Texas Instruments

TI POWER

TI *Live!* BATTERY MANAGEMENT SYSTEMS SEMINAR

DOMINIK HARTL

DEEP DIVE INTO TI'S IMPEDANCE TRACK™ TECHNOLOGY

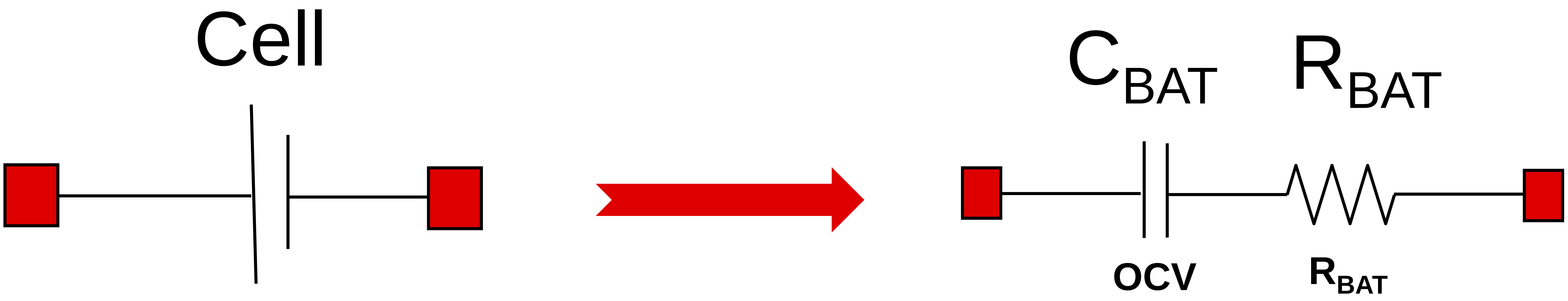
Agenda

- Lithium-ion (Li-ion) battery models.
- Fundamentals of gauging algorithms – Impedance Track™ technology.
- Impedance Track gauging configuration.

Li-ion battery models

Simple battery model

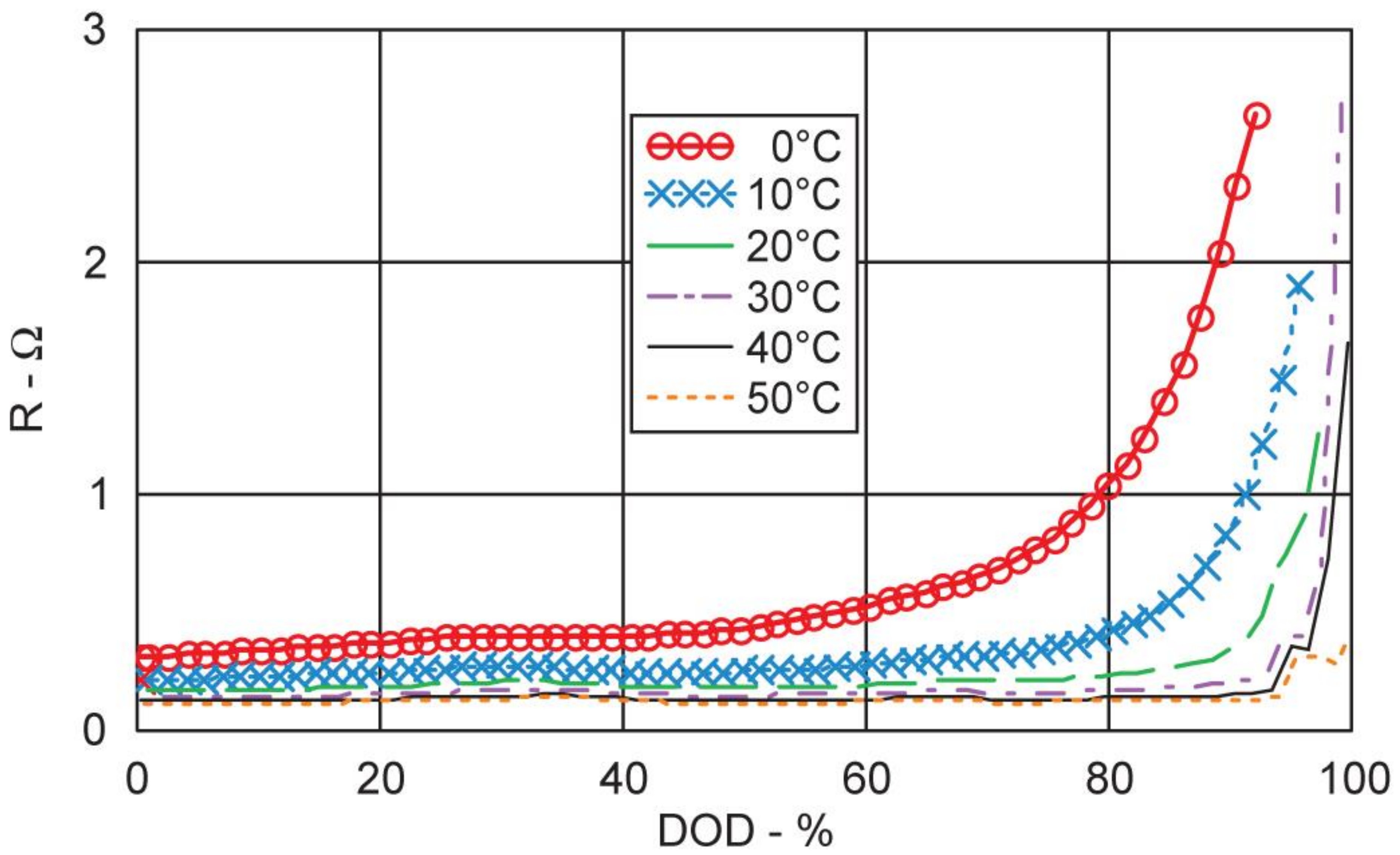
- A battery is a complex electrochemical system.
- A simple steady-state model can determine the full charge capacity.

