TI | Developer Conference
March 7-9, 2007 • Dallas, TX

Minds in Motion

Meeting the Challenges of Battery Management Design for Handheld Devices

Jinrong Qian

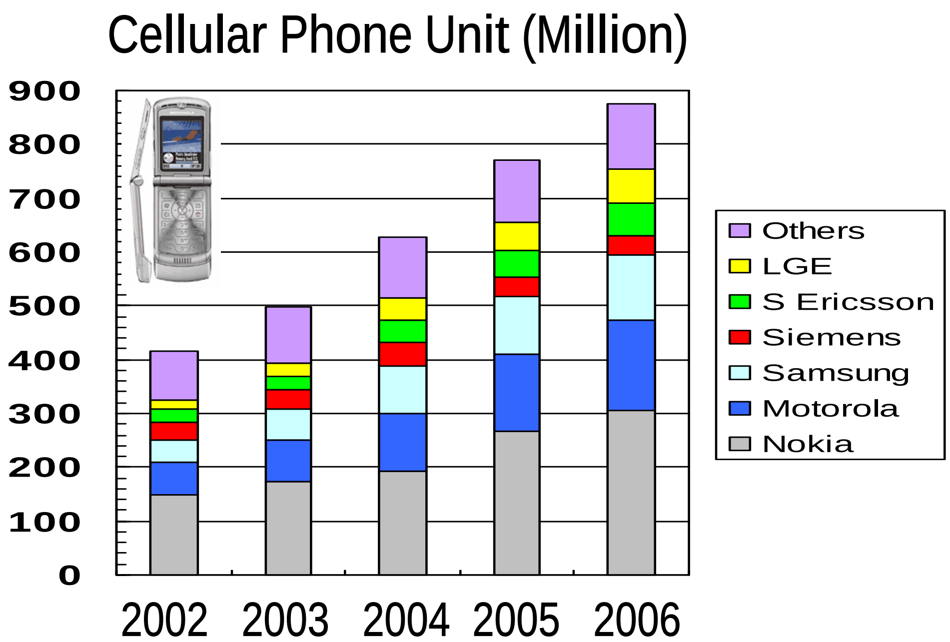
Battery Power Management Applications

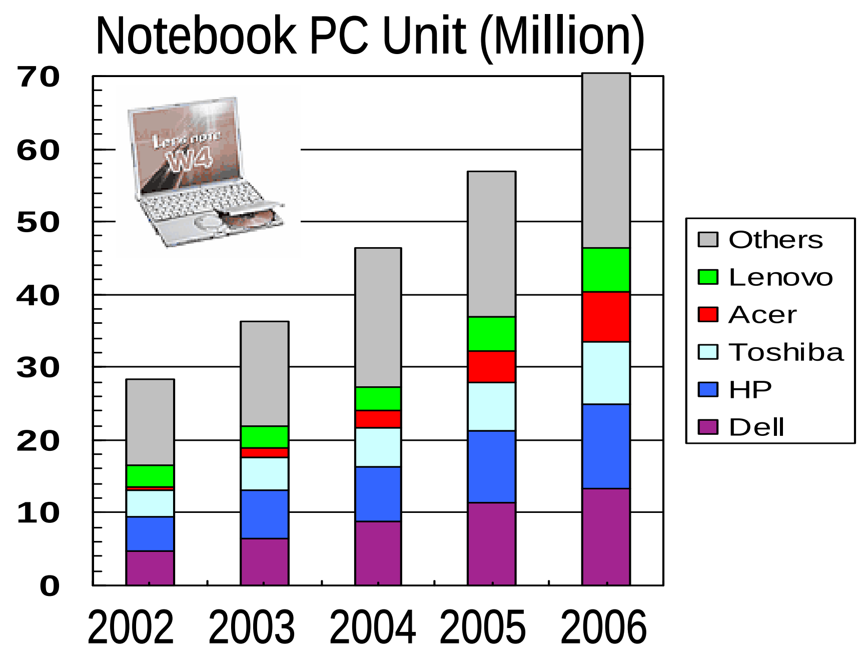
Texas Instruments

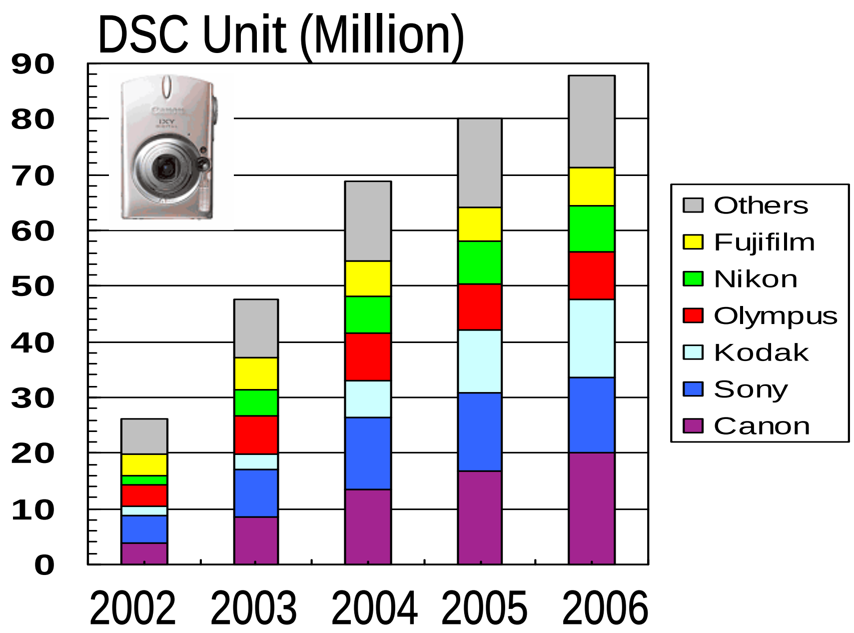
TI | Developer Conference

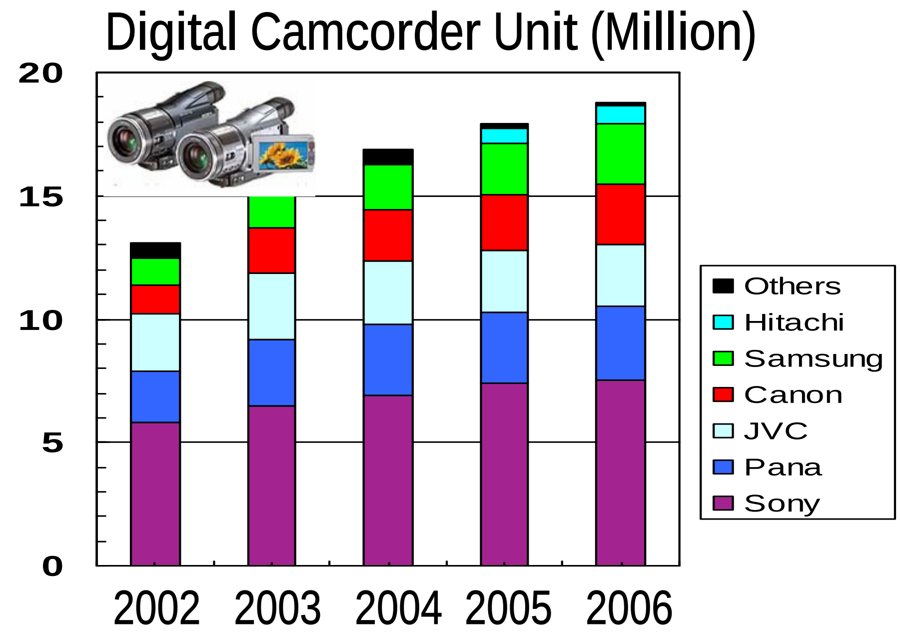
Portable Power Device Market

Hideo Takeshita
Institute of Information Technology, Ltd
The 23rd International Battery Seminar, 2006







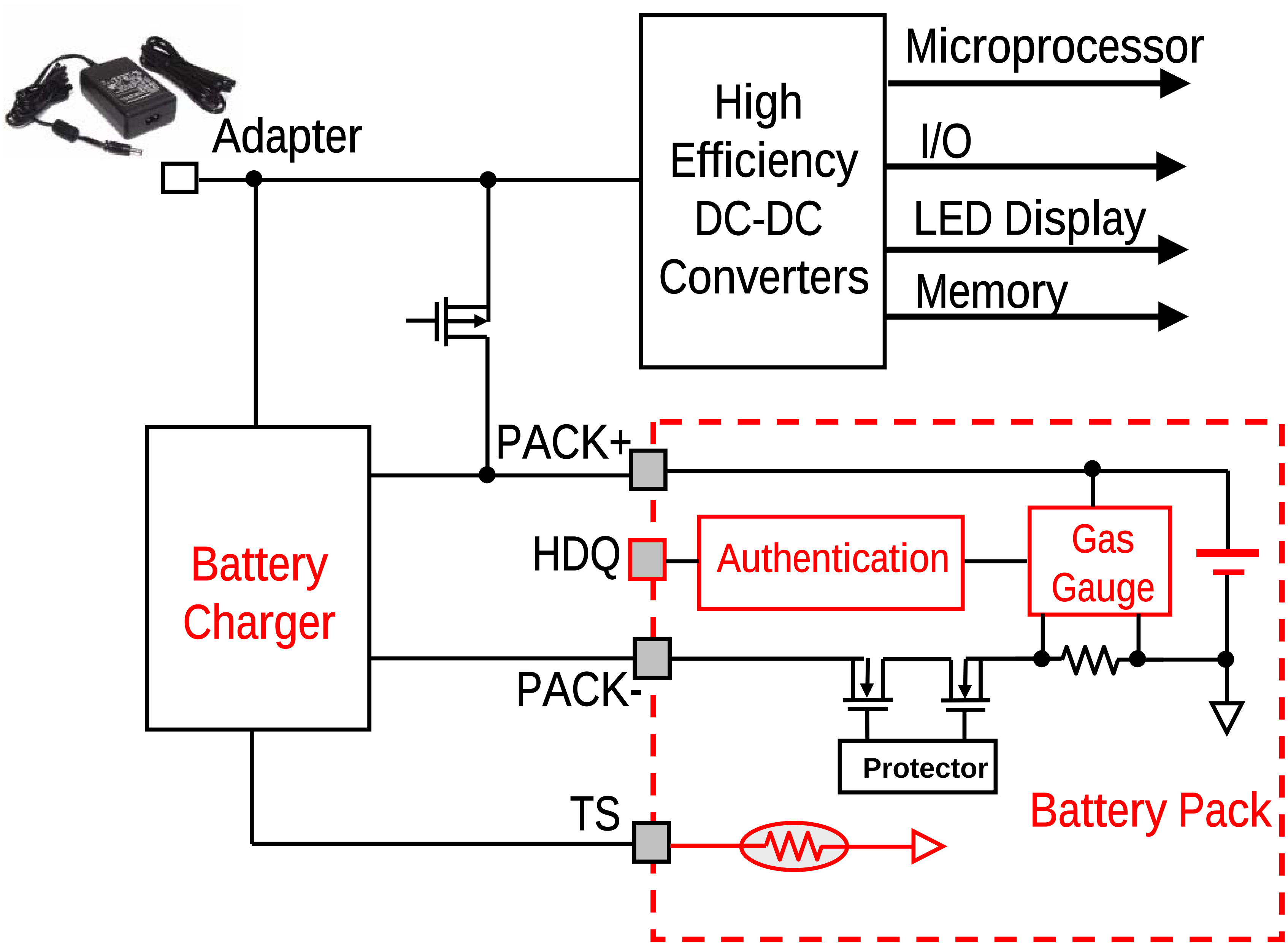


Total Portable Power Management for Battery-Driven Electronics...

