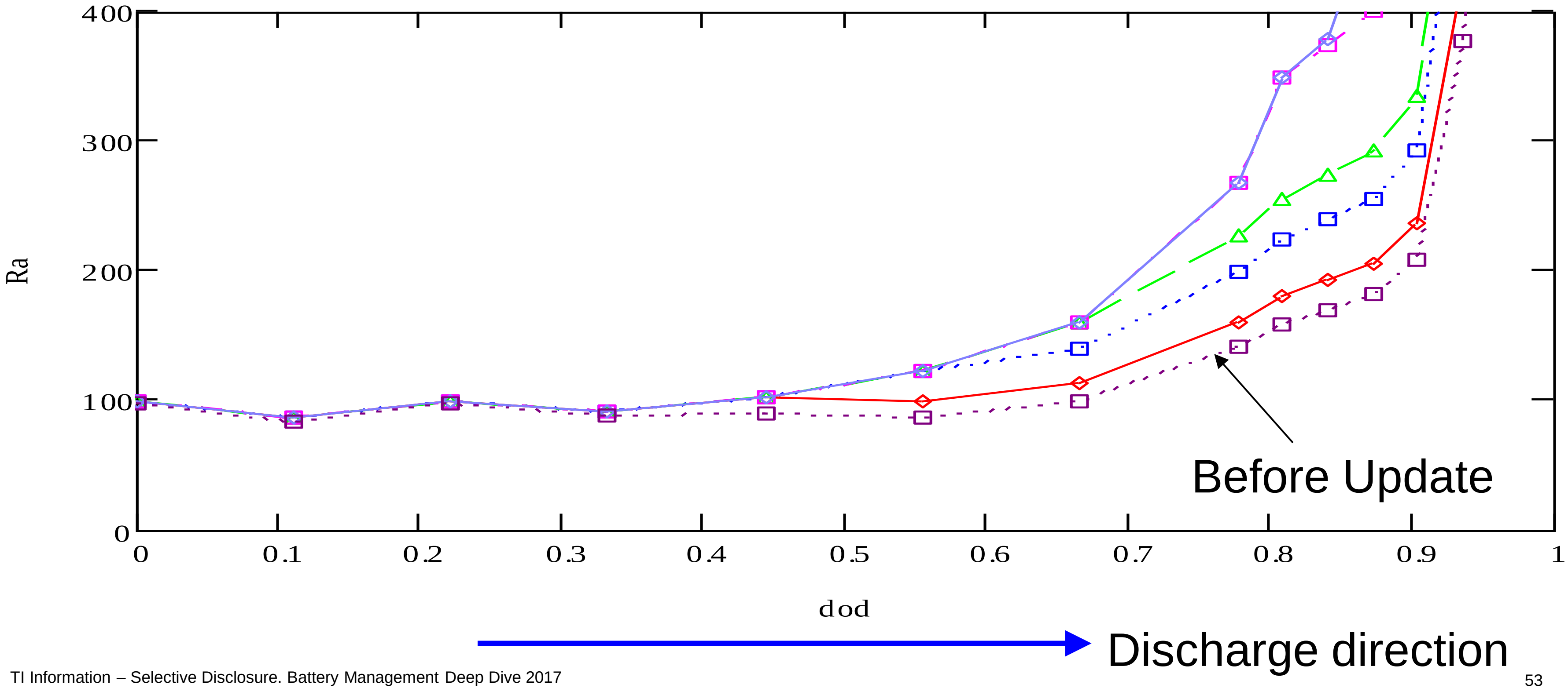


Close-up of a single update interval

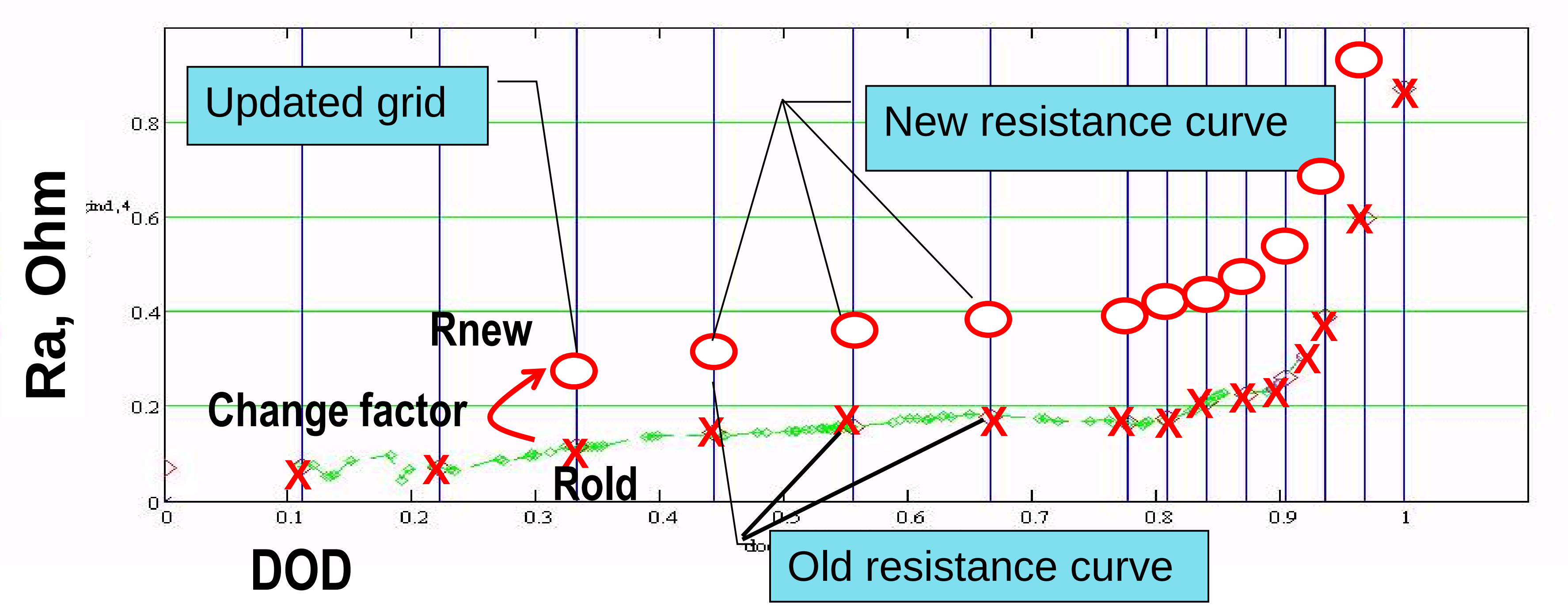
- The Resistance in data flash (Ra table) is updated after 10% (and after 80% DOD after 3%) intervals of DOD.
- During entire interval (for example from 50 to 60% DOD) we take resistance measurements every 50 sec and store them in RAM.
- Many resistance measurements are stored in RAM before GG reaches an actual grid-point (for example DOD exceeds 60%) and makes an update of Ra in data-flash by doing linear regression from the points stored in RAM.

Resistance updates in RAM

Resistance Update



Forward scaling of the resistance curve



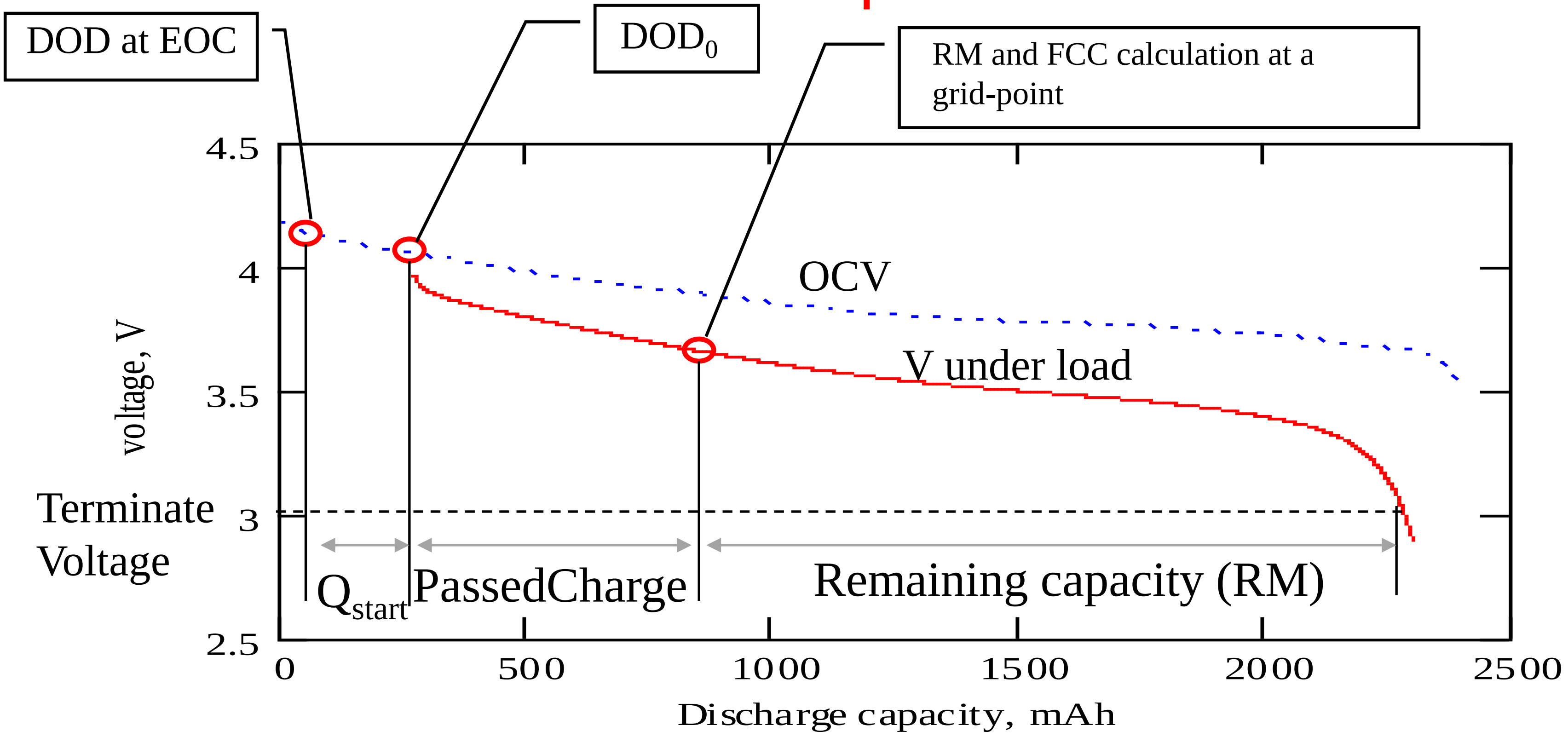
Factor = Rnew / Rold

Rnew[i] = Rold[i]*factor

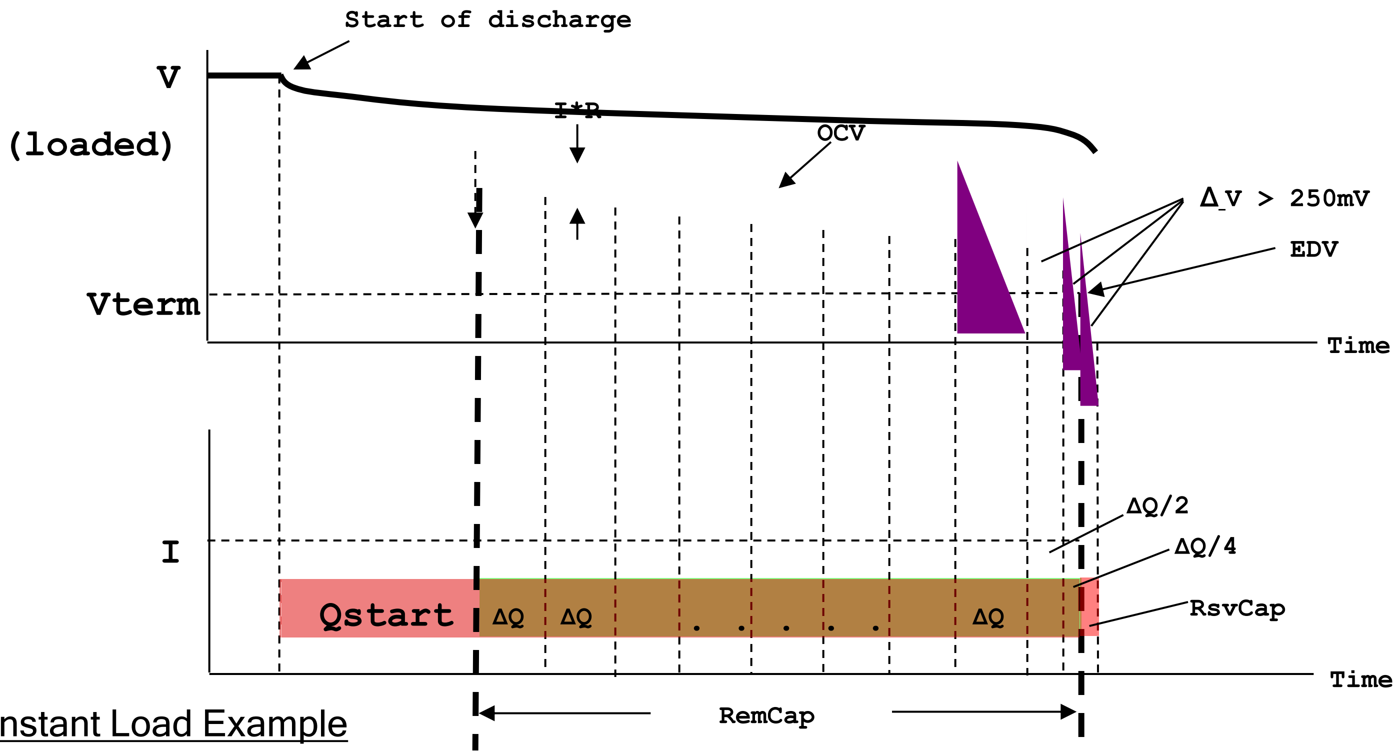
Definitions (part 2)