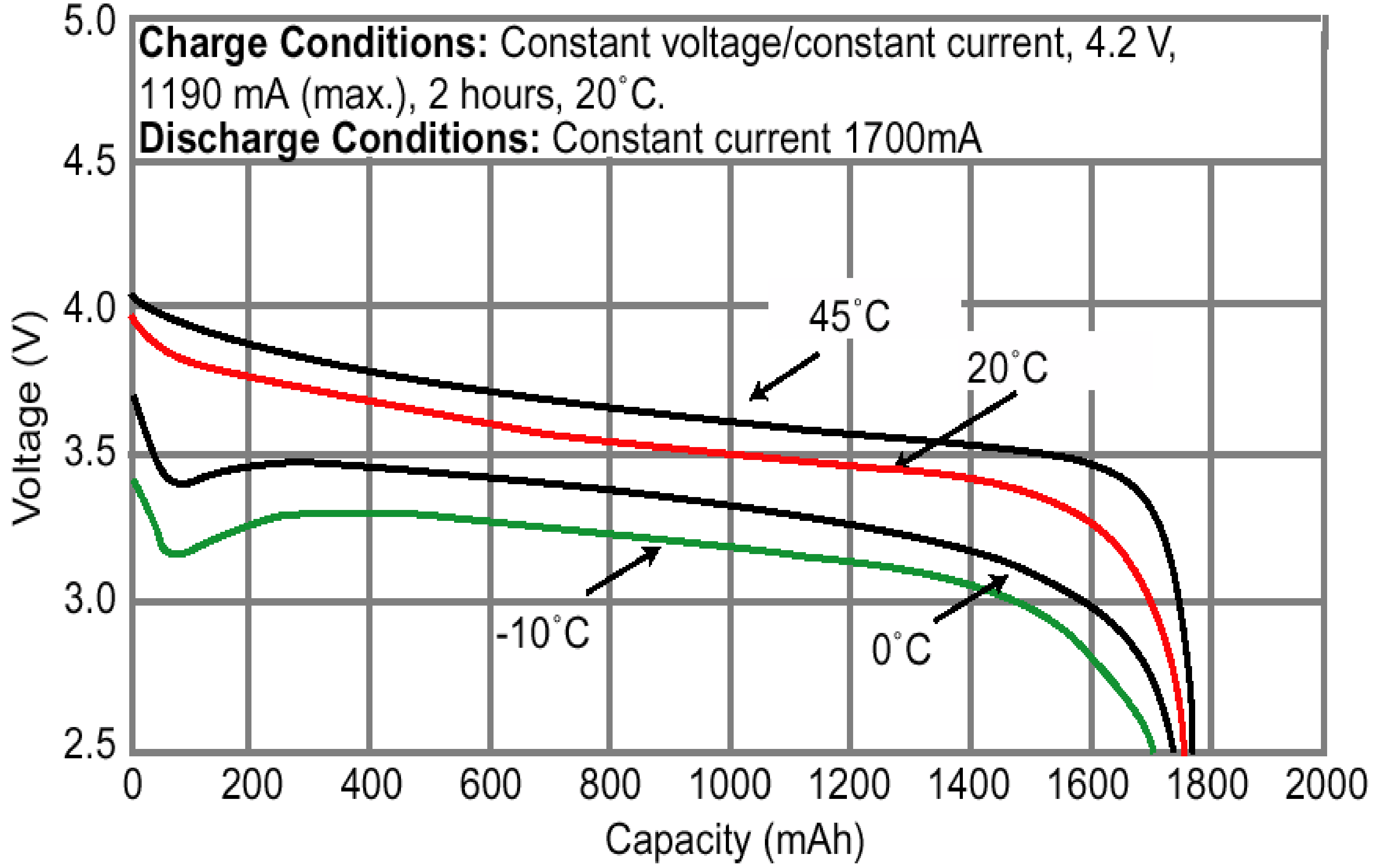


$V = OCV - I \times R_{BAT}$

Battery impedance strongly depends on temperature