Portfolio strength in...

- Battery management
- Low-dropout regulators
- Low-power DC/DC
- White-light and RGB, LED drivers
- Power supervisors
- LCD bias power

Battery Power Operated System



Battery Power Management Design Challenges

- Safe and reliable battery pack
  - Counterfeit battery pack
  - Safe Li-Ion battery chemistry
- Charging the battery while powering the system
- Battery capacity monitoring
  - Voltage-based: cheap, not accurate (50%)
  - Coulomb-counting: (4-10%)
    Requires full discharge/charge
    Cycling and self-discharge
  - Impedance track: 1%

Conference on June 21, 2006, in Japan

www.theinquirer.net

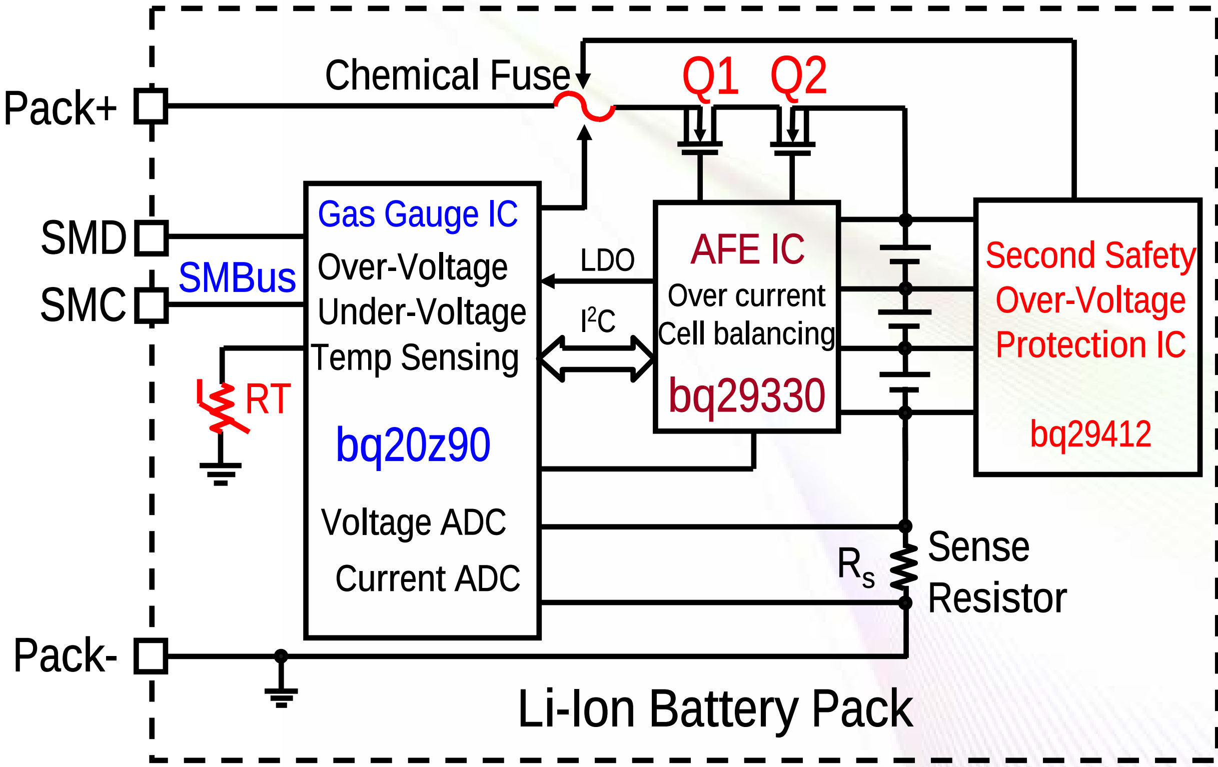
Safety!!!

Safety

- More than 43 cases of events on the notebook PC were reported during 2001 to 2003, according to the U.S. Consumer Product Safety Commission

◇7월 31일 '시드니모닝헤럴드'(http://www.smh.com.au) 보도.

Battery Pack Electronics



- 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

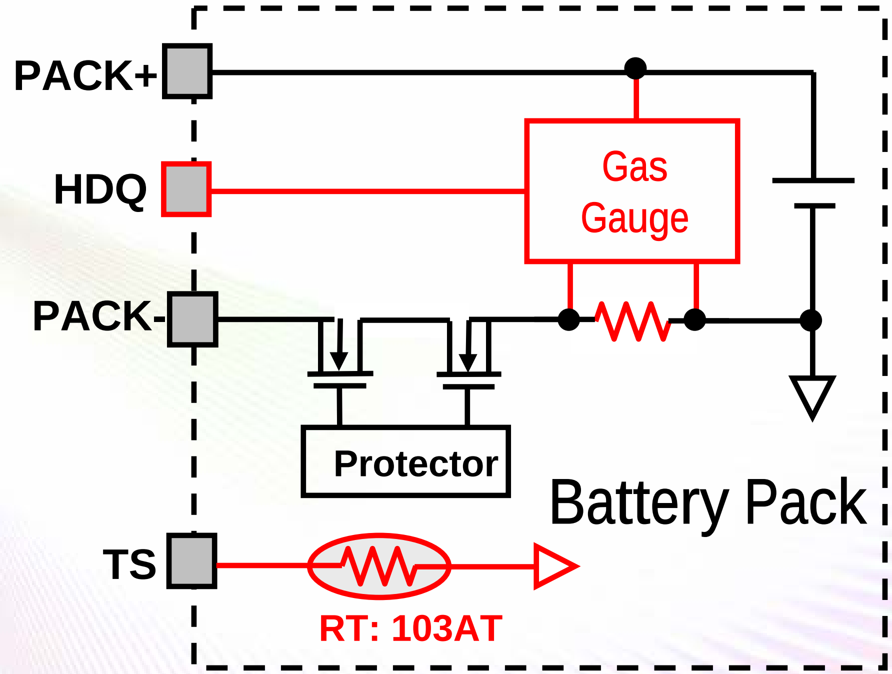
  AFE hardware
  - 3rd level, discharge only
- Short circuit – AFE hardware.
- Over-discharge
- Over temperature

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

Battery Authentication/Security Development

Counterfeit Battery

- Cheap replacement battery
  - Functionality removal
  - Without safety circuit
  - No protection circuit
- OEM loses business and reputation
- Loss of public confidence as safety compromised



What Is Authentication?

- A simple and cost-effective method to identify and validate identity
  - ➢ Identification, driver's license
- Specific to peripherals:

  A simple and cost-effective method to ensure that peripherals come from authorized vendors
- Form factors
  - *Strength: economies of scale*
  - *Weakness: hard to revise*

- Labeling
  - *Strength: cheap*
  - *Weakness: easily copied and moved around*

- User intervention
  - *Strength: informed consent*
  - *Weakness: requires user motivation, difficult to enforce*

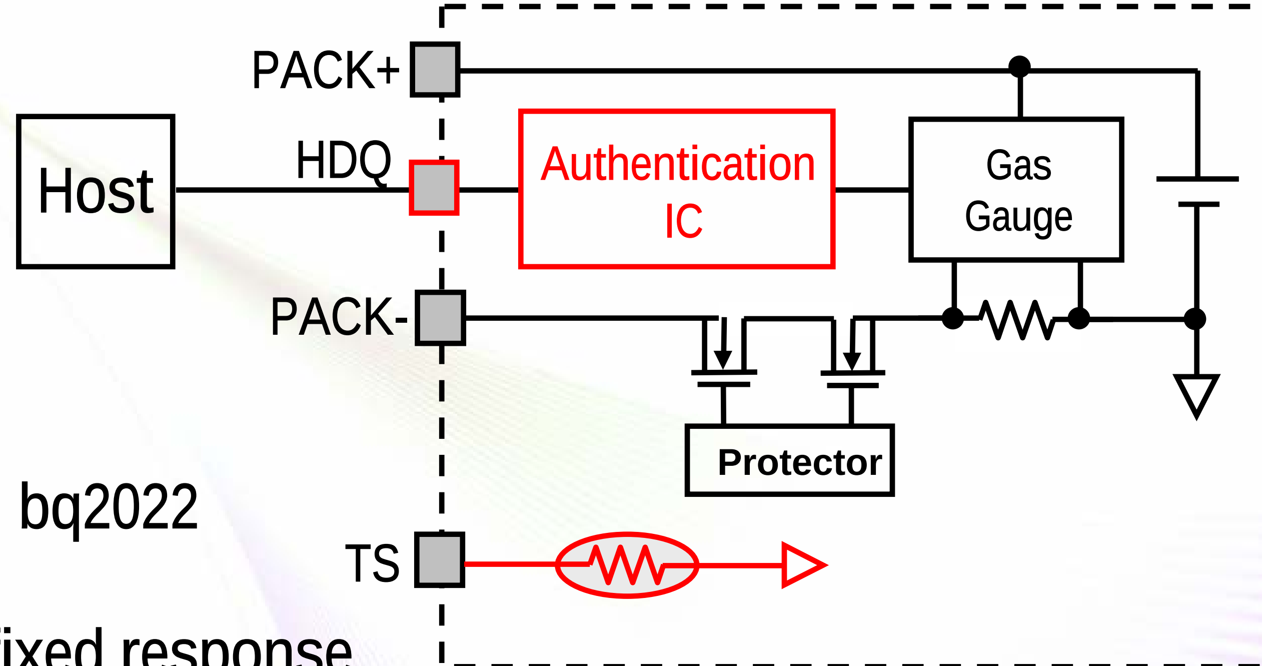
Battery Authentication/Security Development