- DOD0
  - last DOD point measured directly by the gauge
- DODatEOC
  - DOD at End of Charge representing SOC = 100% for a particular system
- Qstart
  - capacity between DODatEOC and DOD0
- Qpass
  - accumulated passed charge since last DOD0 update
- Terminate Voltage
  - voltage at which the system can no longer operate; target for SOC = 0%
- Taper Current
  - Current level at which charger shuts off

Simulation to find RemCap and FCC

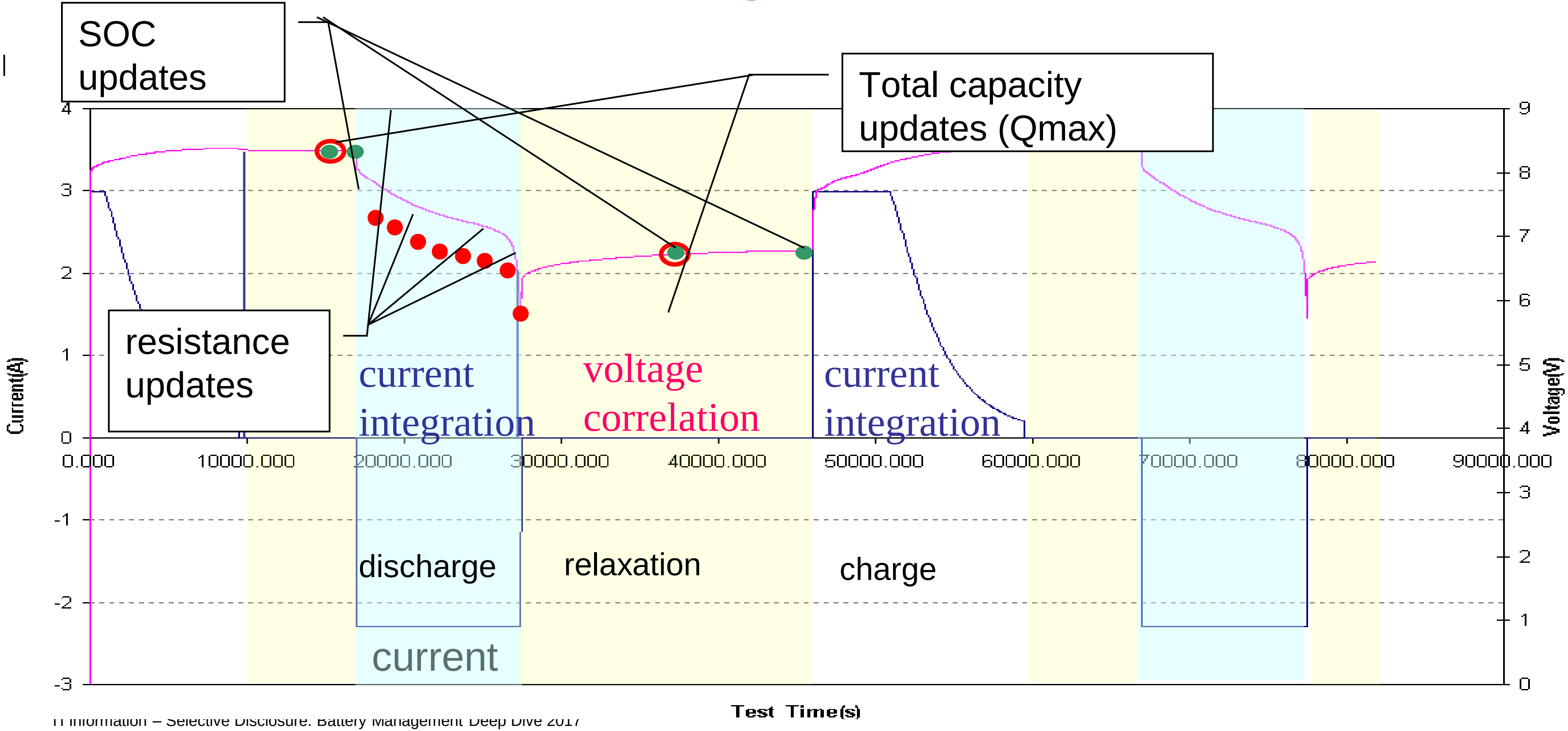


RemCap Simulation (concept)



<u>Constant Load Example</u>

Combination of integration and correlation



Texas Instruments

bq40z50-R2

1S – 4S SBS 1.1–Compliant Gas Gauge and Protector

Features

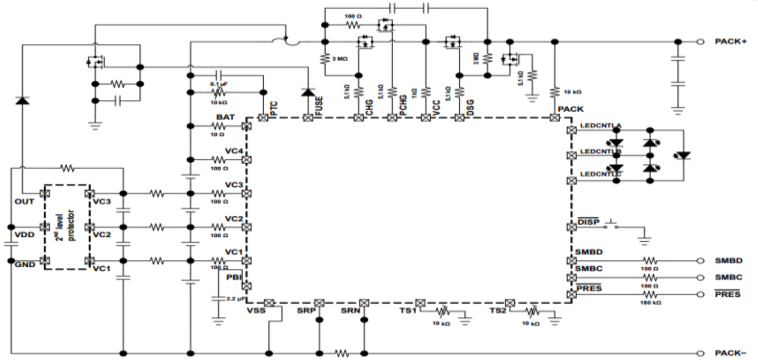
- Integrated AFE Safety Protector
  - Programmable
  - Voltage, Current, Temperature, Cell Imbalance
- Advanced IT gauging with JEITA & additional temp and current sub–ranges & cell balancing at rest or while charging
- Turbo Mode 2 Data Support
- Black box recorder
- N–channel FET drive
- Integrated 1.8v LDO
- SHA–1 Authentication
- LED (up to 5) support option (bq40z50)
- 4 x 4 x 0.9mm 32L–QFN Package

Applications

- Notebook/Netbook PCs
- Medical and Test Equipment
- Portable Instruments

Benefits

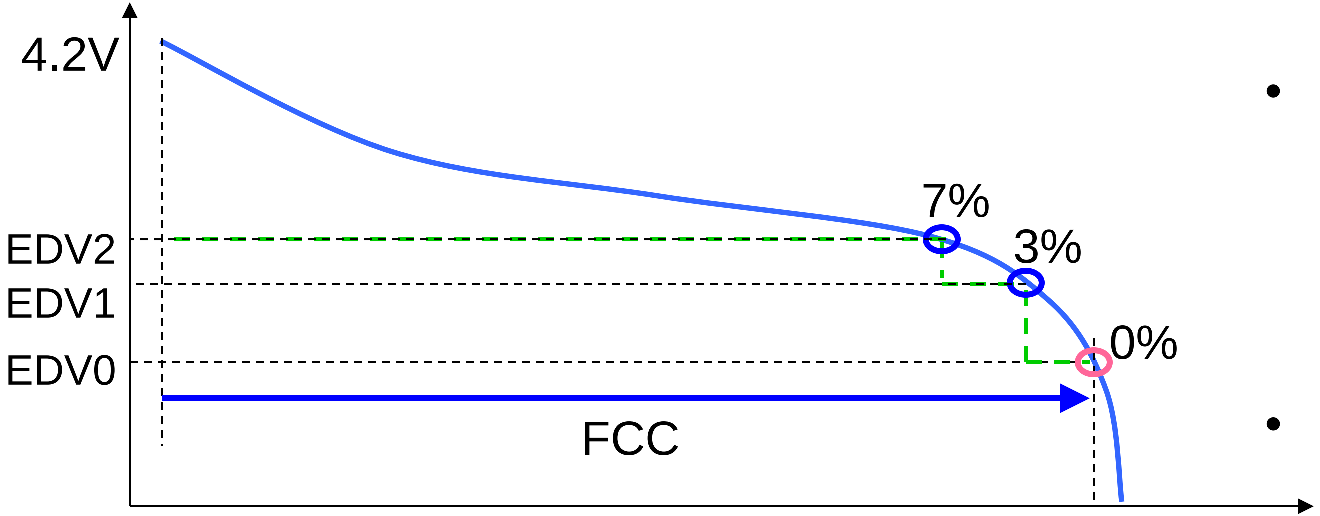
- Reduce BOM count and PCB area with application flexibility and wide array of safety functions
- Ease of use, high gauging accuracy & complex charging profile support
- Analysis of returned battery packs
- Lower BOM cost
- Reduce BOM count
- Anti–counterfeiting
- For applications requiring LED drivers
- Compact footprint



COMPENSATED END OF DISCHARGE (CEDV)

Learning Before Fully Discharged

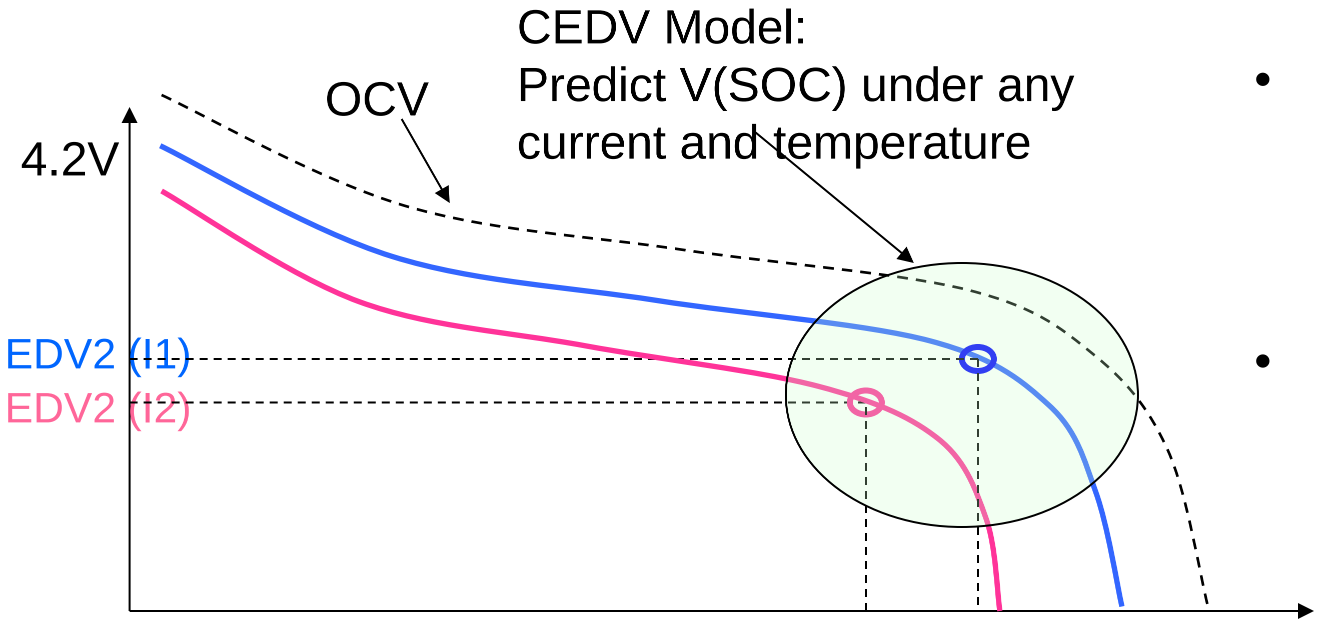
– fixed voltage thresholds



- It is too late to learn when 0% capacity is reached → Learning FCC before 0%
- We can set voltage threshold that correspond to given percentage of remaining capacity
- However, true voltage corresponding to 7% depends on current and temperature

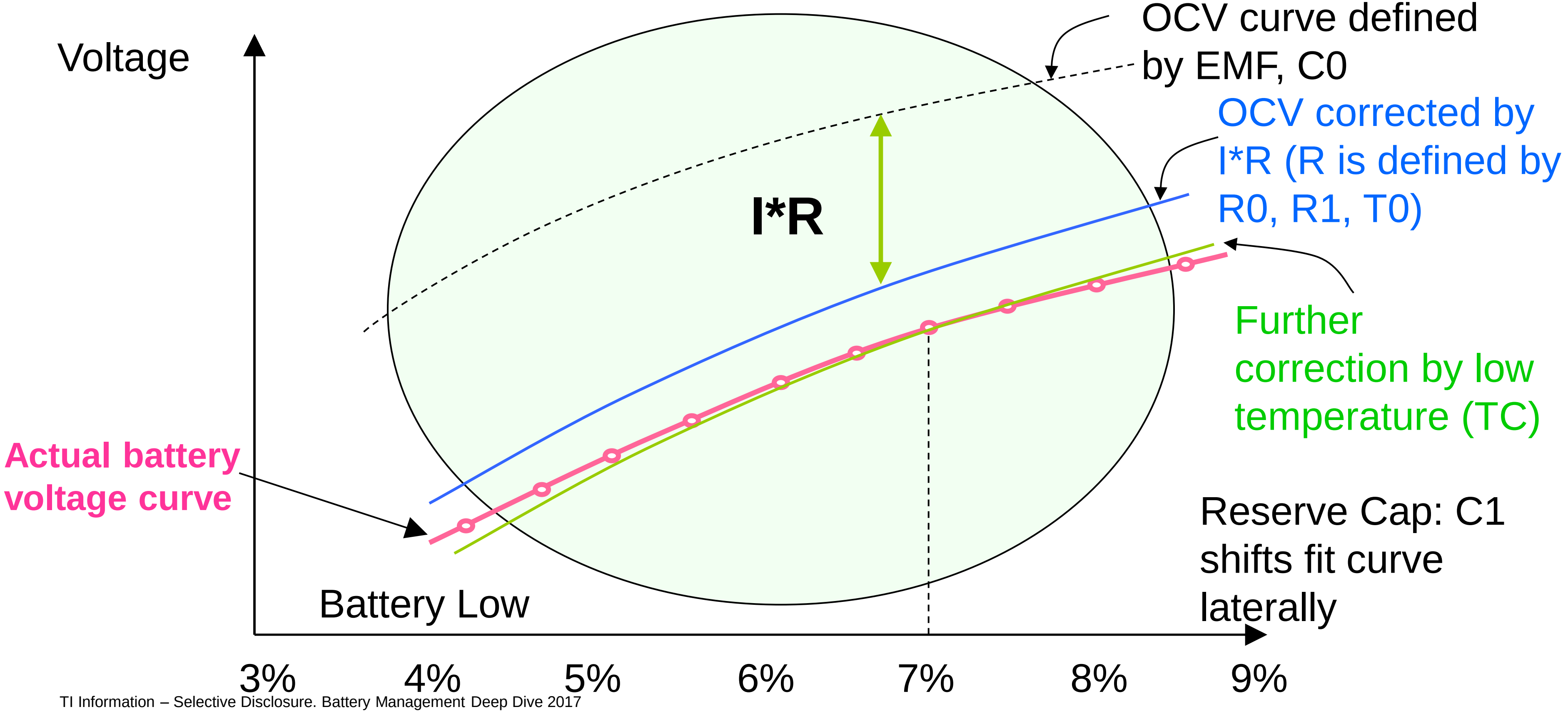
Learning before fully discharged

with current and temperature compensation



- CEDV
- Modeling last part of discharge allows to calculate function V(SOC, I, T)
- Substituting SOC=7% allows to calculate in real time CEDV2 threshold that corresponds to 7% capacity at any current and temperature

CEDV Model Visualization



CEDV Formula

**CEDV = CV - I*[EDVR0/4096]*[1 + EDVR1*Cact/16384]*
[1 – EDVT0*(10T - 10Tadj)/(256*65536)]*[1+(CC*EDVA0)/(4*65536)] * age**

Where:
CV = EMF*[1 – EDVC0*(10T)*log(Cact)/(256*65536)]
Cact = 256/(2.56*RSOC + EDVC1) – 1 for (2.56*RSOC + EDVC1) > 0
Cact = 255 for (2.56*RSOC + EDVC1) = 0
EDVC1 = 2.56 * Residual Capacity (%) + “Curve Fit” factor
Tadj = EDVTC*(296-T) for T< 296oK and Tadj < T
Tadj = 0 for T > 296 oK and Tadj max value = T
age = 1 + 8 * CycleCount * A0 / 65536.