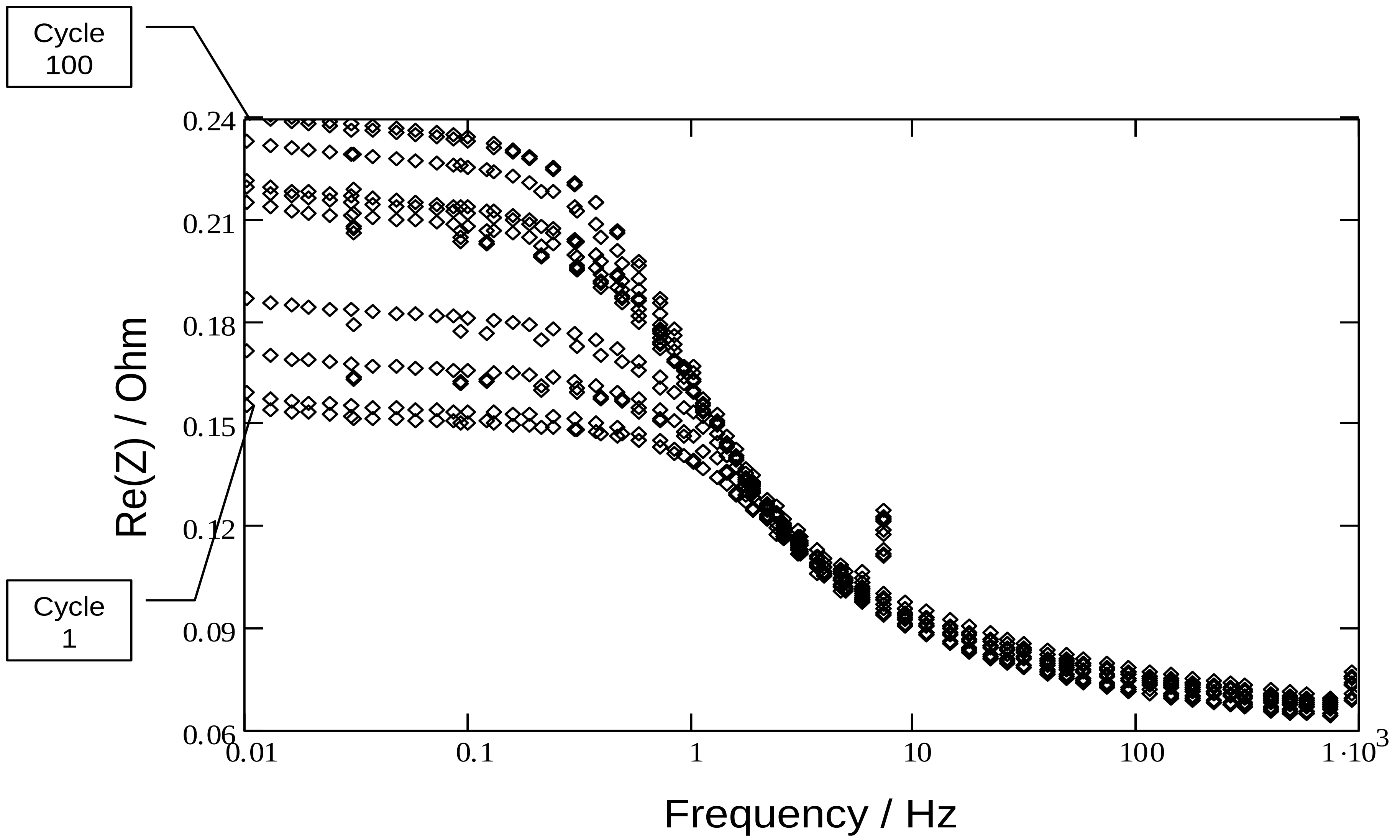
Impedance decreases about 1.5 times per 10°C increase