Solutions

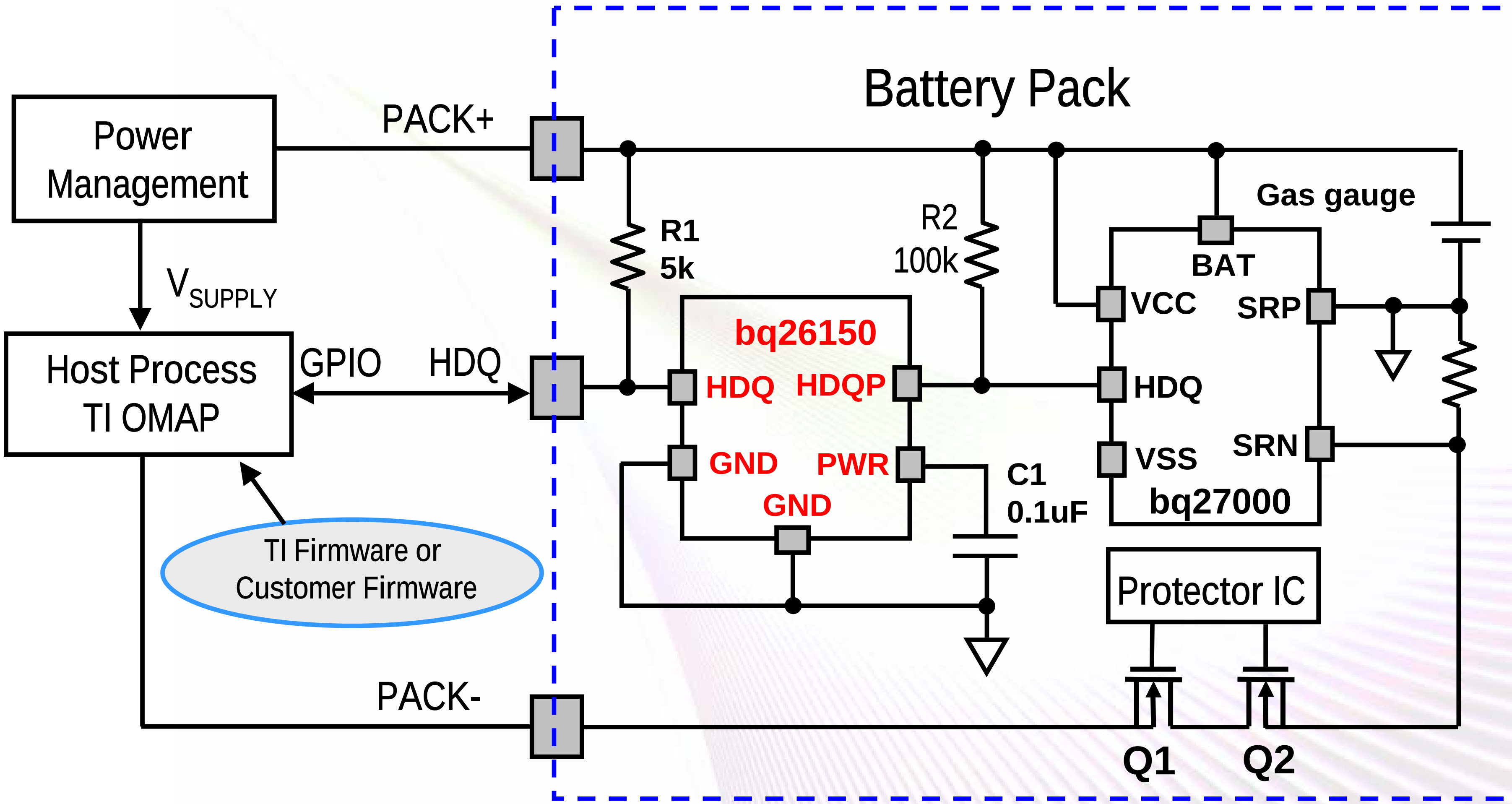
- Form factors
- Labeling
- Identification (ID): bq2022

  Fixed challenge, fixed response
- Random challenge-response

  bq26150 (CRC) and bq26100 (SHA-1)



Typical Application Circuit and System Diagram



What if Not Authenticated?

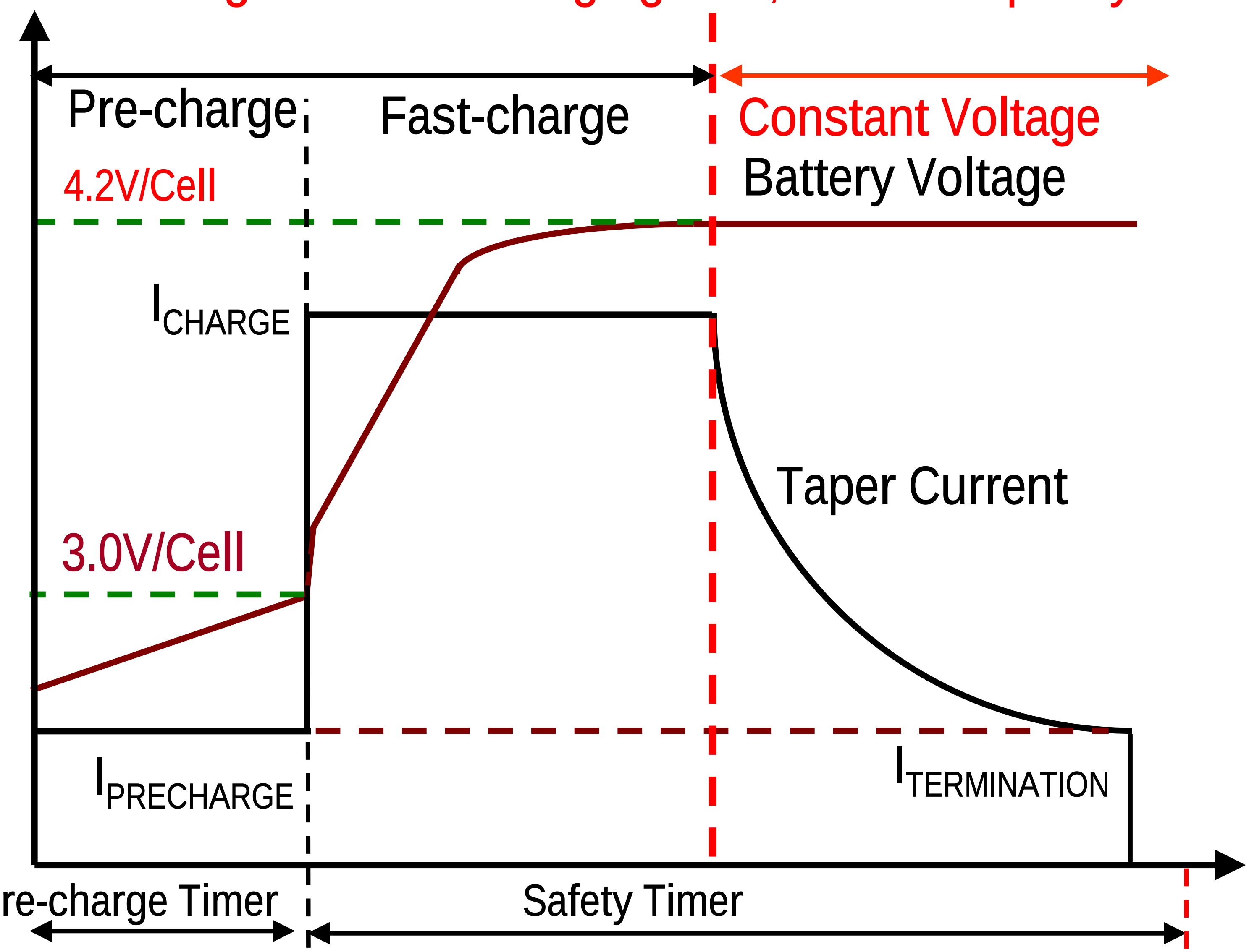
- System-dependent
  - Battery packs:
    - Allow discharge only
  - Chargers:
    - Reduced charging current rate, or lower voltage
  - Other peripherals
    - Reduced functionality
- Might choose simply to log that an unauthorized peripheral was used for warranty information.