CEDV Summary

Current measurement
Temperature measurement
Cycle count (age guess)
RSOC for output voltage

CEDV Constants and Algorithm

Voltage

The seven constants describe:

- OCV curve shape
- Temperature effect on OCV
- Resistance
- Temperature effect on resistance
- Low temperature effects
- Aging properties
- Reserve capacity

bq4050

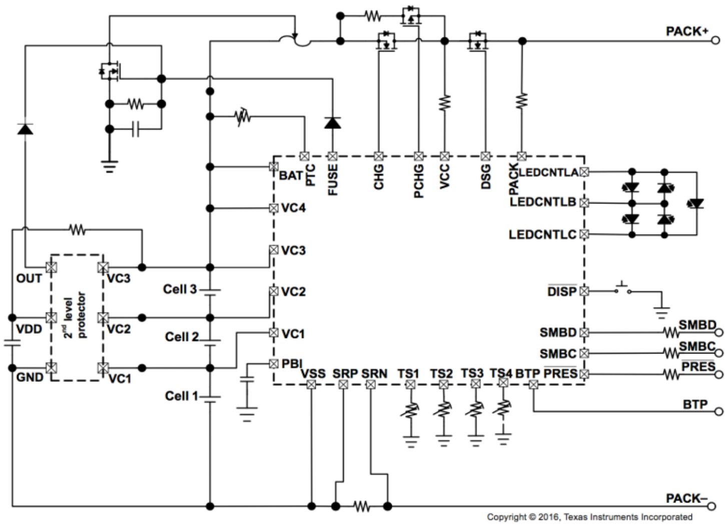
1S – 4S CEDV Fuel Gauge for Li-Ion Packs

Features

- High-Side Protection N-CH FET Drive Allows Serial Bus Communication During Fault Conditions
- Cell Balancing with Internal Bypass Optimizes Battery Health
- Diagnostic Lifetime Data Monitor and Black Box Recorder for Failure Analysis
- Full Array of Programmable Protection Features Voltage, Current, Temperature
- JEITA Charge Algorithms Support Smart Charging
- Analog Front End with Two Independent ADCs
  - Simultaneous Current and Voltage Sampling
  - High-Accuracy Coulomb Counter with Input Offset Error < 1 µV (Typical)
- Supports Battery Trip Point (BTP) Function for Windows® Integration
- LED Display for State of Charge and Battery Status Indication
- 100-KHz SMBus v1.1 Communications Interface for Programming and Data Access with Alternate 400-KHz Mode
- SHA-1 Authentication
- Compact 32-pin VQFN Package (RSM)

Applications

- Notebook/Netbook PCs
- Medical and Test Equipment
- Portable Instruments



bq34110

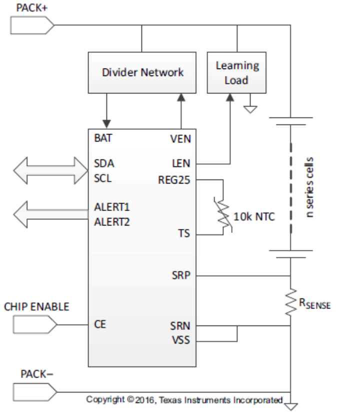
1S – 65V CEDV Fuel Gauge with EOS

Features

- Accurate End-Of-Service (EOS) Determination for Batteries in Rarely Discharged Applications
- Compensated End-of-Discharge Voltage (CEDV) Gas Gauge for Single- and Multi-Cell Batteries, Providing
  - State-Of-Charge (SOC)
  - Time-To-Empty (TTE)
  - State-Of-Health (SOH)
  - Watt-Hour–Based Charge Termination
- Supports Voltages up to 65 V, Capacities up to 32 Ah, and Currents up to 32 A—with Options to Extend Beyond These Levels Using Scaling
- Supports Li-Ion, LiFePO4, Lead-Acid (PbA), NiMH, and NiCd Chemistries
- Dual Configurable Host Interrupt or GPO
- Lifetime Data Logging Options
- Precision Coulomb Counter, Voltage, and Temperature Measurement
- I2C™ Communication with Host
- Accumulated Charge Coulomb Counting with Configurable Interrupt
- SHA-1 Authentication

Applications

- UPS Backup Systems
- Emergency Battery Power Modules
- Energy Storage Systems
- Building Security Systems
- Video Surveillance
- Electronic Smart Locks
- Remote and Emergency Lighting
- Robotics and Toys



bqMAXIMO (bq76920, bq76930, bq76940)

Digital Output Next–Gen AFE Family

Features

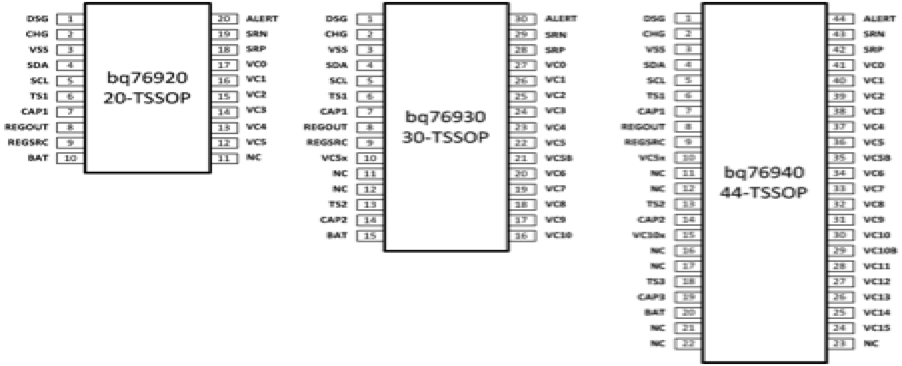
- Measures cell voltage, pack current, thermistor and die temp
- Integrated ADCs
- Built–in hardware protections
- Protection switch FET driver (low–side)
- Cell balancing
- Random cell connection tolerant
- High voltage operation up to 108V (bq76940)
- Ultra low shutdown Iq (typ < 1µA)
- 2.5 or 3.3 V LDO
- I2C

Applications

- Light electric vehicles (LEV): eBikes, eScooters, Pedelec and pedal–assist bicycles
- Cordless household appliances and power tools
- UPS and ESS systems
- General 12–48V battery packs

Benefits

- Pure digital interface
- Unified interface across all 3 devices
- Drop–in gauging solution when paired with bqMAXIMUS CEDV IC
- Supports random cell connection



bqMAXIMUS (bq78350)

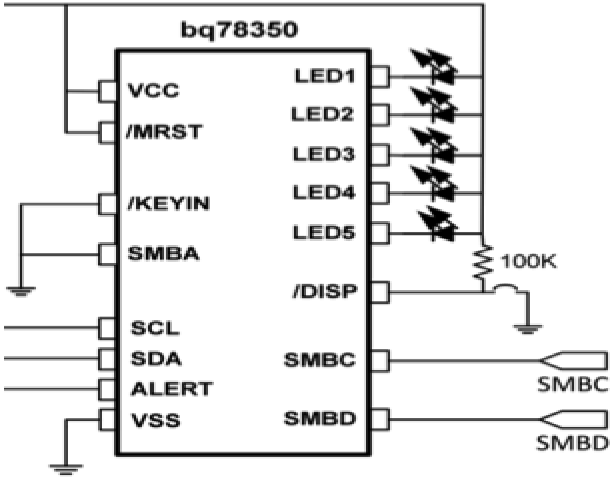
CEDV Gauging Companion Battery Manager

Features

- Advanced CEDV gauging algorithm
- Integrated voltage, current and temperature protections
- Voltage–based cell balancing algorithm
- Supports batteries up to 650 Ah
- Supports charge/discharge currents to 320 A
- Lifetime data logging
- Push–button LED display support (3-5 segment)
- Low–power storage mode ICC of 8 µA
- SHA–1 authentication
- SMBus
- 30–TSSOP (DBT)

Benefits

- Gas Gauge, Protection and Balancing turnkey solution
- Fully compatible with bq76920, 930, 940
- No customer F/W programming



Applications

- Light electric vehicles (LEV): eBikes, eScooters, Pedelec and pedal–assist bicycles
- Cordless household appliances and power tools
- Battery backup, wireless basestation and UPS systems
- General 12–48V battery packs

END-OF-SERVICE (EOS)

End-of-Service (EOS)

- Impedance Track and CEDV gauges require at least 37% to 93% discharge to allow the gauge to update gauging parameters as the cells age and lose capacity.
- Most usage profiles meet these requirements periodically.
- Some applications cannot allow periodic deep discharges and still provide capacity in the event that the pack is used. E.g. server back-up systems.
- The EOS algorithm only requires a shallow 1% to 2% discharge to detect changes in the series resistance and provide an early warning before the cells become unusable.
- The EOS algorithm supports Li-rechargeable, Li-primary, PbA, NiCd and NiMH cell chemistries.

bq34110 and bq35100 Fuel Gauges

We have two new gauges that offer the EOS (end-of-service) gauging algorithm.

bq34110 **(Detailed presentation Thursday afternoon)**

- Supports 1-series cell and up to 65V cell stacks.
- Uses the full featured CEDV gauging and EOS for rarely discharged applications.
- Offers a control output to switch a “learning load” independent of the normal system load.

bq35100 **(Detailed presentation Thursday afternoon)**

- Supports 1s to 4s cell configurations for Li-primary cell chemistries.
- Offers three gauging modes: Charge accumulation, State-of-Health and EOS.
- Can be powered down when not in use for the lowest possible quiescent current consumption.

bq35100

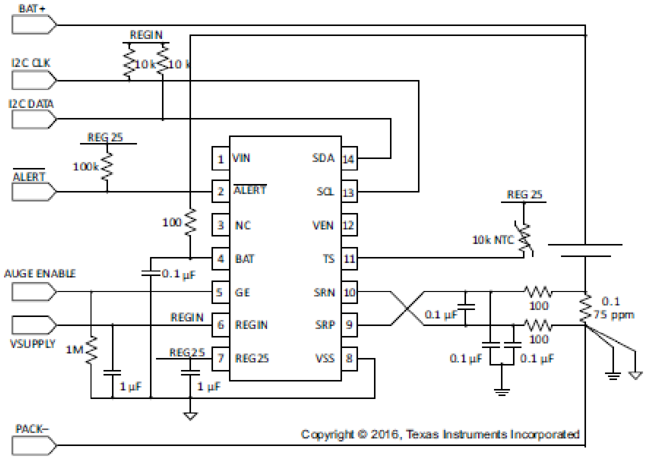
1s – 4s Li-Primary Fuel Gauge with EOS

Features

- Fuel Gauge for Single- and Multi-Cell Primary (Non-Rechargeable) Batteries
- Supports Lithium Thionyl Chloride (LiSOCl2) and Lithium Manganese Dioxide (LiMnO2)
- Provides Four Configurable Algorithm Options:
  - Coulomb Accumulation (ACC)
  - State-Of-Health (SOH)
  - End-Of-Service (EOS)
- Ultra-Low Average Power Consumption Supported Through Gauge-Enable Control
- Accurate Coulomb Counter, Voltage, and Temperature Measurement Options
- I²C™ Host Communication, Providing Battery Parameter and Status Access
- Configurable Host Interrupt
- Data Logging Options
- SHA-1 Authentication

Applications

- Smart Metering
- Door Access Control
- Smoke/Gas Detection
- Building Automation
- IoT, Including Sensor Node
- Asset Tracking



HOW TO USE A GAUGE

CEDV flow

- Characterize battery
- Determine CEDV constants
- Test gauge and optimize
- Finalize golden file
- Ready for production
  - Program and test PCB

Where do the 7 CEDV Constants come from?