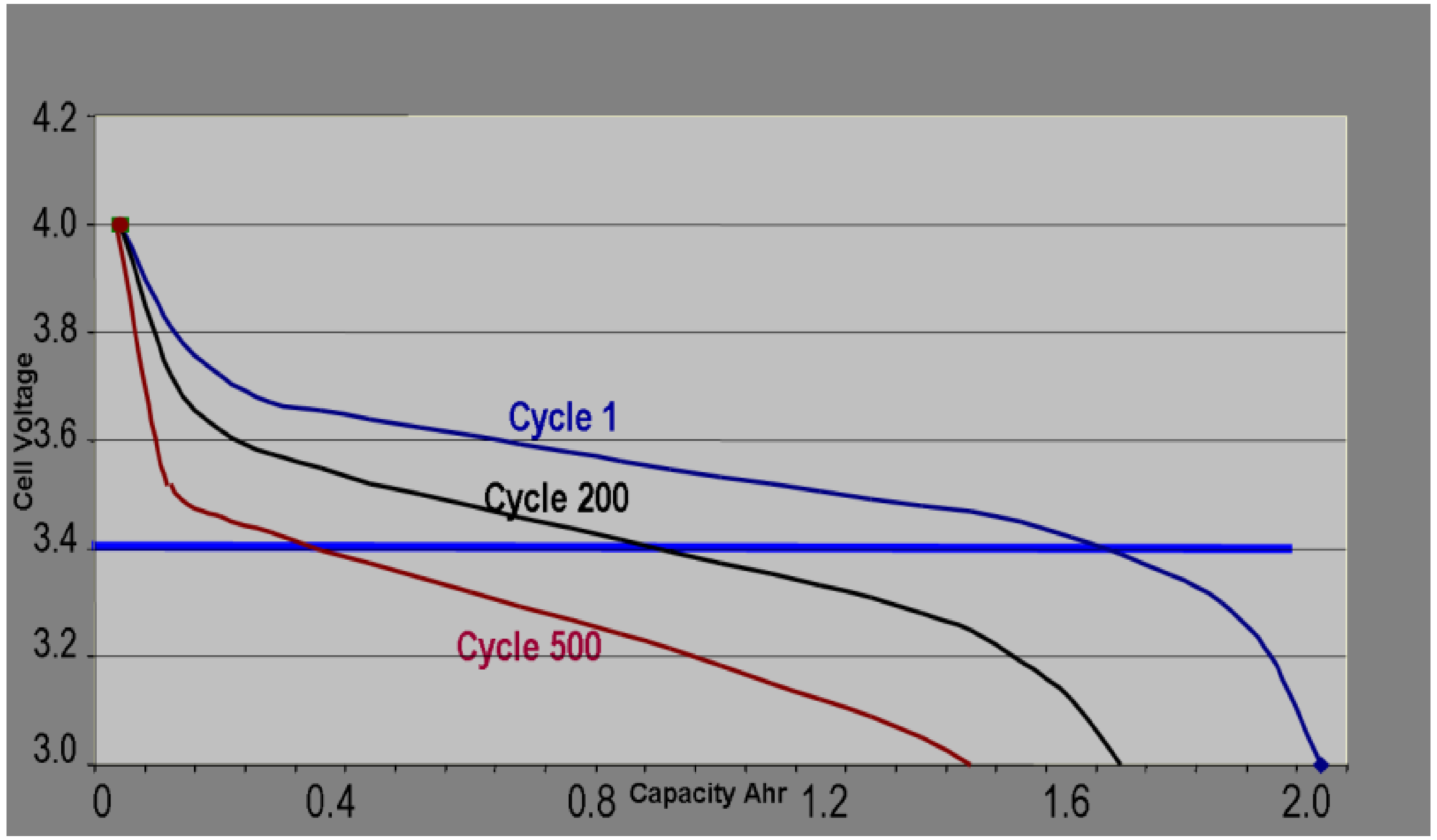