Power Path Management Battery Charging Technology

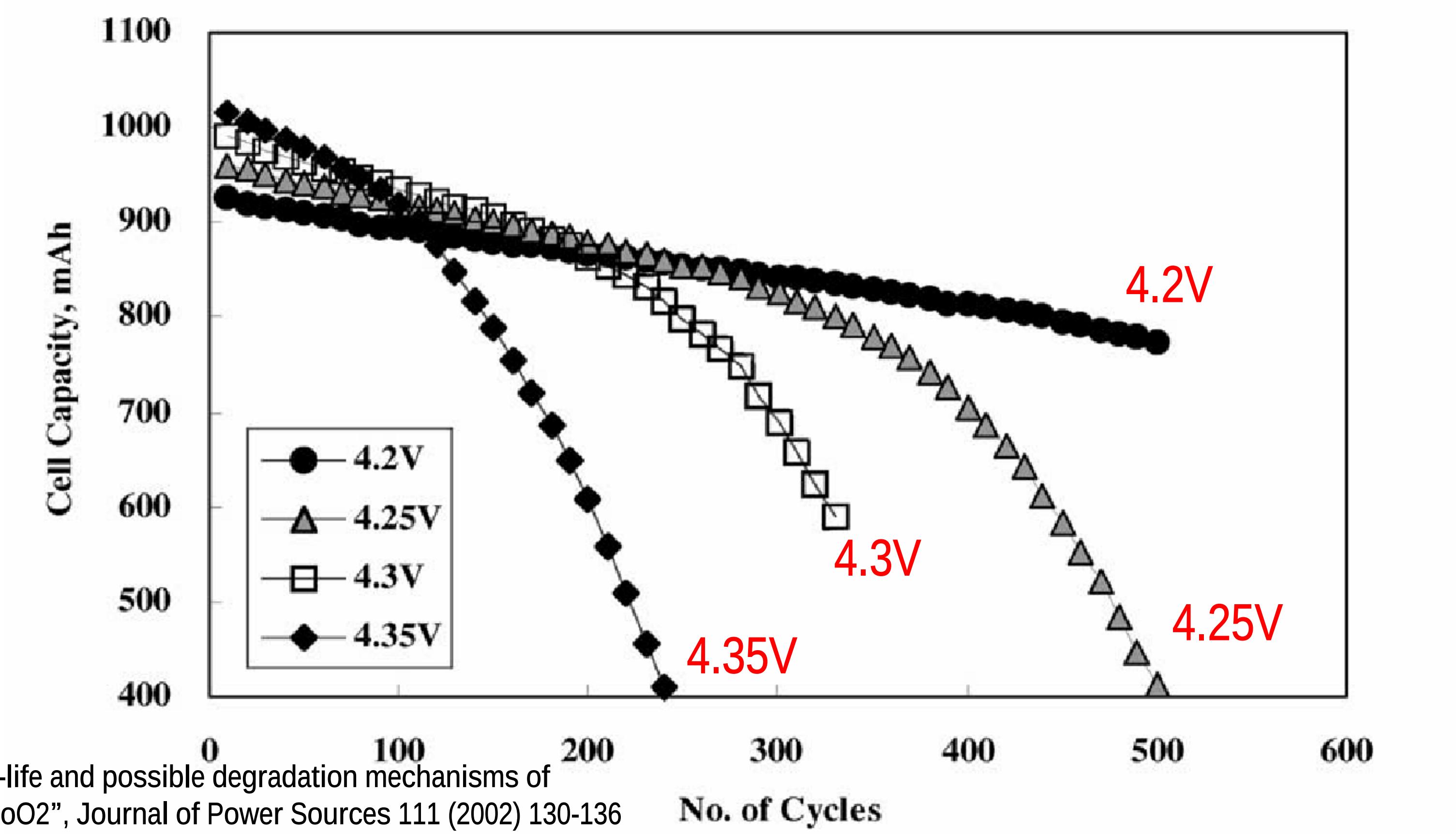
Li-Ion Charge CC-CV Profile

Constant Current: 20-30% charging time, 70-80% capacity

Constant Voltage: 70-80% charging time, 20-30% capacity



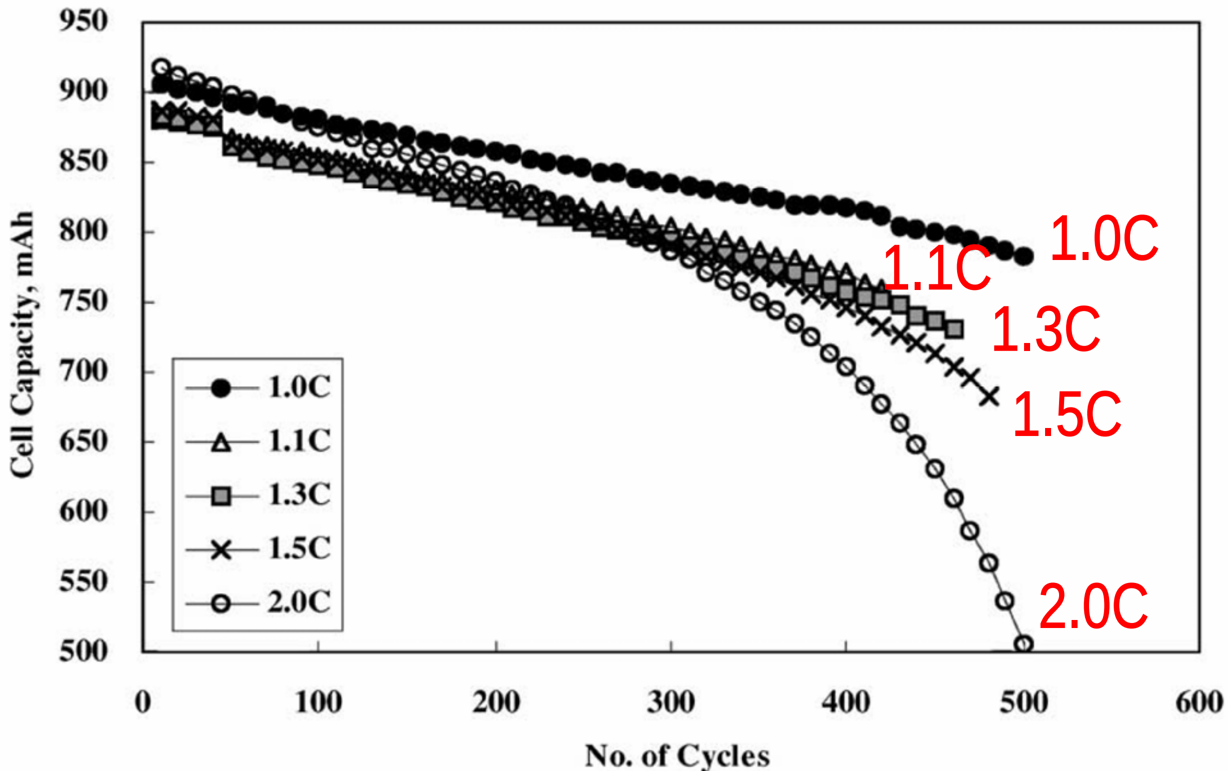
Charge Voltage Affects Battery Service Life



"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

- The higher the cell voltage, the higher the capacity
- Over-charging shortens battery cycle life
- Requirements: High accuracy battery charge voltage <1%

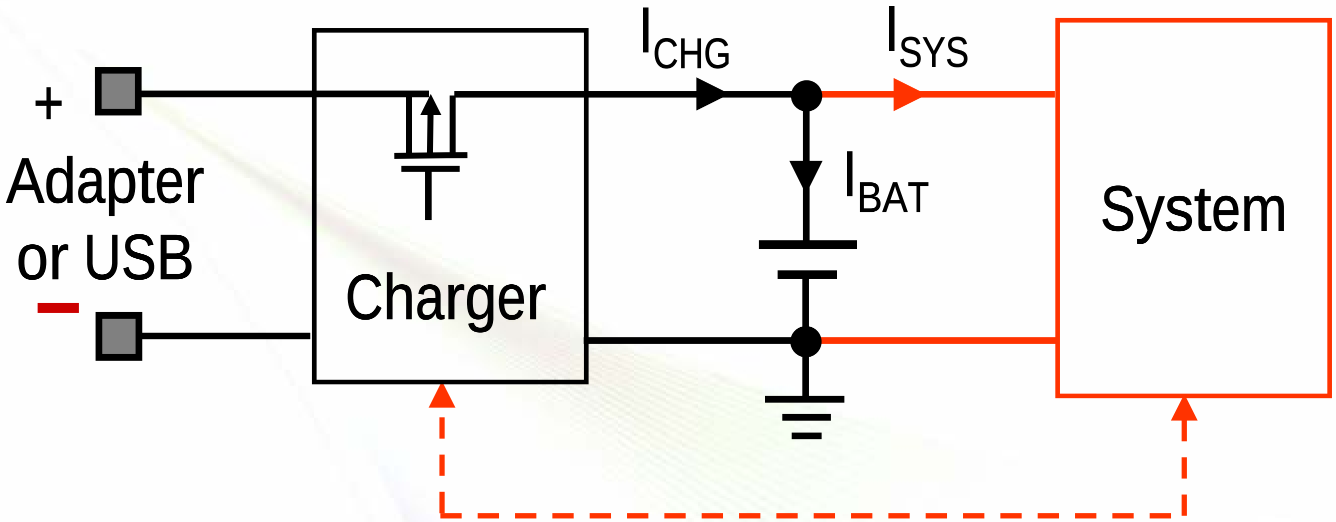
Charge Current vs. Battery Degradation



"Factors that affect cycle-life and possible degradation mechanisms of a Li-ion cell based on $LiCoO_2$", Journal of Power Sources 111 (2002) 130-136

- Charging current ≤ 1C rate to prevent overheating, degradation.
- The higher charge current will not short the charge time too much!

Charging with an Active System Load



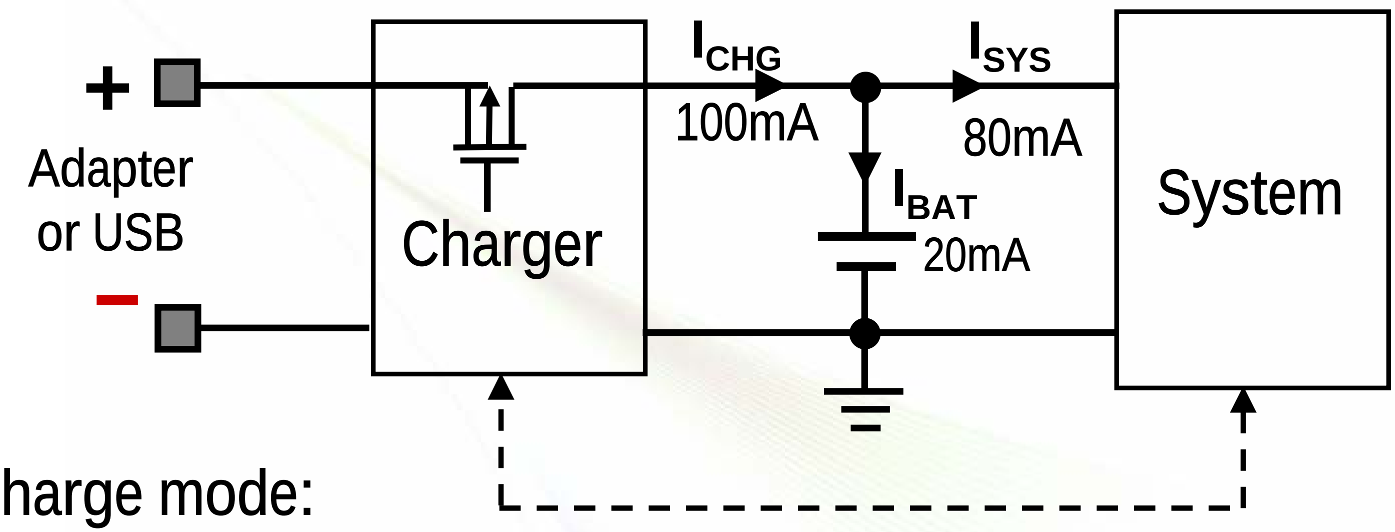
Charger output current is shared:

$I_{CHG} = I_{BAT} + I_{SYS}$

Design challenges:

- Charger and system interaction
- Safety timer
- Charge termination detection

Challenge 1: Pre-charge and Safety Timer Fault



Pre-charge mode:

Battery voltage might NOT reach the fast charge voltage threshold

- ➢ Pre-charge timer false warning

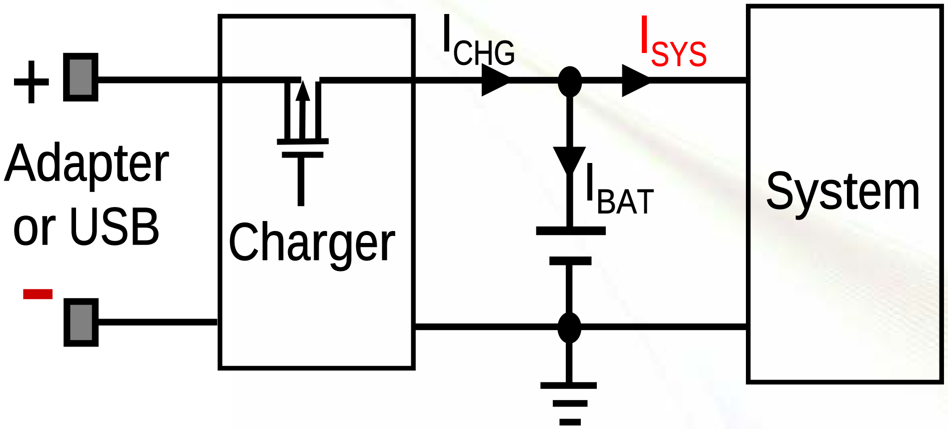
Battery might NOT be fully charged when the safety time expires

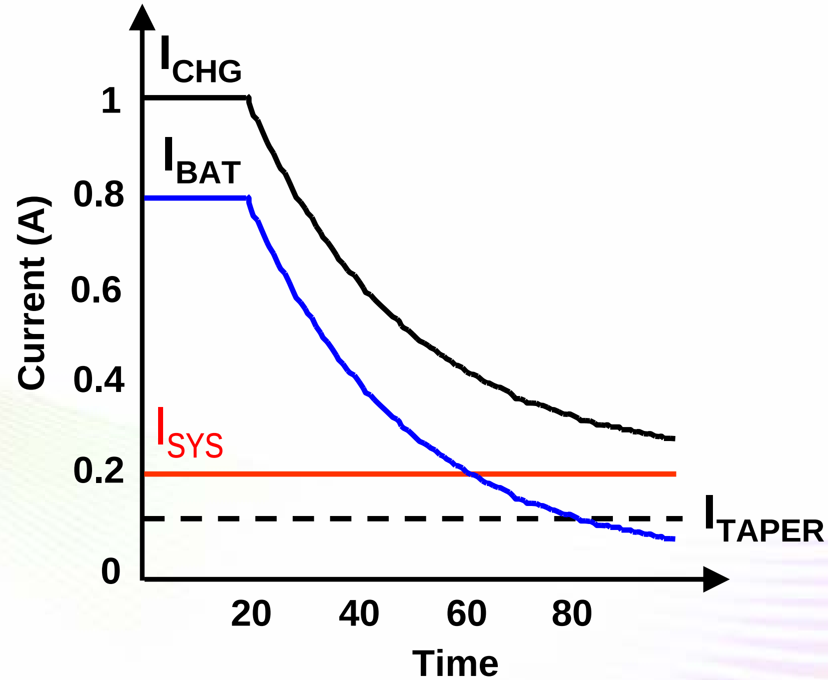
- Safety timer false warning

Solution: keep system off or in low-power mode in pre-charge mode

Drawback: cannot operate the system while charging a deeply discharged battery simultaneously