Created from **seven text files**

- Discharge log at high temperature & high average current
- Discharge log at room temperature & high average current
- Discharge log at low temperature & high average current
- 3 more, as above for low average current
- Simple config file
  - ➢ Number of cells in series
  - ➢ Termination voltage
  - ➢ Miscellaneous

- Web-based tool – Just remember:
  - ➢ TI.com
  - ➢ Search for "Gauging" or "GPC"
  - ➢ Choose link to Gauging Parameter Calculator - GPCCEDV

Gauging Parameter Calculator - GPCCEDV

TI Home > Semiconductors > Power Management > Gauging Parameter Calculator for CEDV gauges

Gauging Parameter Calculator for CEDV gauges

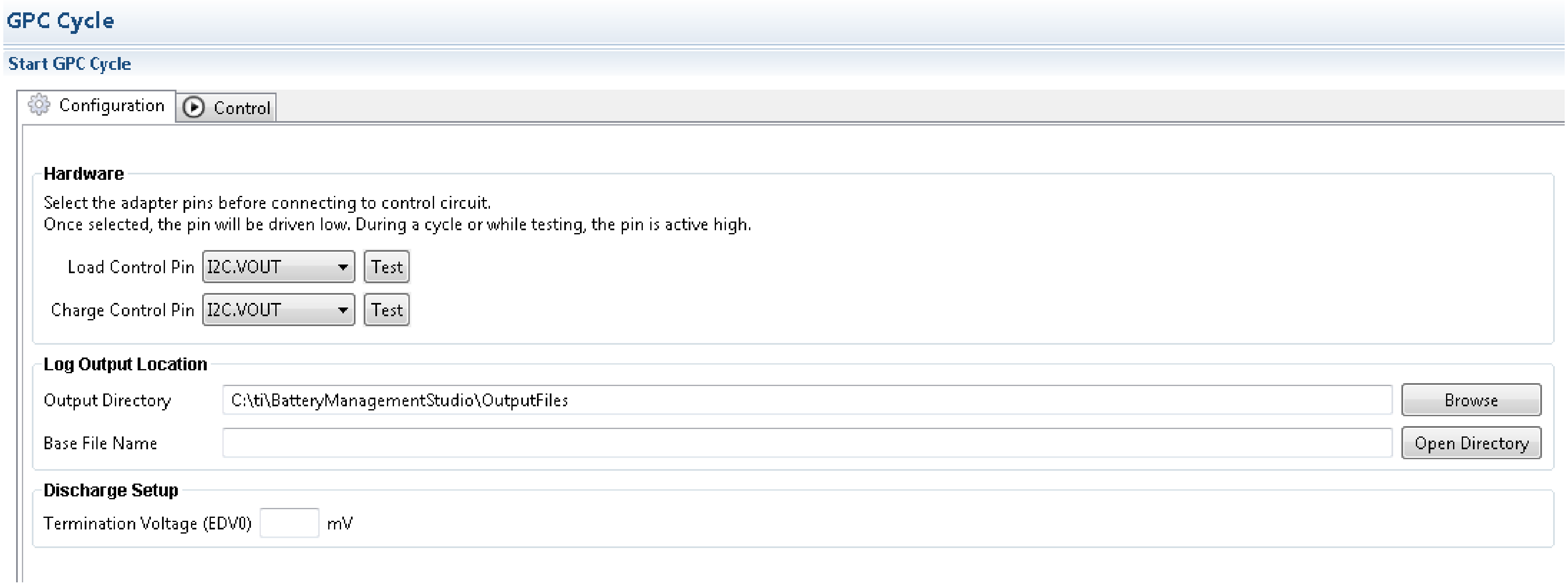
(ACTIVE) GPCCEDV

Description & Features | Technical Documents

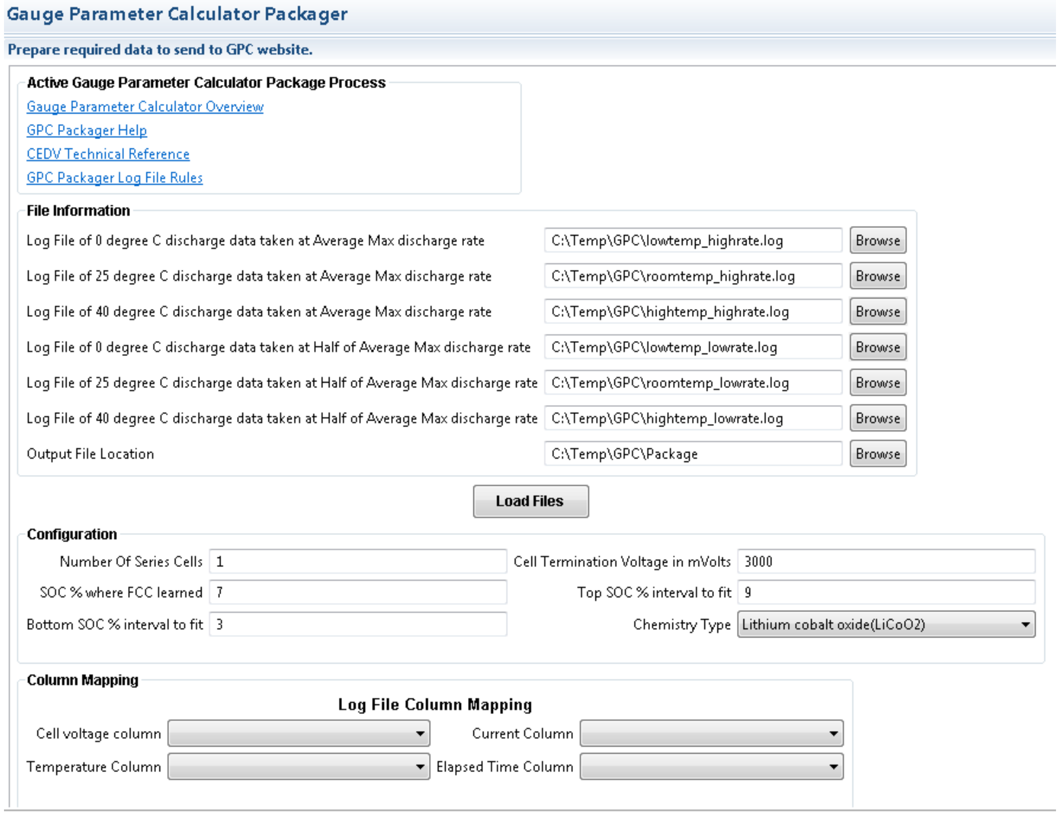
http://www.ti.com/tool/GPCCEDV?keyMatch=gpccedv&tisearch=Search-EN-Everything

- The online GPCCEDV tool can be used to calculate the CEDV coefficients to program the data flash.
- The GPCCEDV tool calculates the new 11-point OCV table that is customized for your cells. This eliminates the need to change the ChemID to improve the Remaining Capacity estimate upon reset.
- bqStudio offers the GPC Cycle and GPC Packager plug-ins to collect the log files and package them to submit to GPCCEDV.

bqStudio - GPC Cycle



bqStudio - GPC Packager



Impedance Track flow

- Determine ChemID (battery profile) - GPCCHEM
- Perform learning cycle
- Test gauge and optimize
- Finalize golden file
- Ready for production
  - Program and test PCB

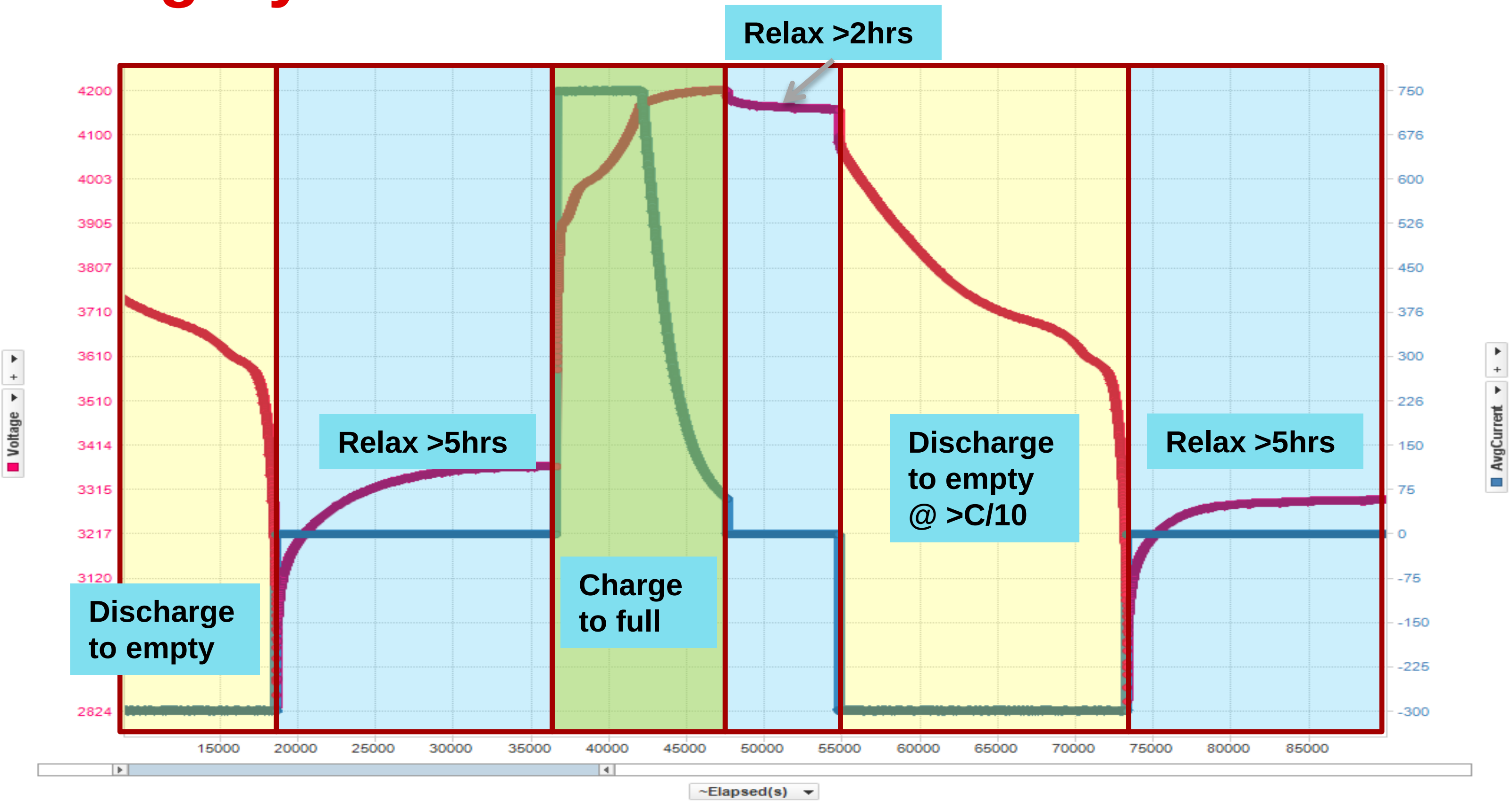
1-2-3 Battery Characterization for Impedance Track Chemistry ID

1. Lookup the cell/pack in the TI database to see if there is an existing ChemID.

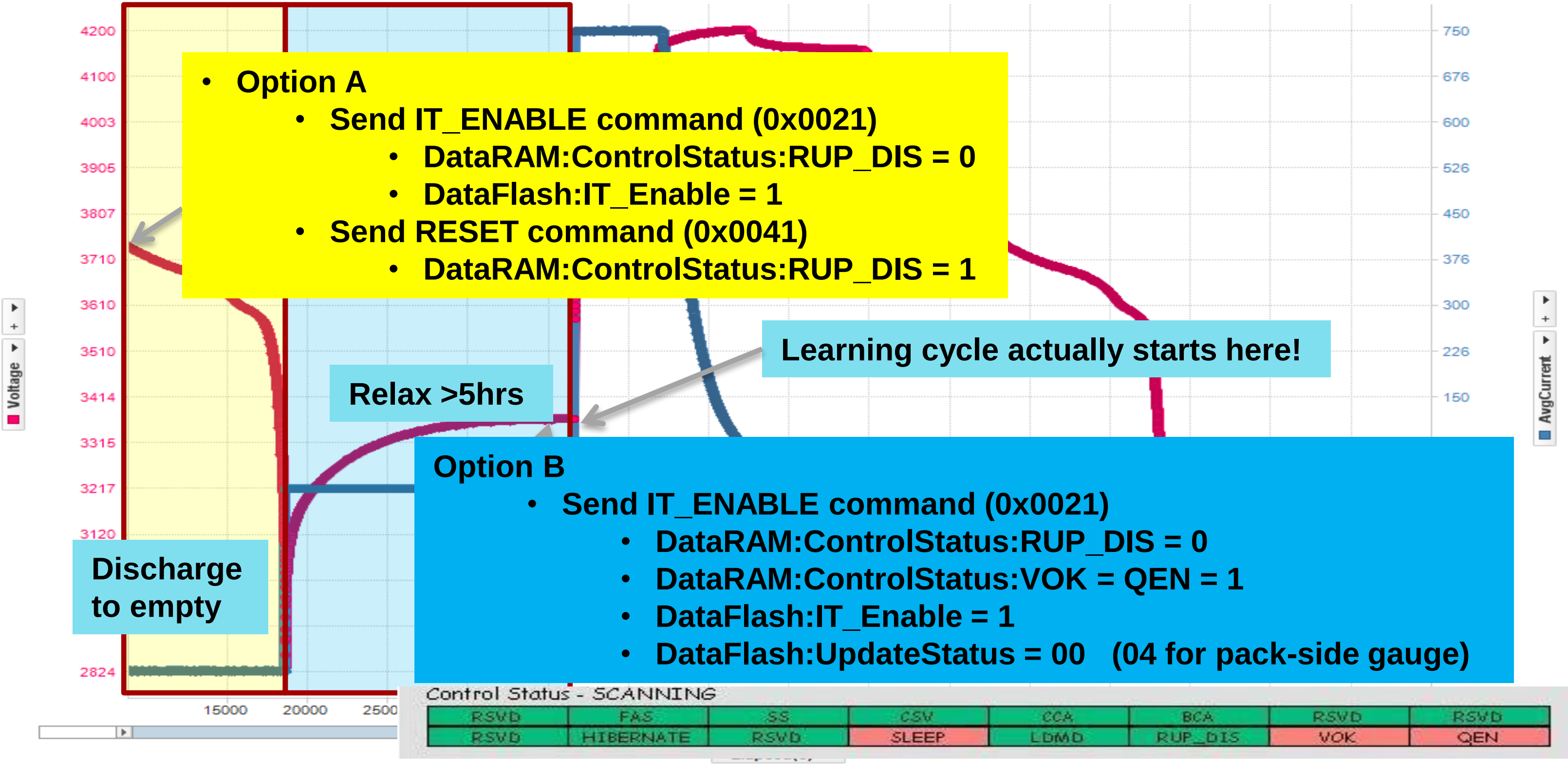
2. If not found, create discharge logs and test for match to existing ChemID with TI tool. Use GPCCHEM tool.