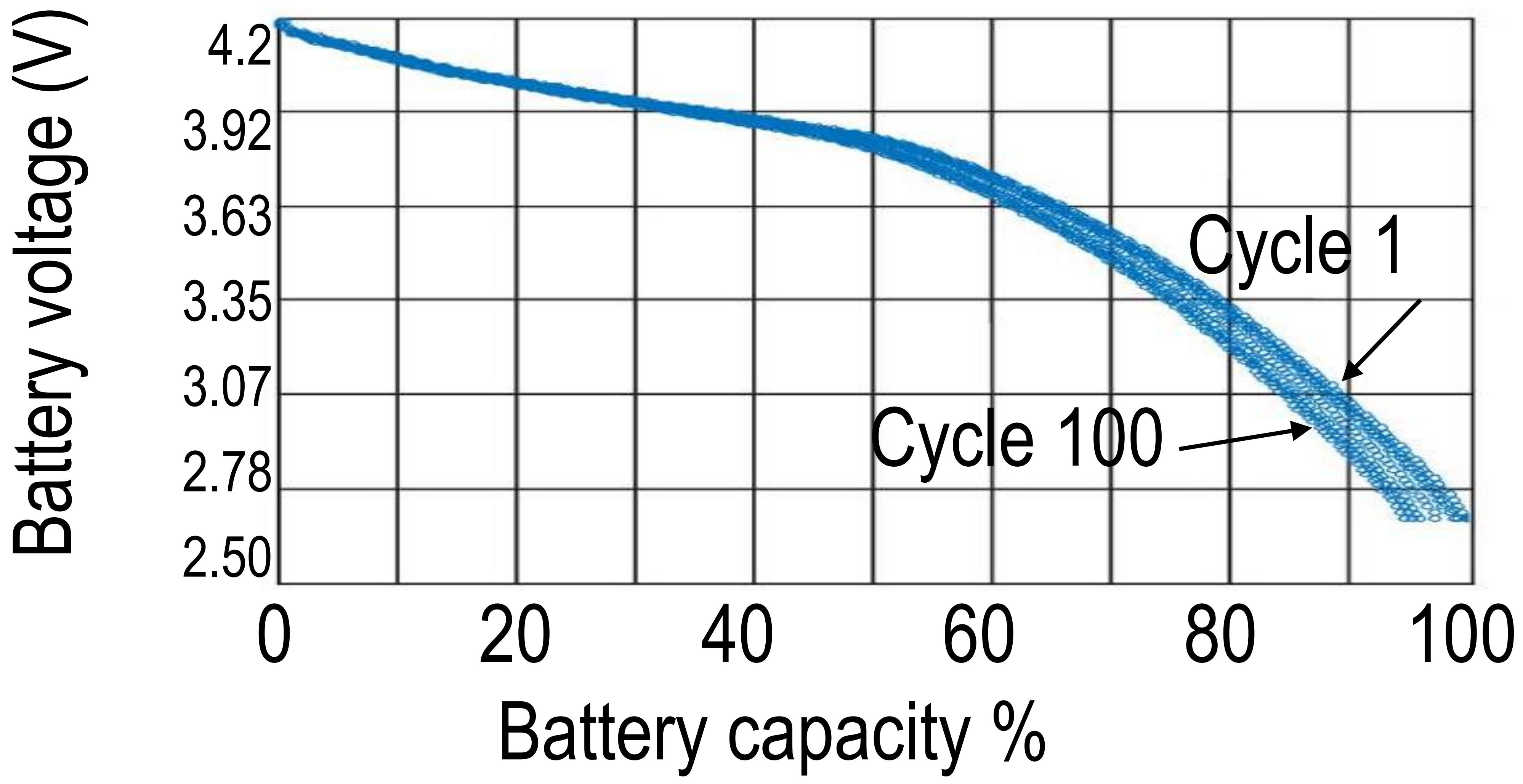
Battery impedance strongly depends on age