Challenge 2: Charge Termination NOT Detected

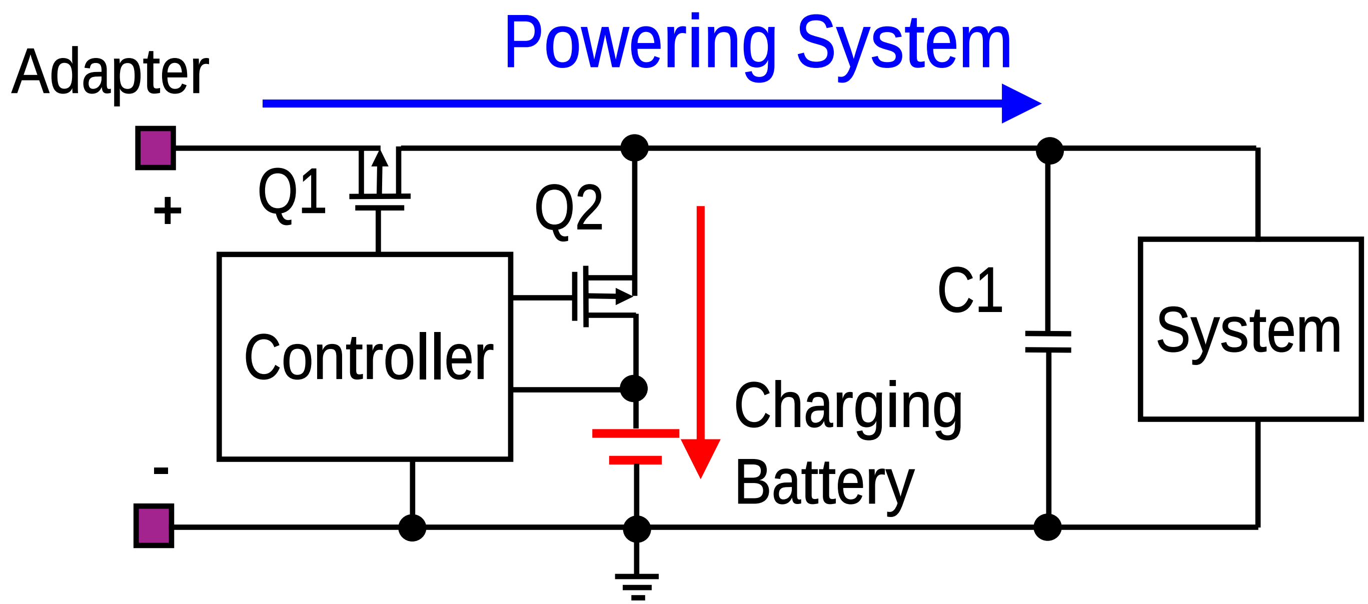




Voltage regulation mode:

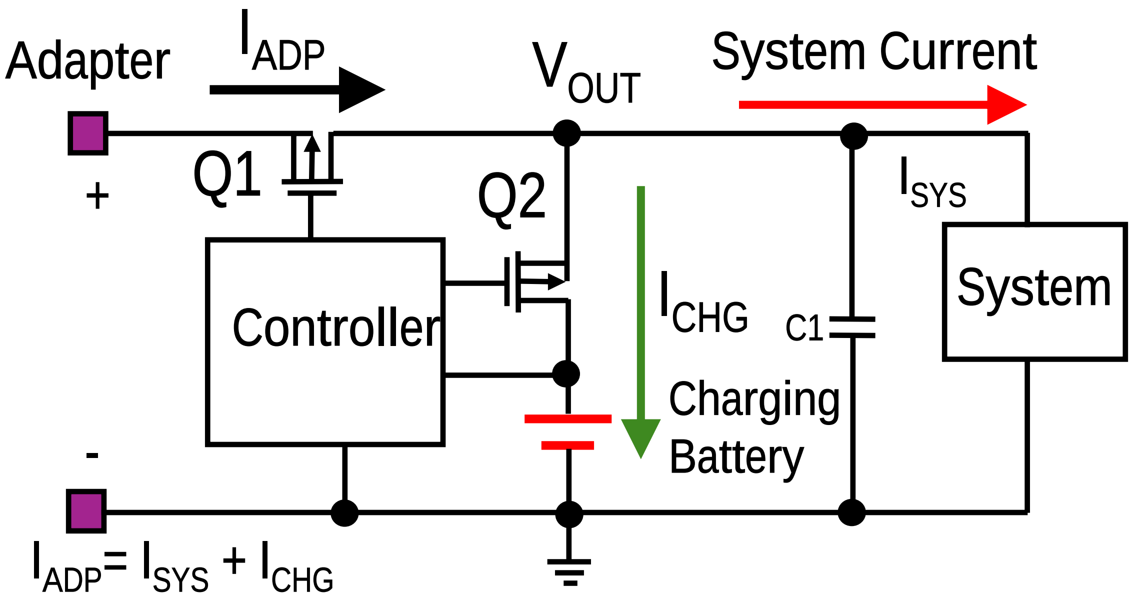
- If $I_{SYS} > I_{TAPER}$, termination is never detected
  Solution: current supplement circuit

Power Path Management Battery Charge Architecture

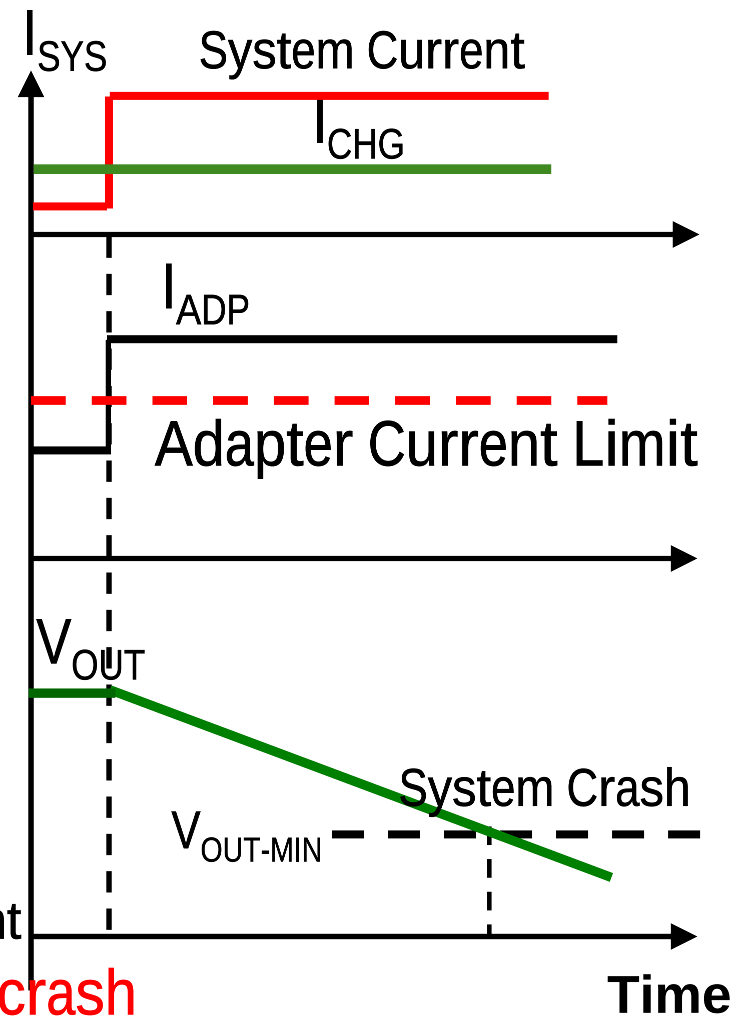


- Decoupling charge current path from system current path
- Charge current controlled by Q2
- Powering system from adapter through Q1
- Simultaneously powering system and charging battery
- No interaction between charge current and system current

Challenge for Power Path Management Charger



$I_{ADP} = I_{SYS} + I_{CHG}$

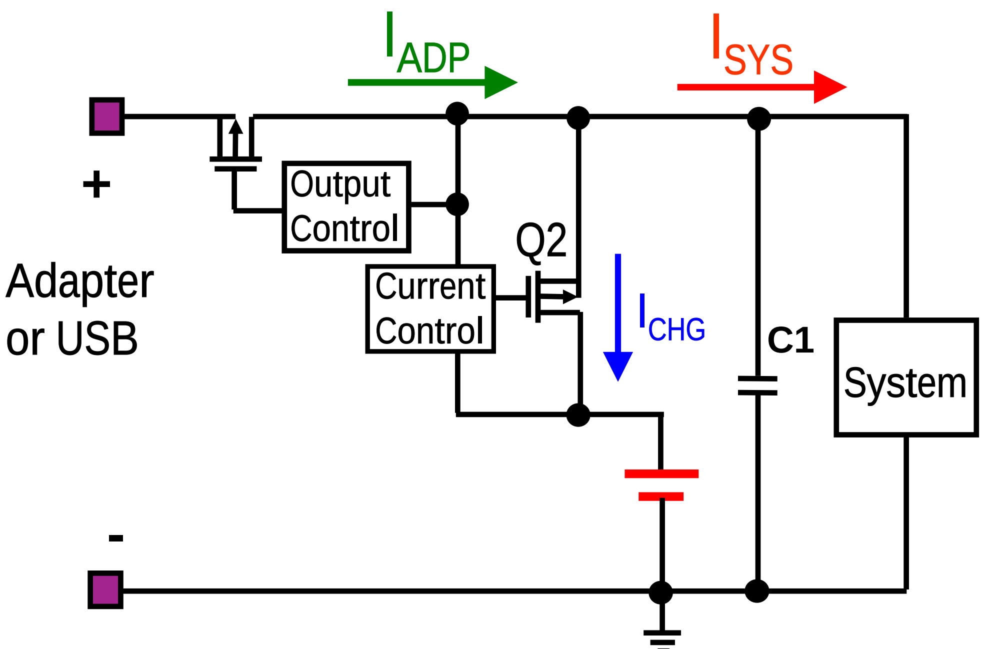


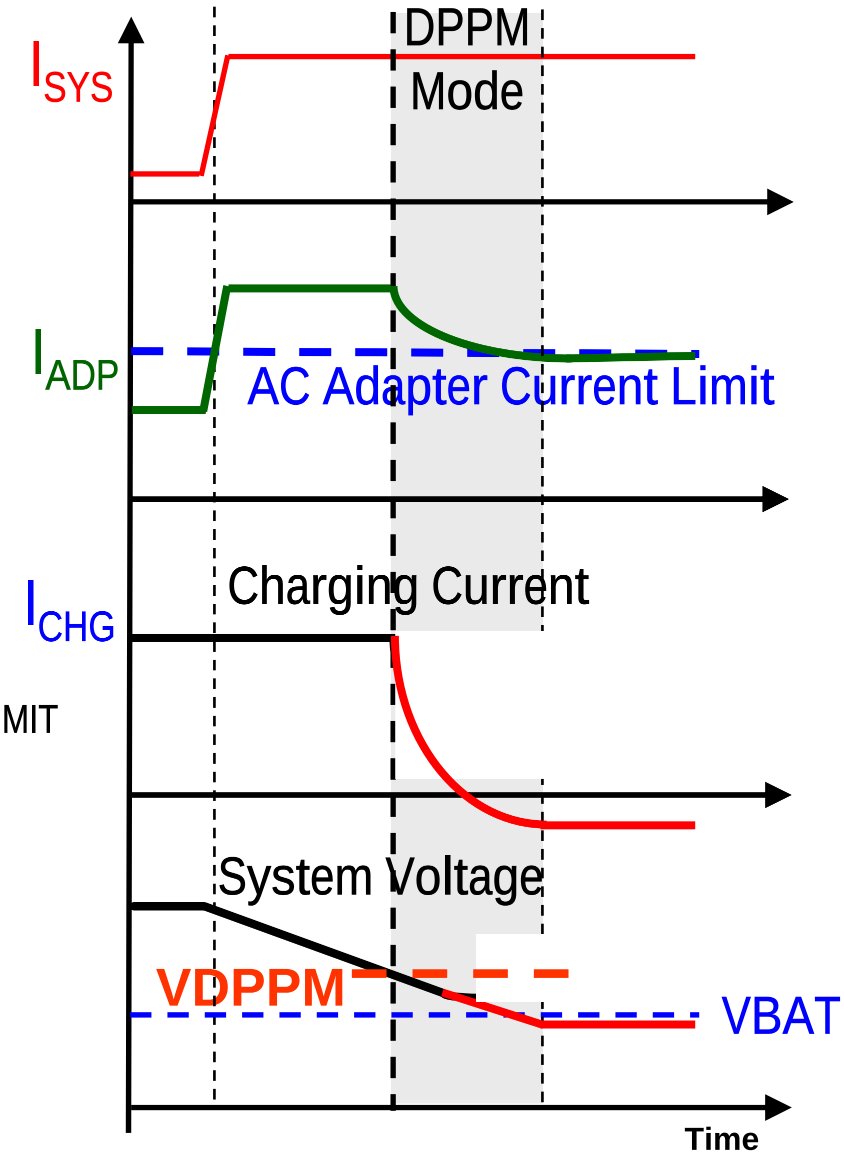
- High AC adapter current
- Designing the AC adapter with peak power
  - Higher cost
  - larger size
- Might crash the system for high pulse system current