3. If no match, send cells to TI to characterize and create a new ChemID.

Learning Cycle



Gauge Configuration – Optimization Cycle (Step 1)



- **Option A**
  - **Send IT_ENABLE command (0x0021)**
    - **DataRAM:ControlStatus:RUP_DIS = 0**
    - **DataFlash:IT_Enable = 1**
  - **Send RESET command (0x0041)**
    - **DataRAM:ControlStatus:RUP_DIS = 1**

Learning cycle actually starts here!

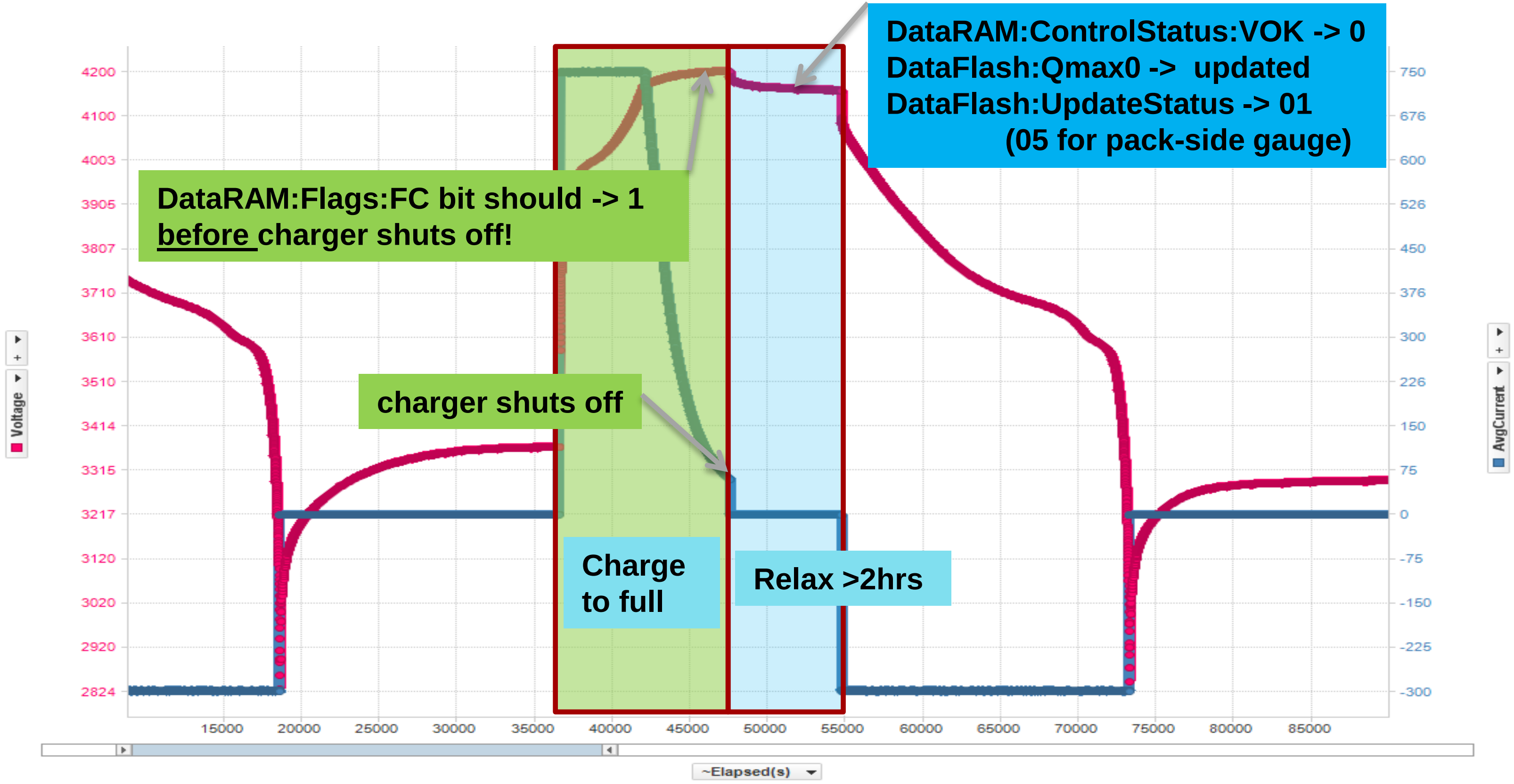
Relax >5hrs

Discharge to empty

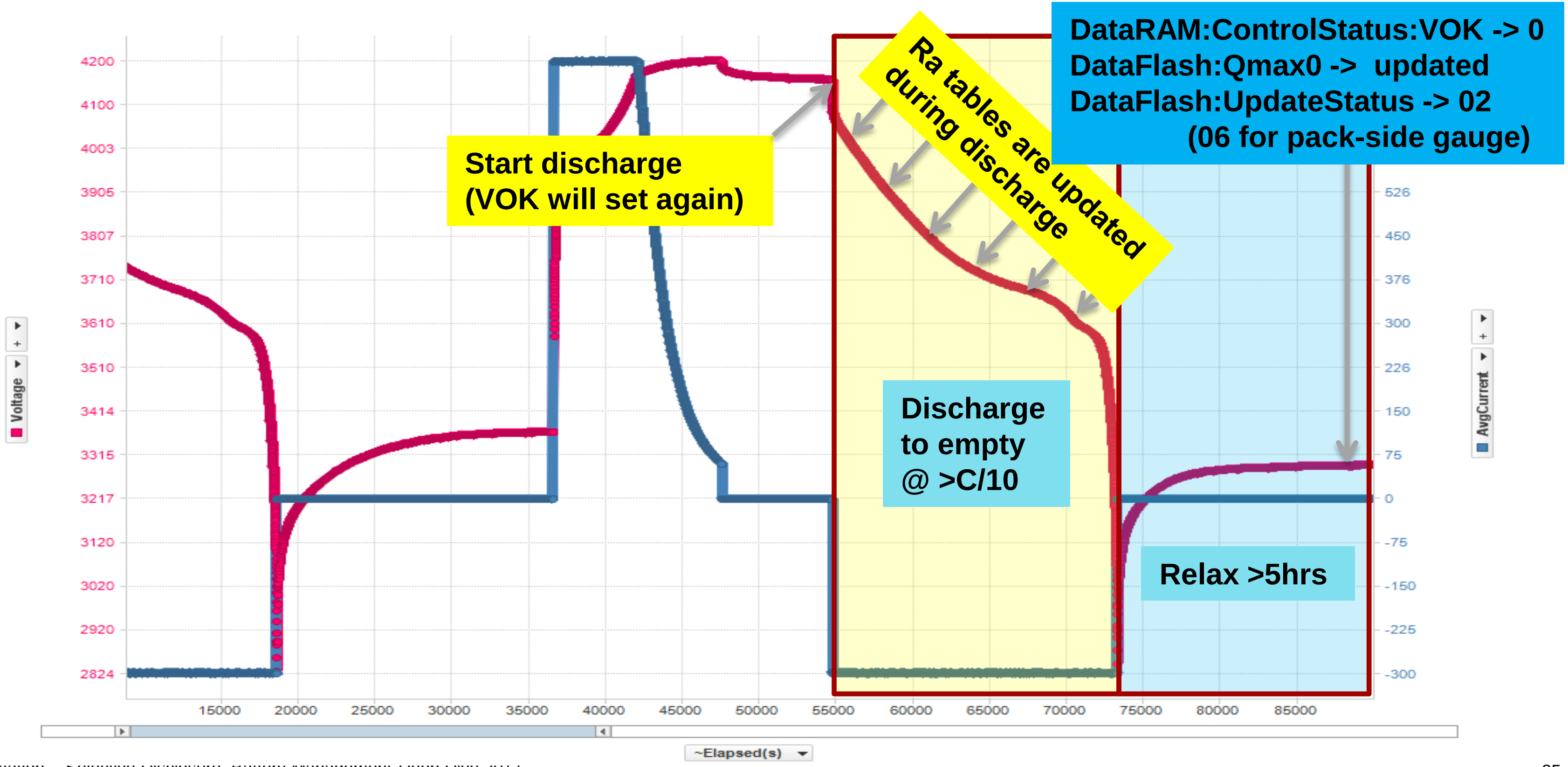
Option B

- **Send IT_ENABLE command (0x0021)**
  - **DataRAM:ControlStatus:RUP_DIS = 0**
  - **DataRAM:ControlStatus:VOK = QEN = 1**
  - **DataFlash:IT_Enable = 1**
  - **DataFlash:UpdateStatus = 00 (04 for pack-side gauge)**

Gauge Configuration – Optimization Cycle (Step 2)



Gauge Configuration – Optimization Cycle (Step 3)



DIFFERENCES BETWEEN MULTI-CELL AND SINGLE-CELL GAUGING

Pack-side vs. System-side

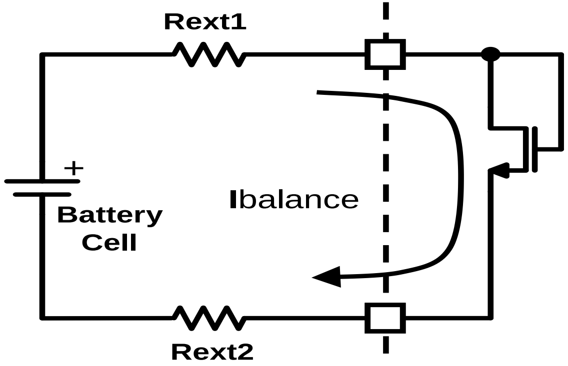
- Relevant mostly to single-cell systems.
- Typically multi-cell systems include the gauge in the pack, but solutions do exist for gauging “dumb” multi-cell packs.

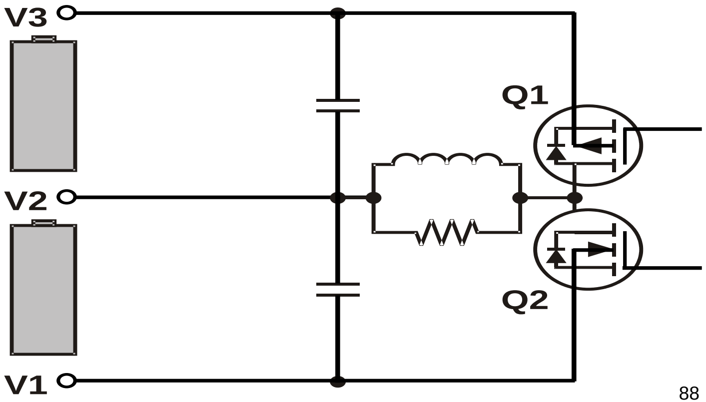
Solution to cell imbalance

- Battery cell needs continuous conditioning → **cell balancing** to avoid abuse and extend life

Type of cell balancing

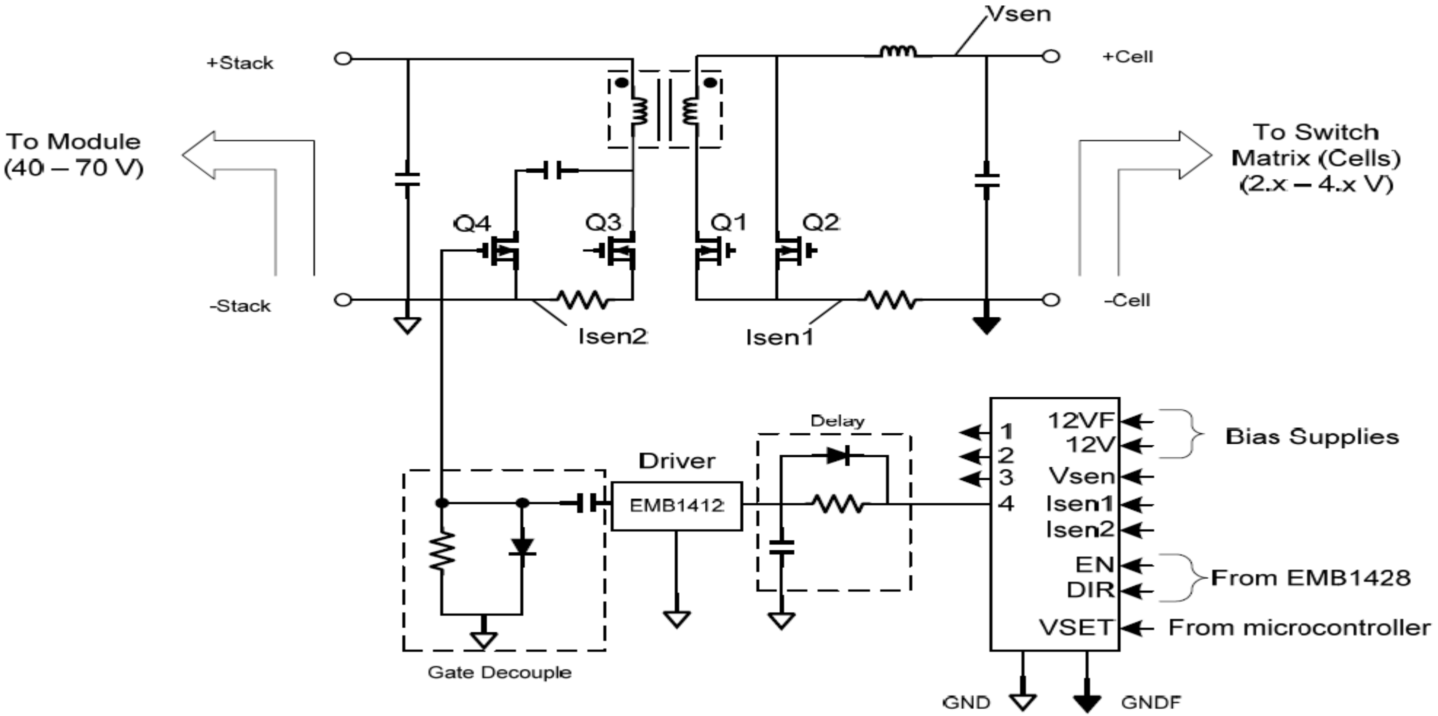
- Passive cell balancing → Resistor bleeding
- Active cell balancing → Inductive Charge shuttling:



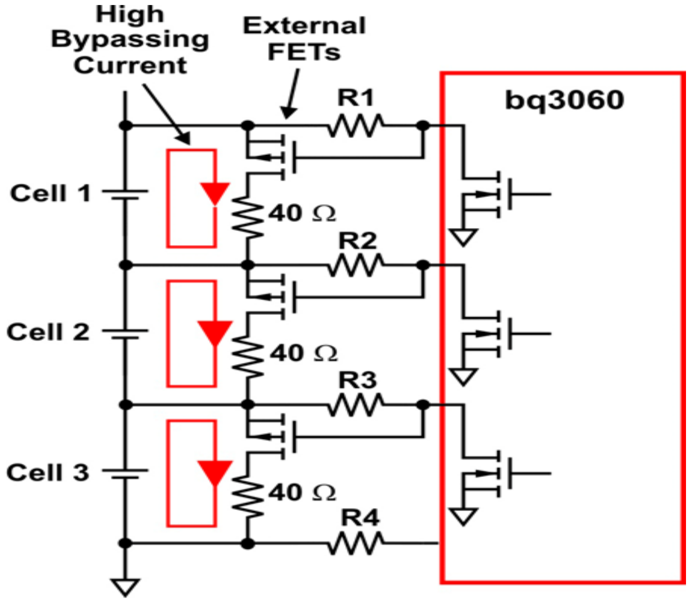


Solutions to cell imbalance

- High Cell Count – Bidirectional Stack to Cell Balancing

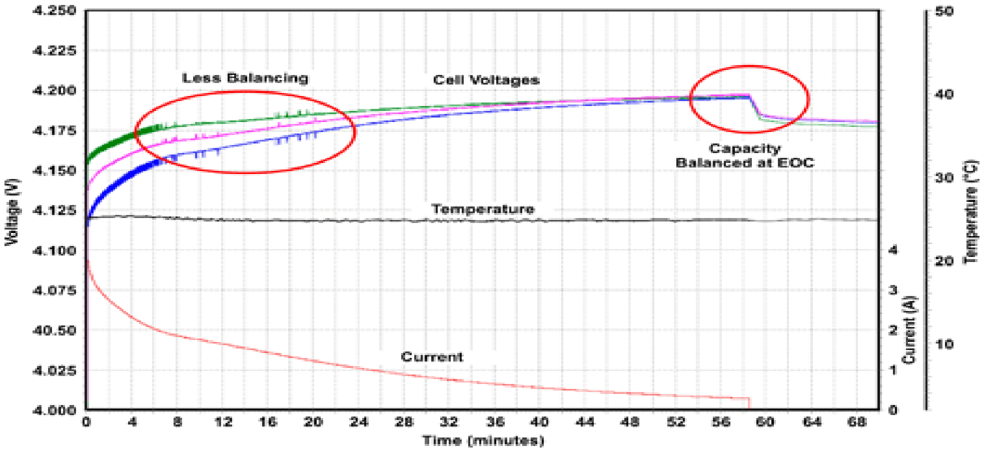


Cell Balancing



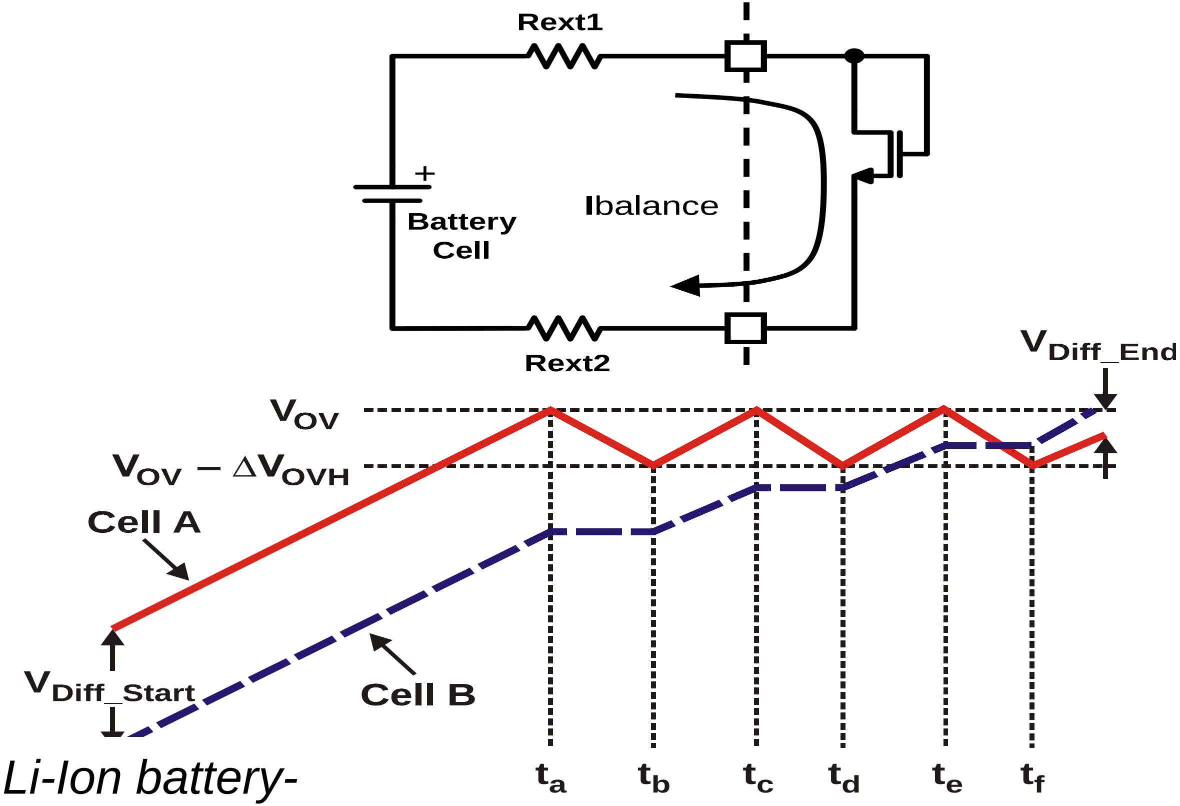
Battery cells voltages can get out of balance, which could lead to over charge at a cell even though the overall pack voltage is acceptable.

Cell balance can be achieved through current bypass or cross-cell charge pumping



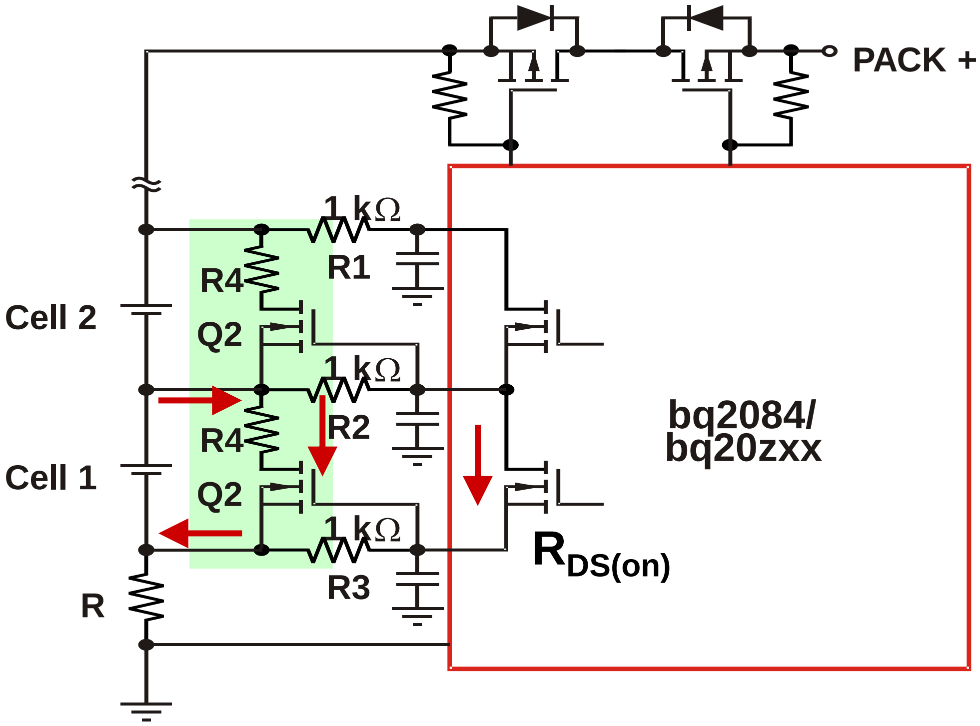
Passive Cell Balancing: Simplest Form

- Simple, voltage based
- Stops charging when any cell hits V_{OV} threshold
- Resistive bypassing turns on
- Charge resumes when cell A voltage drops to



bq77PL900, 5 to 10 series-cell Li-Ion battery-pack protector for power tools

Fast Passive Cell Balancing



- Needed for **high-power packs**, where cell self-discharge overpowers internal balancing
- Fast cell balancing strength is 10x ~ 20x higher

Internal CB $$I_{CB} = \frac{V_{Cell}}{R_{DS(on)}}$$

Fast CB $$I_{CB} = \frac{V_{Cell}}{R4}$$

Where $R4 << R_{DS(on)}$

Mass production flow

Check current DF version on gauge

- Golden file version stored in “DF Version”
- Can have multiple versions for different batteries
- Can perform field updates if necessary

Program gauge

- Use *.dfi* or *.dffs* file
- Skip if already using latest version

Check basic function

- Read voltage, SOC, temperature, etc.
- Confirm values are within expected range

SHIP

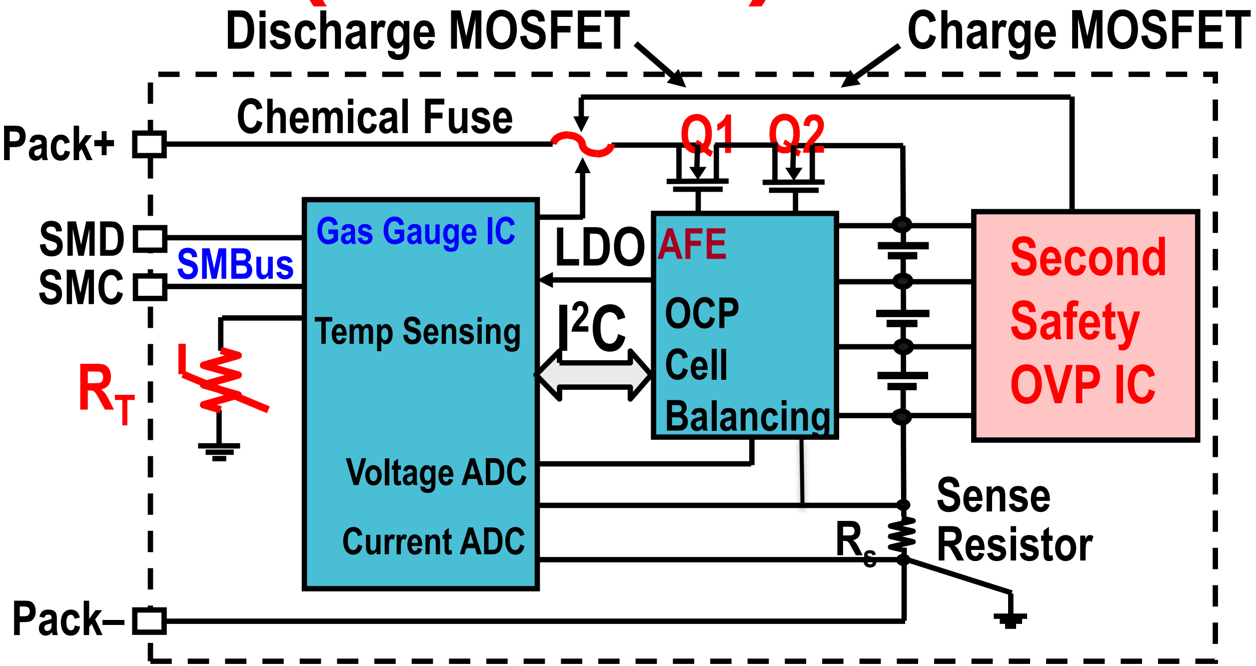
Mass production flow

	Multi-cell gauges/packs	Single-cell gauges/packs
Calibration	Performed on every PCB / pack	Not required in production (use average values for golden file)
Programming	SREC, ROM, or DFI binary file	Flashstream file for system-side gauges; binary file optional
Testing	Read Voltage, SOC, Temperature Confirm values are in expected range	

Protection

- Single-cell packs require minimum protections
  - Typically over-current and over/under-voltage only
  - Additional protection available with integrated solution
    - bq27742-G1 and bq27750 adds temperature protection and more
- Multi-cell packs require much more protection