Avoid system crash

Power regulation: dynamic power path management

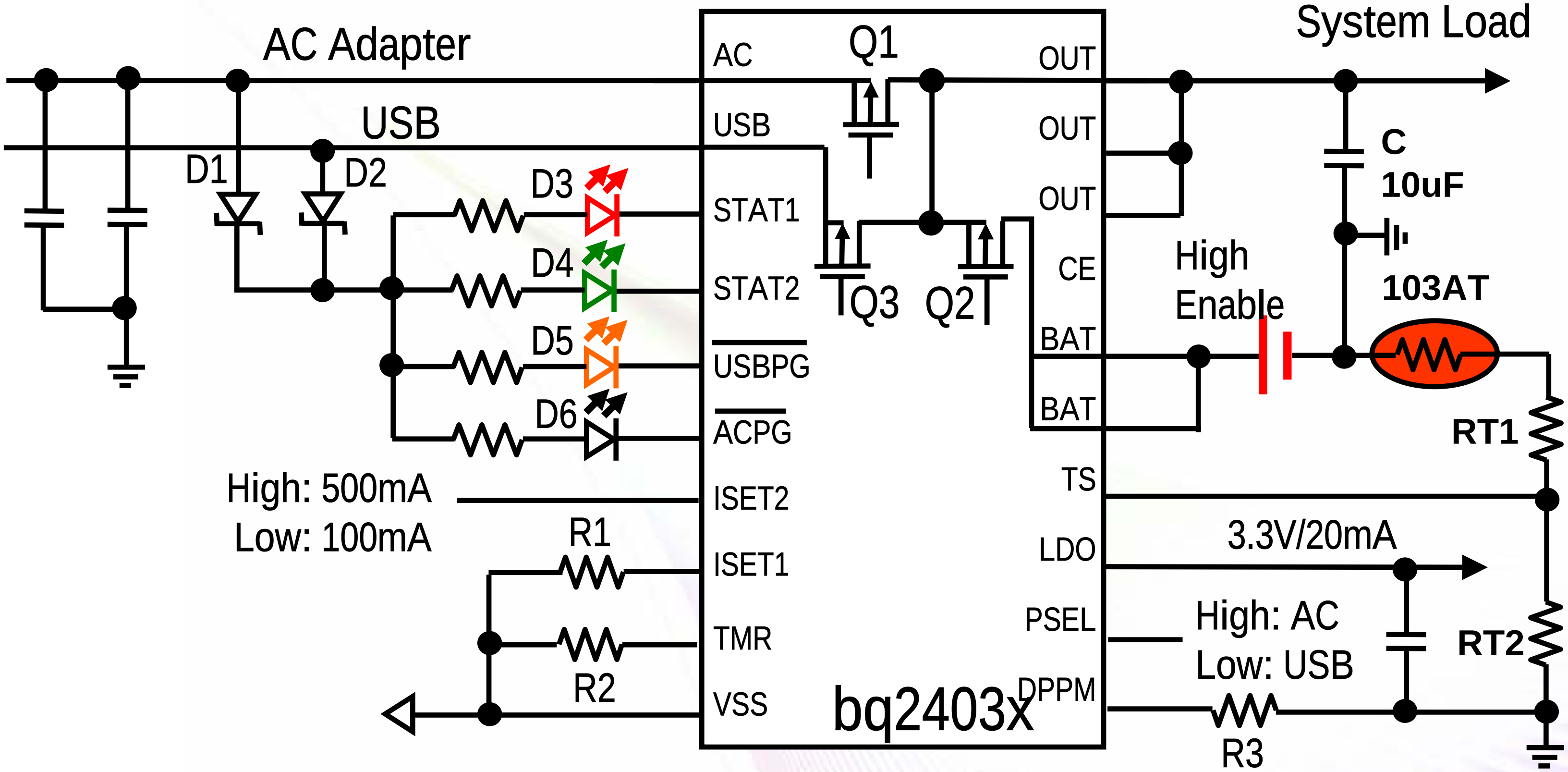
Dynamic Power Path Management (DPPM)





- System voltage drops if $(I_{SYS} + I_{CHG}) > I_{AC\_LIMIT}$
- DPPM function :
  - Reduces the charge current when the system voltage is below V_{DPPM}
  - "Finds" maximum adapter power!
- Battery supplement mode

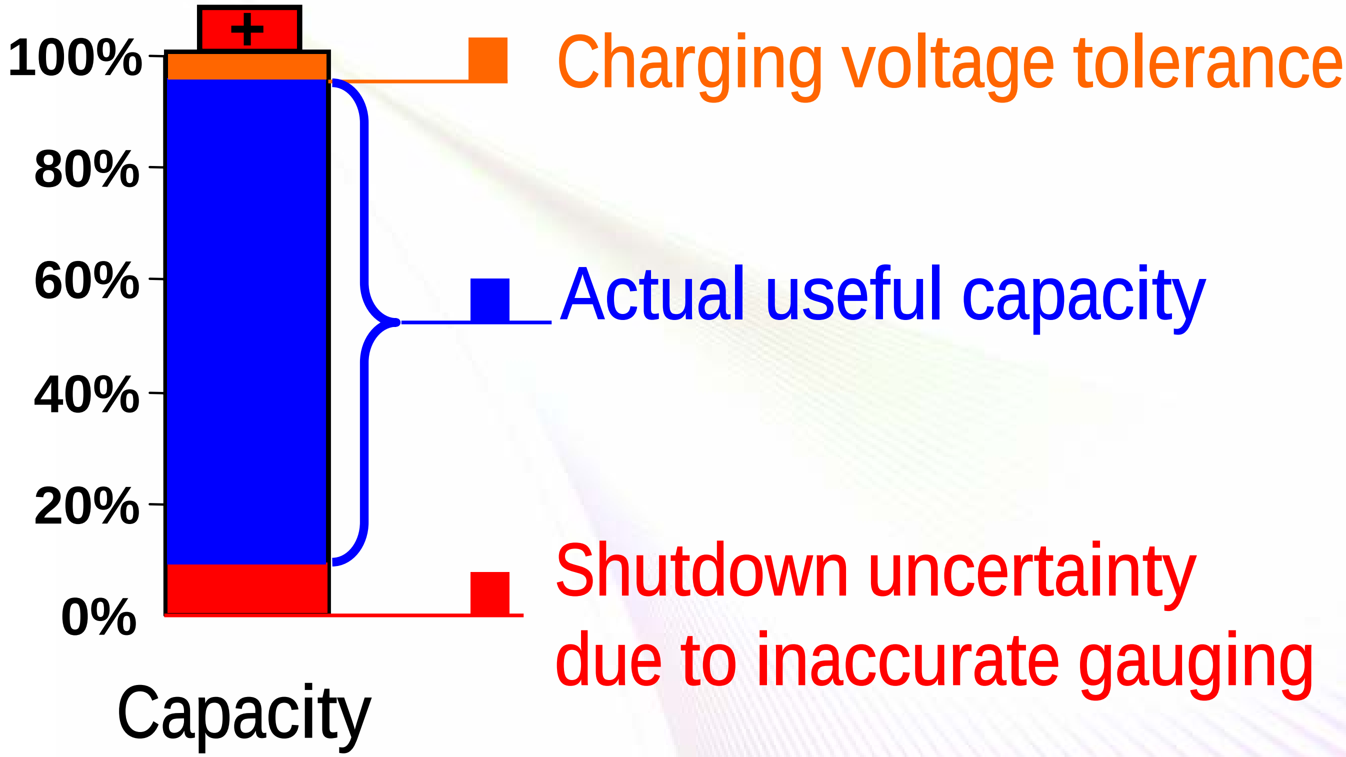
Solution Example: DPPM Battery Charger



- AC adapter or USB can power the system and charge the battery simultaneously
- Dynamically reduces charge rate to supply sufficient system current
- Selectable USB charge current limits of 100/500mA and up to 1.5A from AC adapter
- Thermal regulation and battery temperature monitoring

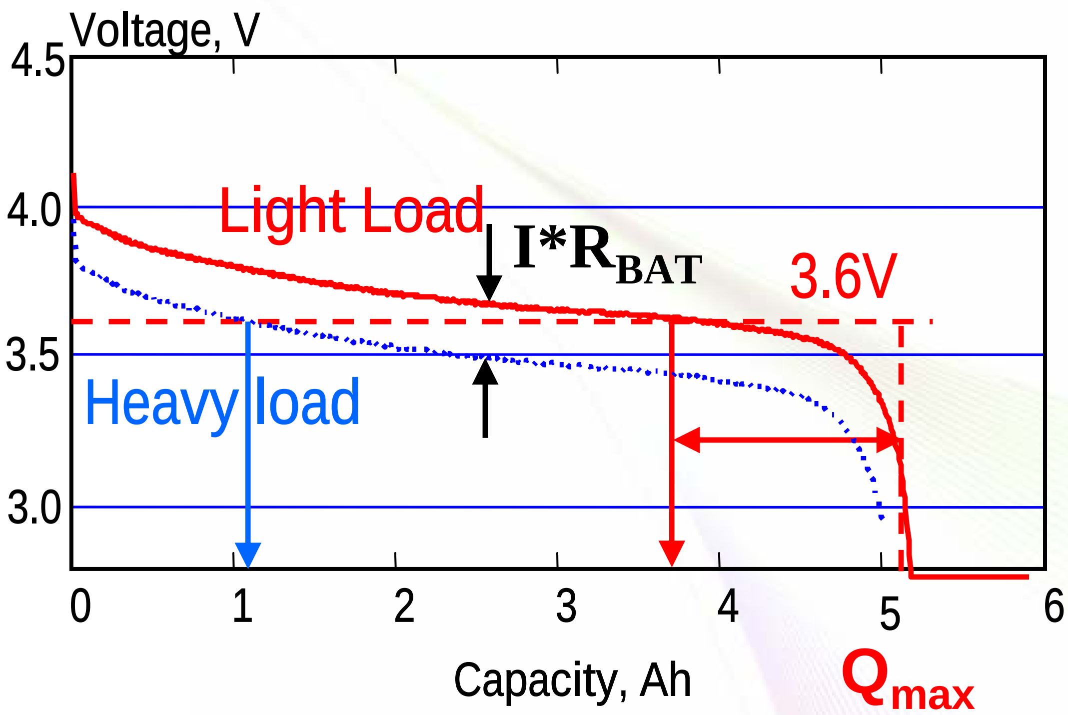
High Accuracy Battery Gas Gauge Technology

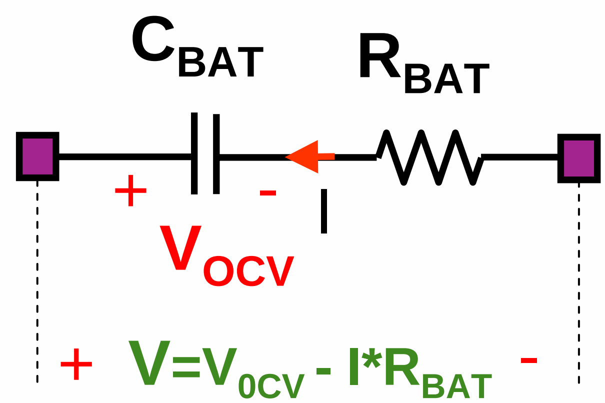
Full Use of Available Battery Capacity



- Only 80-90% of available capacity may actually be used!
- High accuracy gas gauge increases the battery run-time

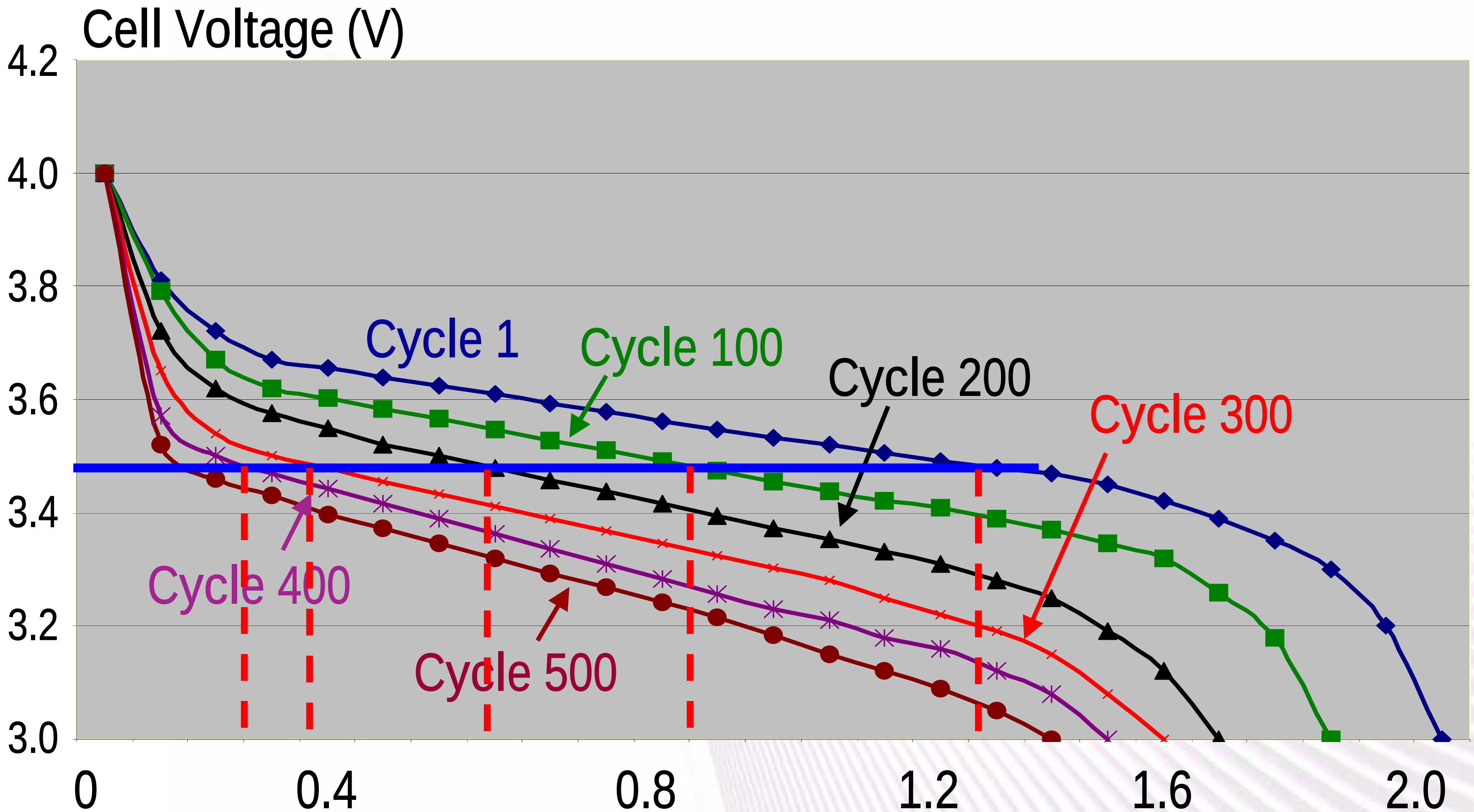
Voltage-Based Gas Gauge





- External battery voltage can be roughly modeled as $V=V_{0CV}-I*R_{BAT}$
- Higher voltage with light load, lower voltage under heavy load Issue
- Display remaining capacity error: 50-100%

Voltage-Based Gauging with Aging



- Same voltage, different state of charge

Voltage-Based Fuel-Gauging Summary

Advantages

- Learning can occur without full discharge
- No correction for self-discharge needed
- Very accurate with small load current

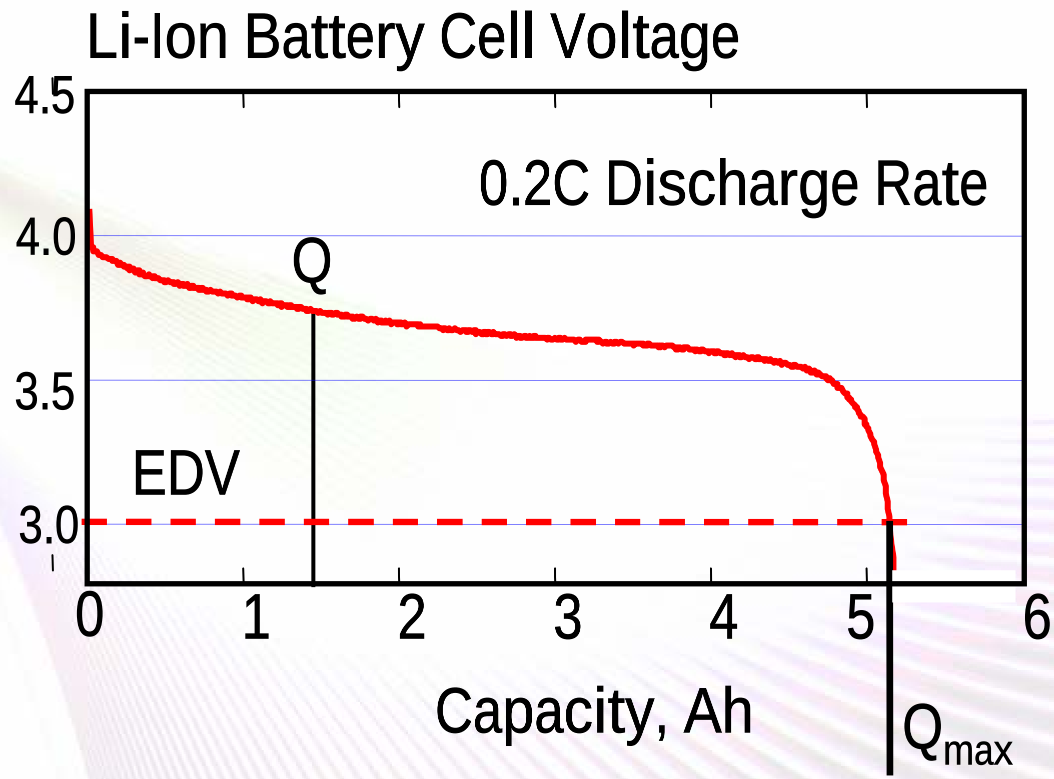
Disadvantages

- I· R correction introduces significant error because of relaxation effects and variations of R from cell to cell, so accuracy is generally lower than in integration methods
- Common noisy operation environment results in SOC value fluctuations
- Significant data collection for SOC(V,I,T) database is needed for every new battery model

Coulomb Counting–Based Gauging

- 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

Current Integration–Based Fuel-Gauging Summary

Advantages

- Not influenced by distortions of voltage measurement during operation
- Accuracy is defined by current integration hardware
- Gauging error: 3-20% depending operation conditions and usage

Disadvantages

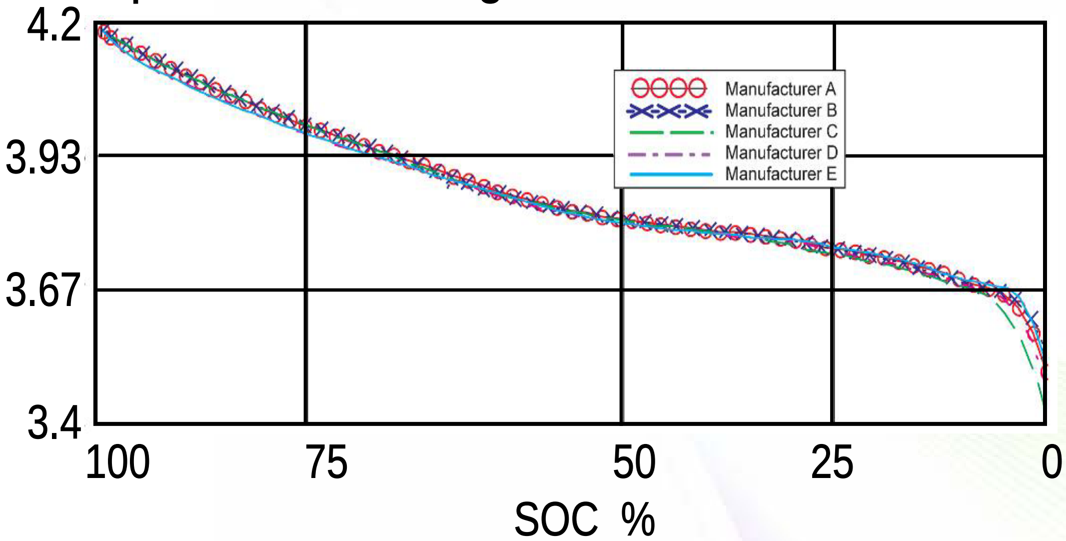
- Learning cycle needed to update Q_{max}
  - Battery capacity degradation with aging (Qmax reduction: 3-5% with 100-cycles)
  - Gauging error increase 1% for every 10-cycle with learning
- Self-discharge has to be modeled: Not accurate
- With increasing impedance, increases difference between Q_{max} value learned at different discharge rates

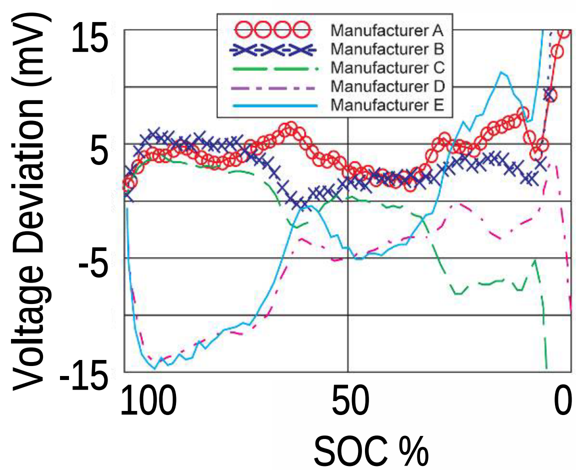
Impedance Track™ Improves Handling of Battery Aging

- Combine advantages of voltage and current based methods
- Use voltage-based method where no load is applied to battery, to determine starting SOC and no-load capacity degradation
- Use current integration based method when under load
- Update impedance at every cycle using voltage and current information
- Calculate remaining run-time at given average load using both open circuit voltage and impedance information.