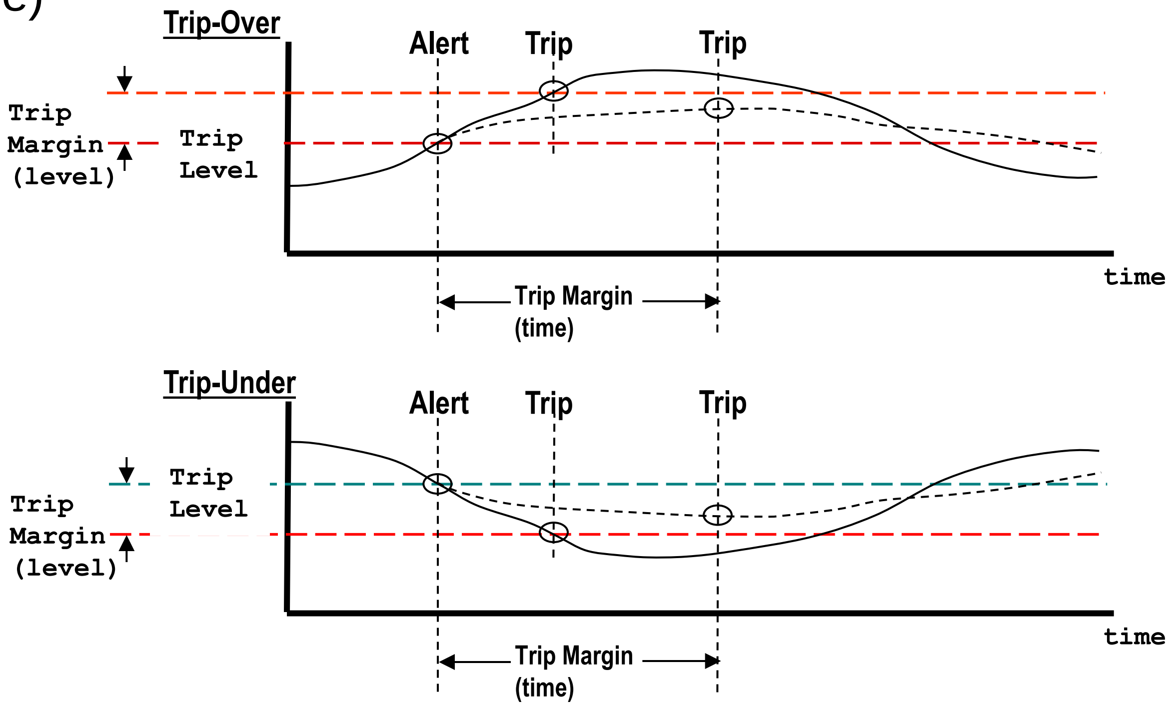
Protection (multi-cell)



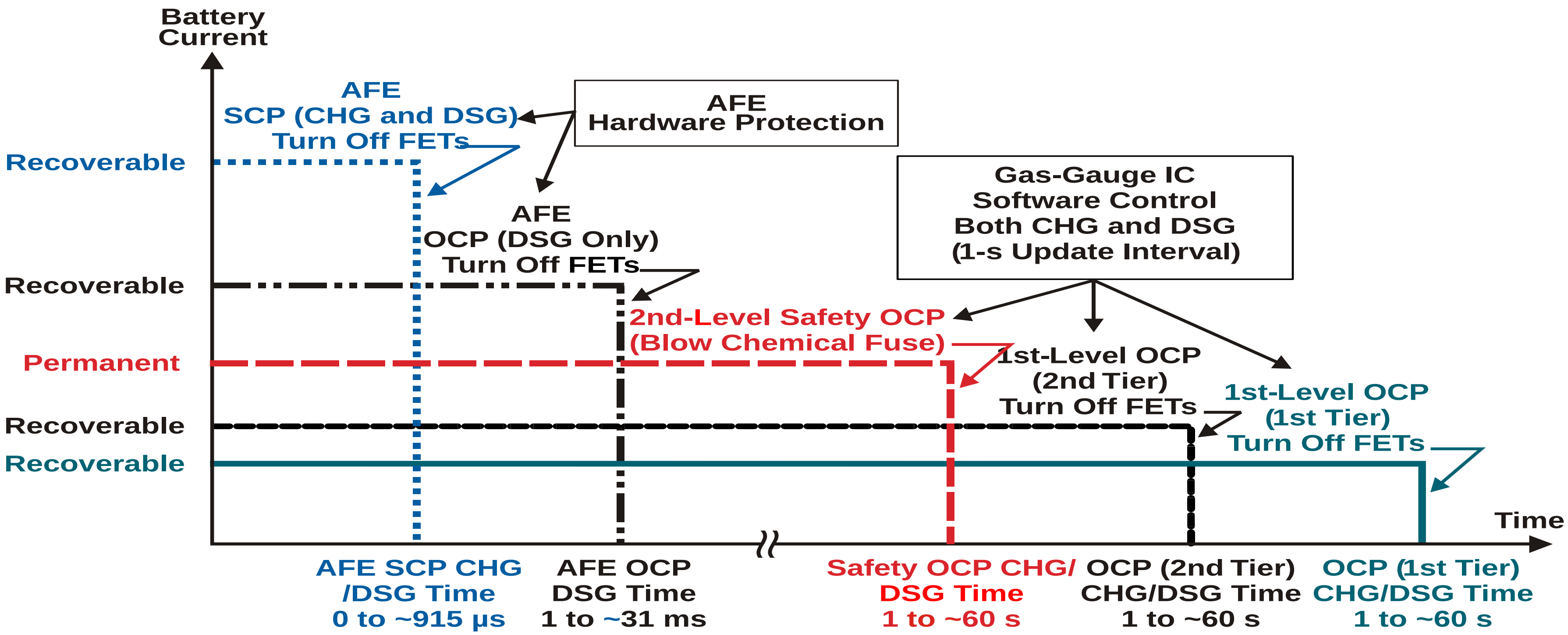
- Measure: Current, voltage, and temperature
- Protection levels: notify host, open Q1 or Q2, blow chemical fuse

Protection firmware (multi-cell)

- Short circuit
- Over/under (charge/discharge) current
- Over/under voltage
- Over temperature
- FET failure
- Fuse failure
- Communication failure
- Lock-up
- Flash failure
- ESD
- Cell imbalance

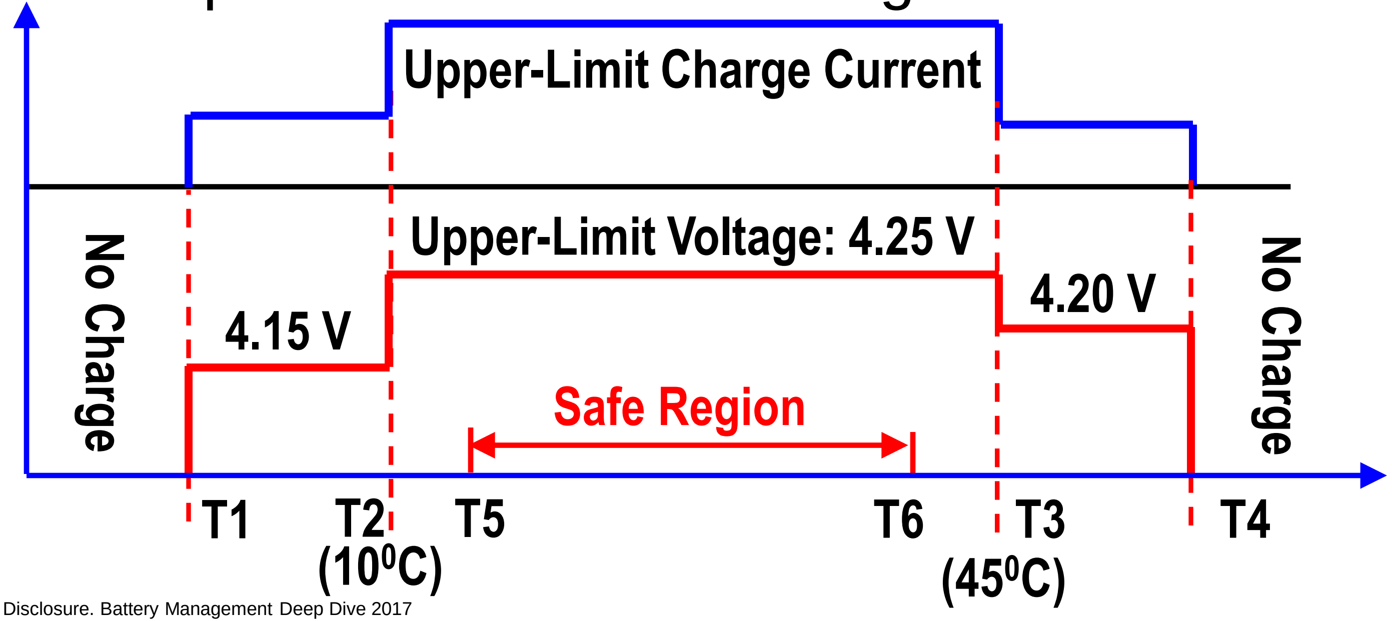


Overcurrent Protection Scheme



JEITA/BAJ Charging Guidelines

- Do not charge if **T< 0°C or T> 50°C**
- Minimize temperature variation among cells



RESOURCES

For more information…Google the P/N

Google bq20z45

Web Images Maps Shopping More Search tools

About 11,900 results (0.33 seconds)

bq20z45-R1 - Texas Instruments
www.ti.com/product/**bq20z45**-r1
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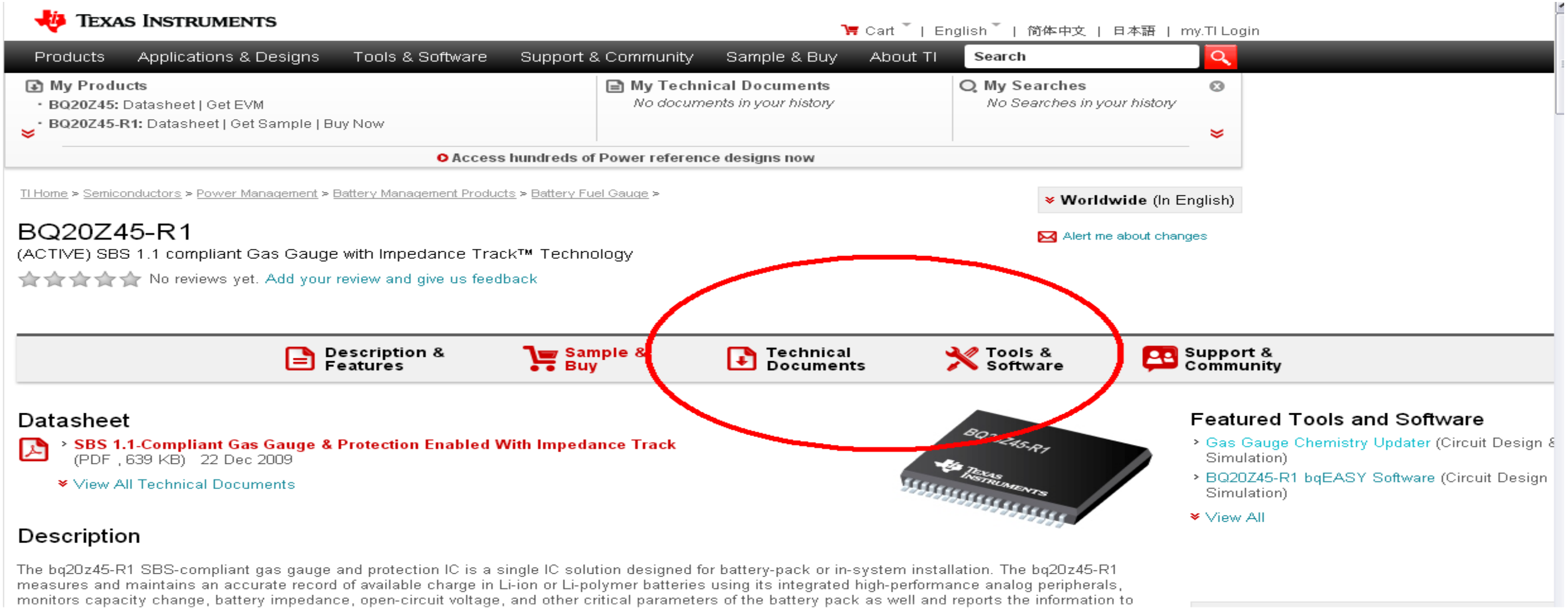
Technology Accurately Measures Available. The **bq20z45** SBS-compliant gas gauge and. Charge in Li-Ion and Li-Polymer Batteries protection IC is a single IC ...

BQ20Z45-R1 bqEASY Software - BQ20Z45-R1_BQEASY-SW - TI ...
www.ti.com › Semiconductors › Power Management
bqEASY is a tool that simplifies the bq gas gauge configuration and parameter optimize process.