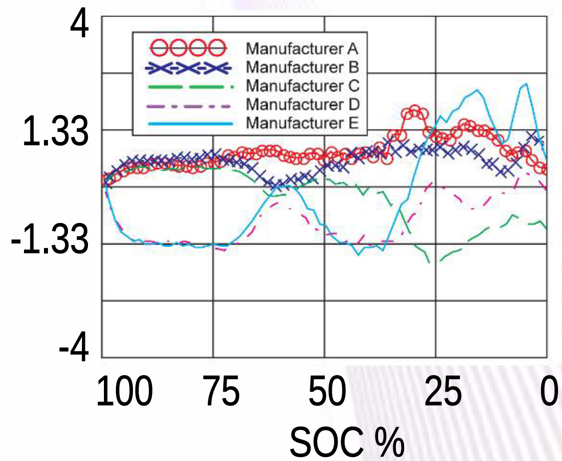
Comparison of OCV/DOD Profiles for 5 Manufacturers

Open Circuit Voltage Profile





SOC Error %



- OCV profiles similar for all tested manufacturers
- Most voltage deviations from average are below 5 mV
- Average SOC prediction error based on average voltage / SOC dependence is below 1.5%
- Same database can be used with batteries produced by different manufacturers for the same chemistry
- Generic database allows significant simplification of fuel-gauge implementation at user side

How to Measure Impedance

- Data flash contains a fixed table for open circuit voltage as a function of remaining capacity *OCV = f (SOC)*
  This is true for all standard Li-ion cells, regardless of manufacturer

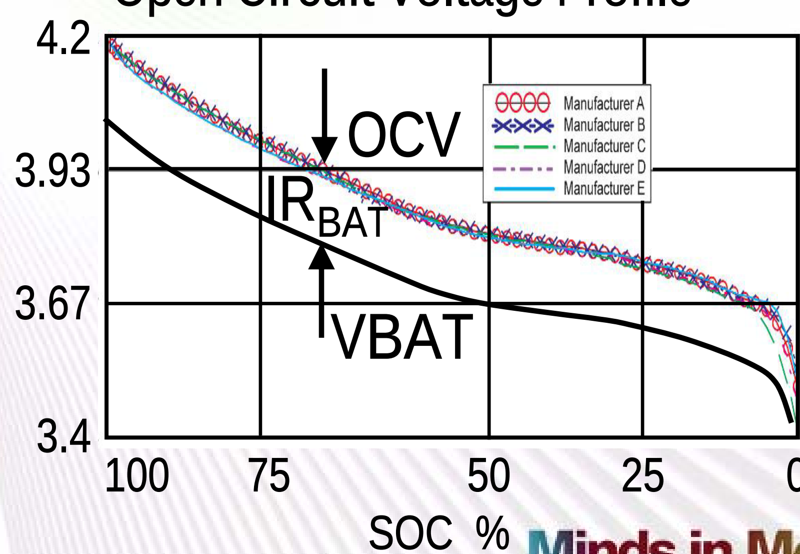
- The IT algorithm performs real-time measurements and calculations during charge and discharge cycles.

$$\text{Impedance } R_{BAT} = \frac{OCV - VBAT}{I}$$

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

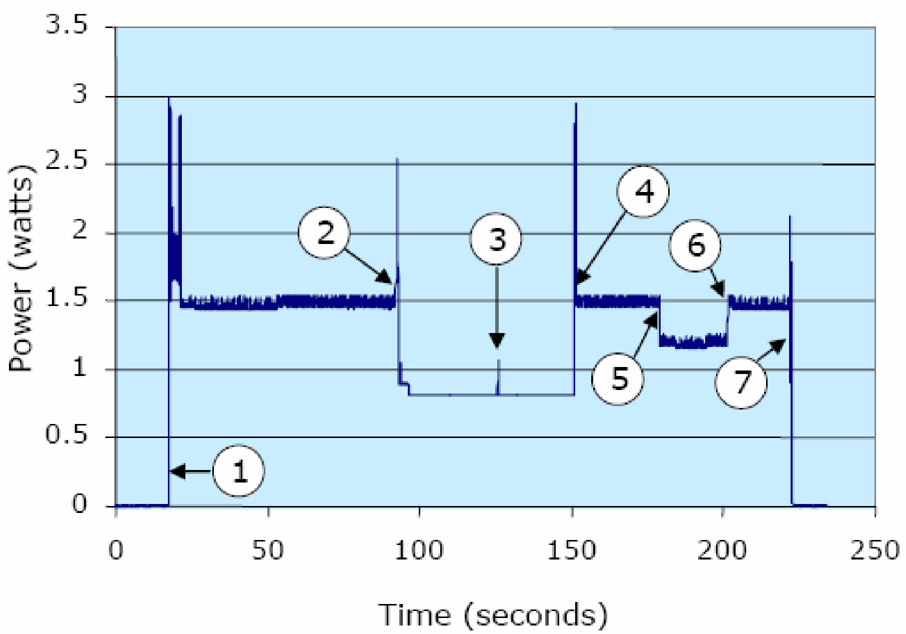
$$V = V_{OCV} - I \times R_{BAT}$$

Open Circuit Voltage Profile



Application to Digital Still Camera Load profile

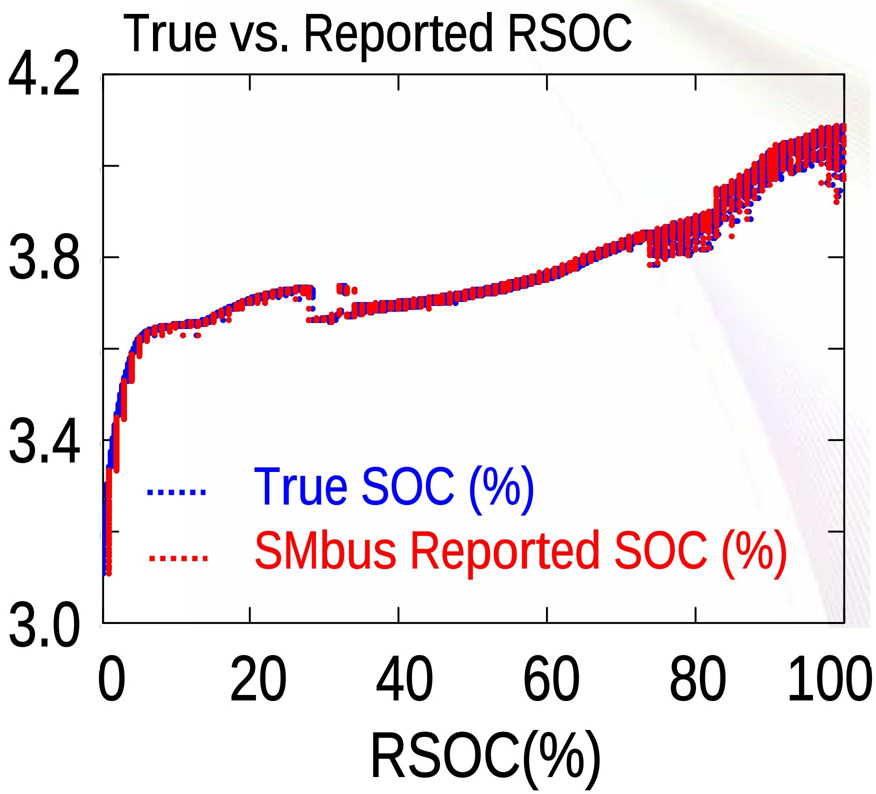
Power on/off sequence-record mode-play mode-display backlight

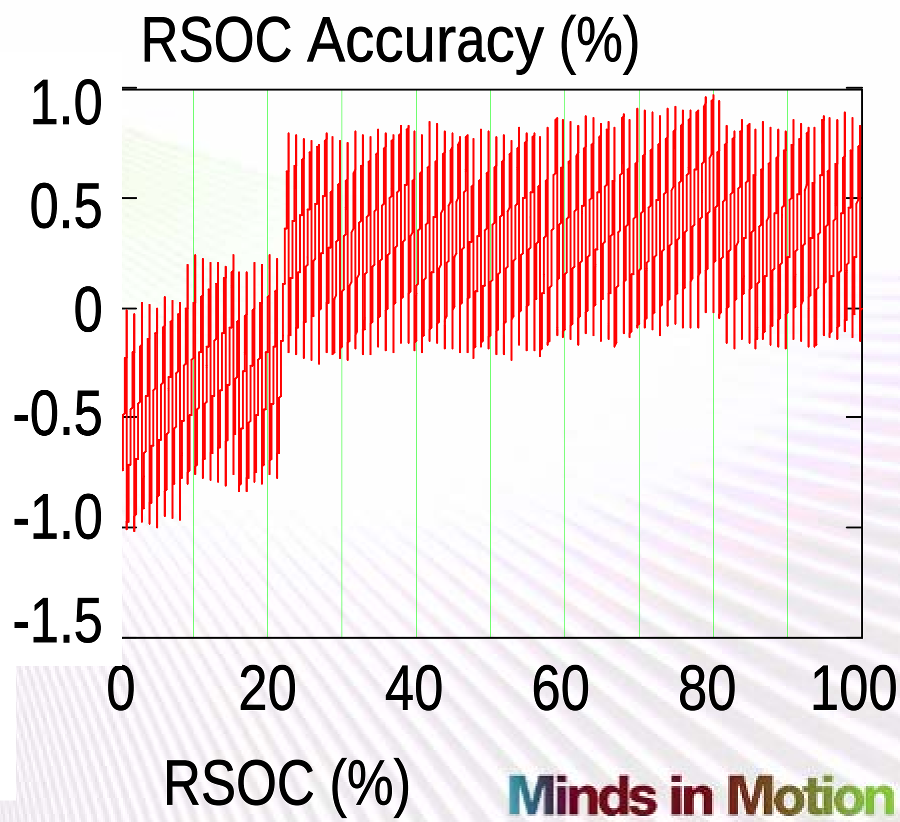


1. Turn power on – Camera comes up in "record mode" – Display backlight on.
2. Switch to "Play mode" – View photo.
3. View next photo.
4. Go back to "Record mode".
5. Turn display backlight off.
6. Turn display backlight back on.
7. Turn power off (by closing camera)

bq27350 System Test Results

- Single Li-Ion battery
- DSC-like load discharge profile
- 1% accuracy





Summary

- Battery authentication ensures the safety and satisfaction
- Charging is critical for battery cycle life and system operation
- Gas gauge:

  Voltage-based gas gauge: >50% error

  Coulomb-counting: 3-15%

  Impedance track gas gauge: 1% over battery life

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