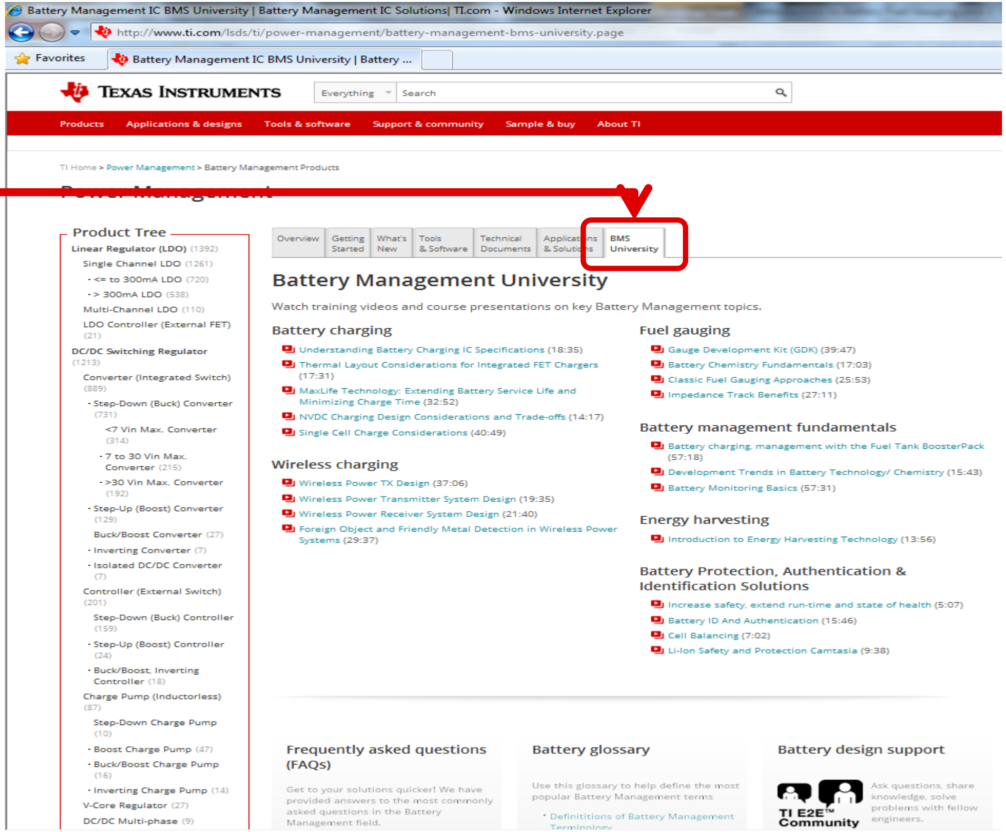
Technical docs, app notes, tools in each product folder

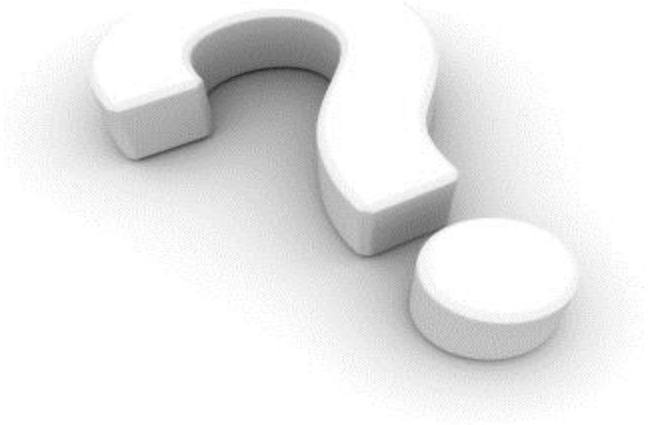


BMS University

TI.com/battery

Presentations, videos, documents, and more





Questions

How can you extend run-time with an accurate gauge?

APPENDIX A

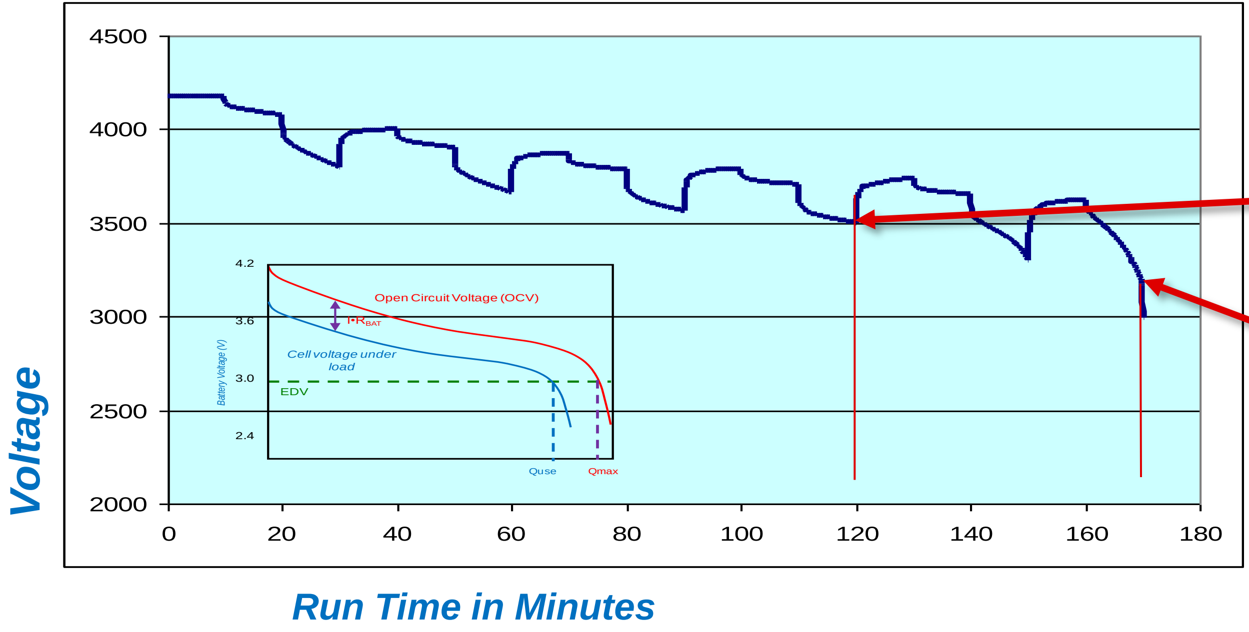
Run Time Comparison Example

Impedance Track^{TM} gauge shutdown vs. OCV shutdown point

- **Systems without accurate gauges simply shutdown at a fixed voltage**
- **Smartphone, Tablets, Portable Medical, Digital Cameras etc… need reserve battery energy for shutdown tasks**
- **Many devices shutdown at 3.5 or 3.6 volts in order to cover worst case reserve capacity**
  - ***3.5 volt shut down used in this comparison***
  - ***Gauge will compute remaining capacity and alter shutdown voltage until there is exactly the reserve capacity left under all conditions***
  - ***10 mAH reserve capacity is used***
  - ***Temperature and age of battery are varied***

Fuel Gauging

OCV vs. IT Use Case exp – NEW battery w/ variable load mix



Conditions:

- *New Battery*
- *Room temp (25°C)*
- *10 mAh reserve capacity for shutdown*

OCV

Shutdown @ 3.5V

120 minutes run time

Impedance Track™ Gauge

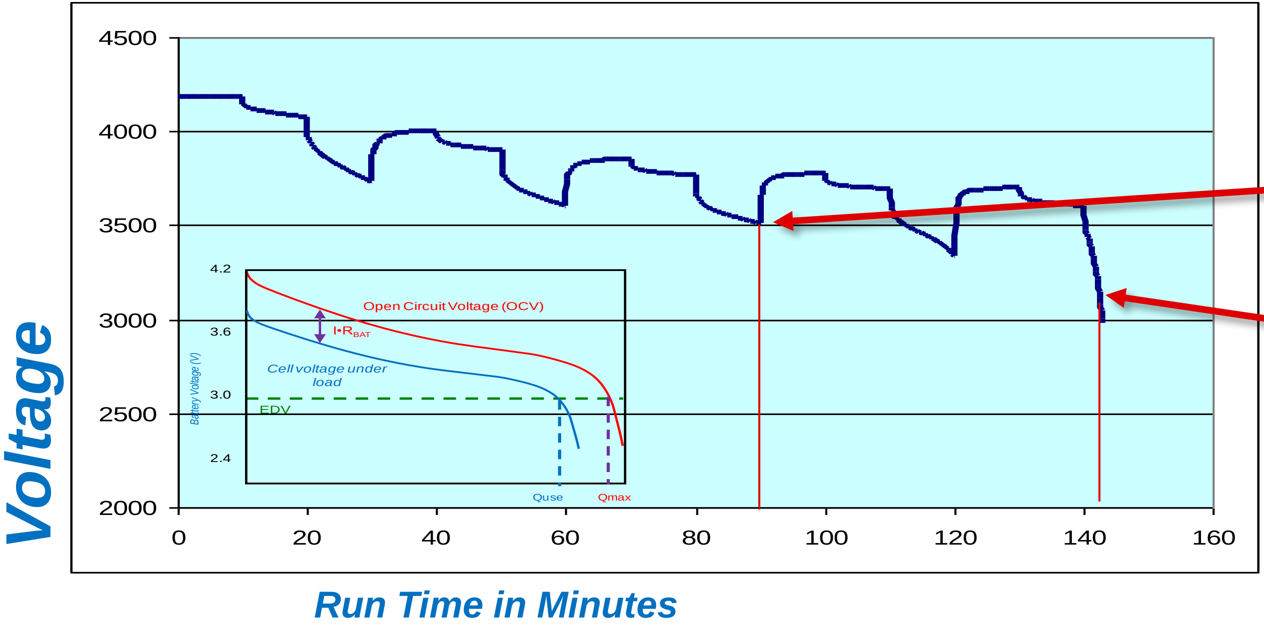
Shutdown @ 3.295V

168 minutes run time

Extended runtime with TI Gauge: +40%

Fuel Gauging

OCV vs. IT Use Case Exp – OLD battery w/ variable load mix



Conditions

- *Room temp (25°C)*
- *10 mAh reserve capacity for shutdown*

OCV

Shutdown @ 3.5V

90 minutes run time

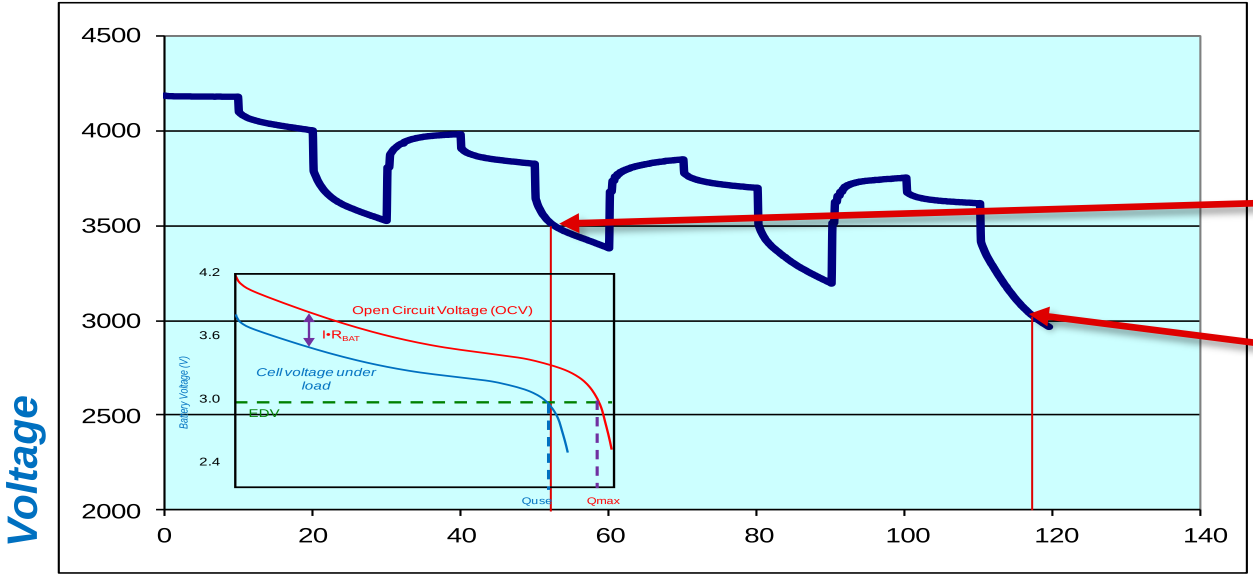
Impedance Track™ Gauge Shutdown @ 3.144V

142 minutes run time

Extended runtime with TI Gauge: +58%

Fuel Gauging

OCV vs. IT Use Case Exp – NEW battery COLD w/ variable load mix



Conditions *Batty*

- ***Cold (0°C)***
- ***10 mAh reserve capacity for shutdown***

OCV

Shutdown @ 3.5V

53 minutes run time

Impedance Track™ Gauge

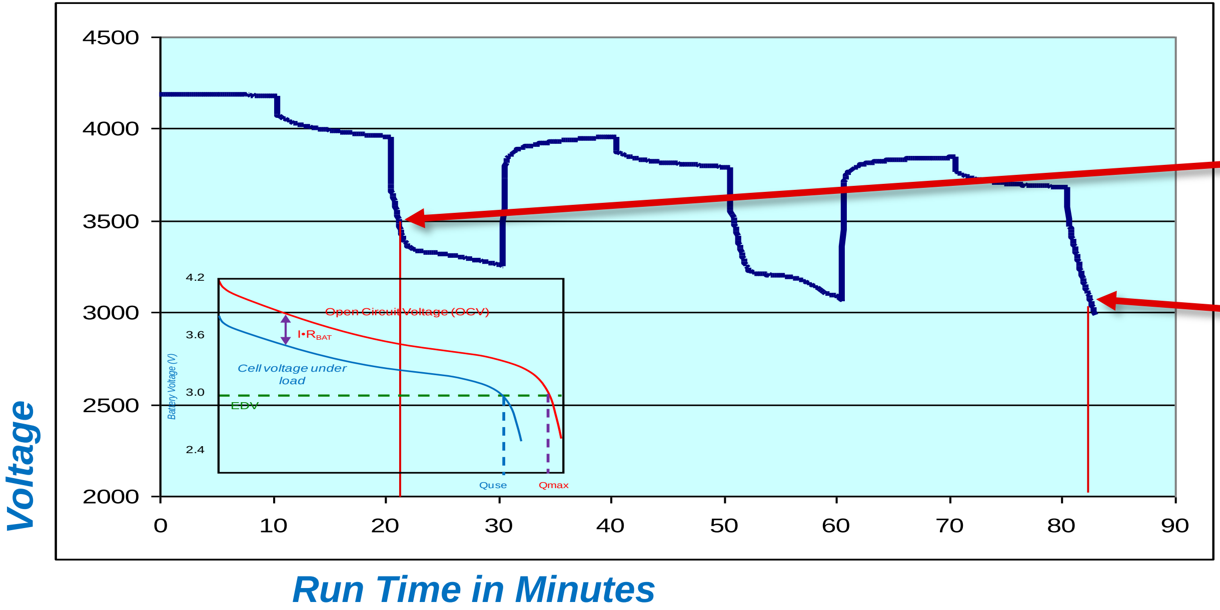
Shutdown @ 3.020V

117 minutes run time

Extended runtime with TI Gauge: +121%

Fuel Gauging

OCV vs. IT Use Case Exp – OLD battery COLD w/ variable load mix



Conditions *(0°C)*

- ***Cold (0°C)***
- ***10 mAh reserve capacity for shutdown***

OCV

Shutdown @ 3.5V

21 minutes run time

Gauge shutdown at 3.061 volts:

82 minutes run time

Extended runtime with TI Gauge: +290%