Impedance doubles after approximately 100 cycles





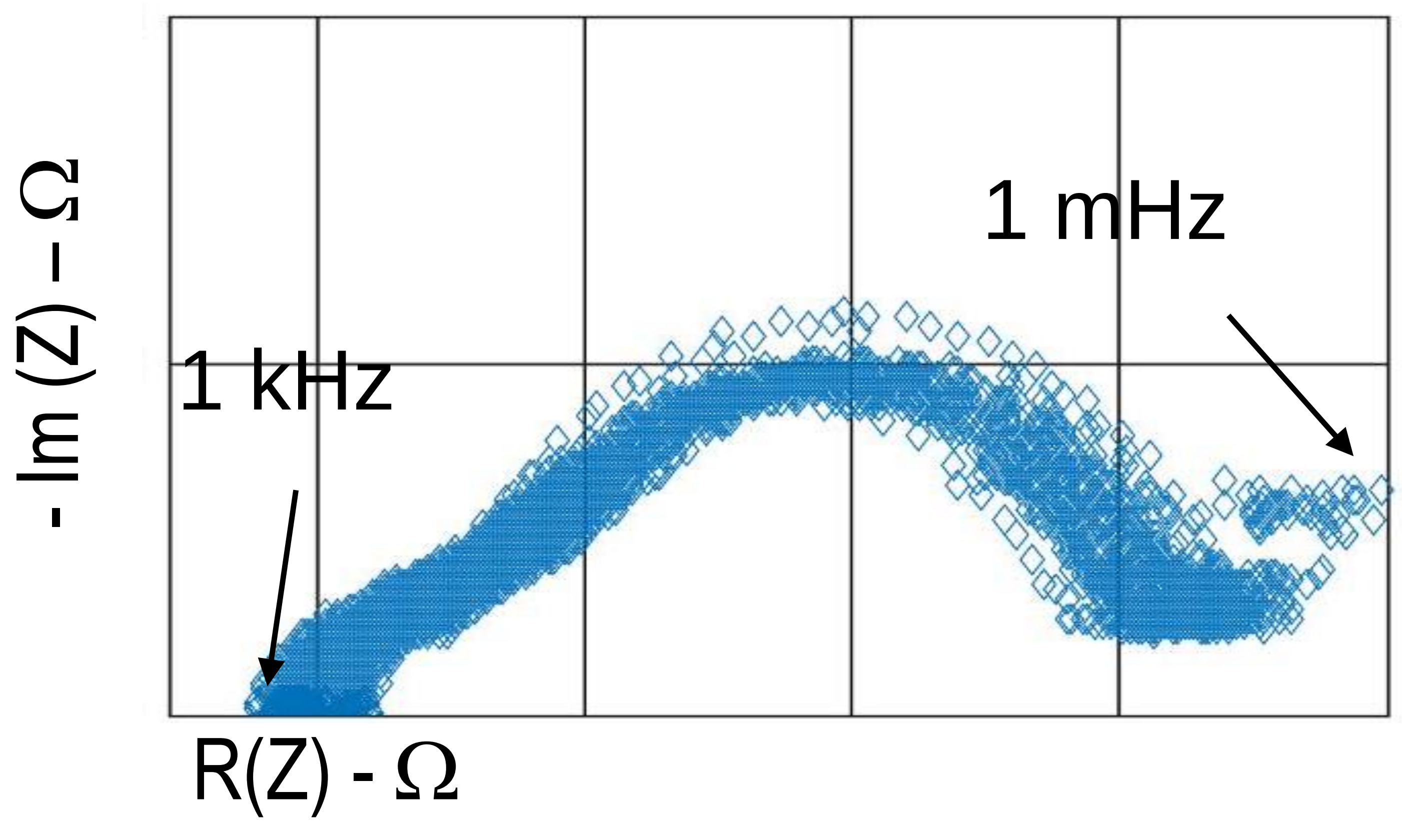
Chemical capacity (Q_{max}) decreases with age



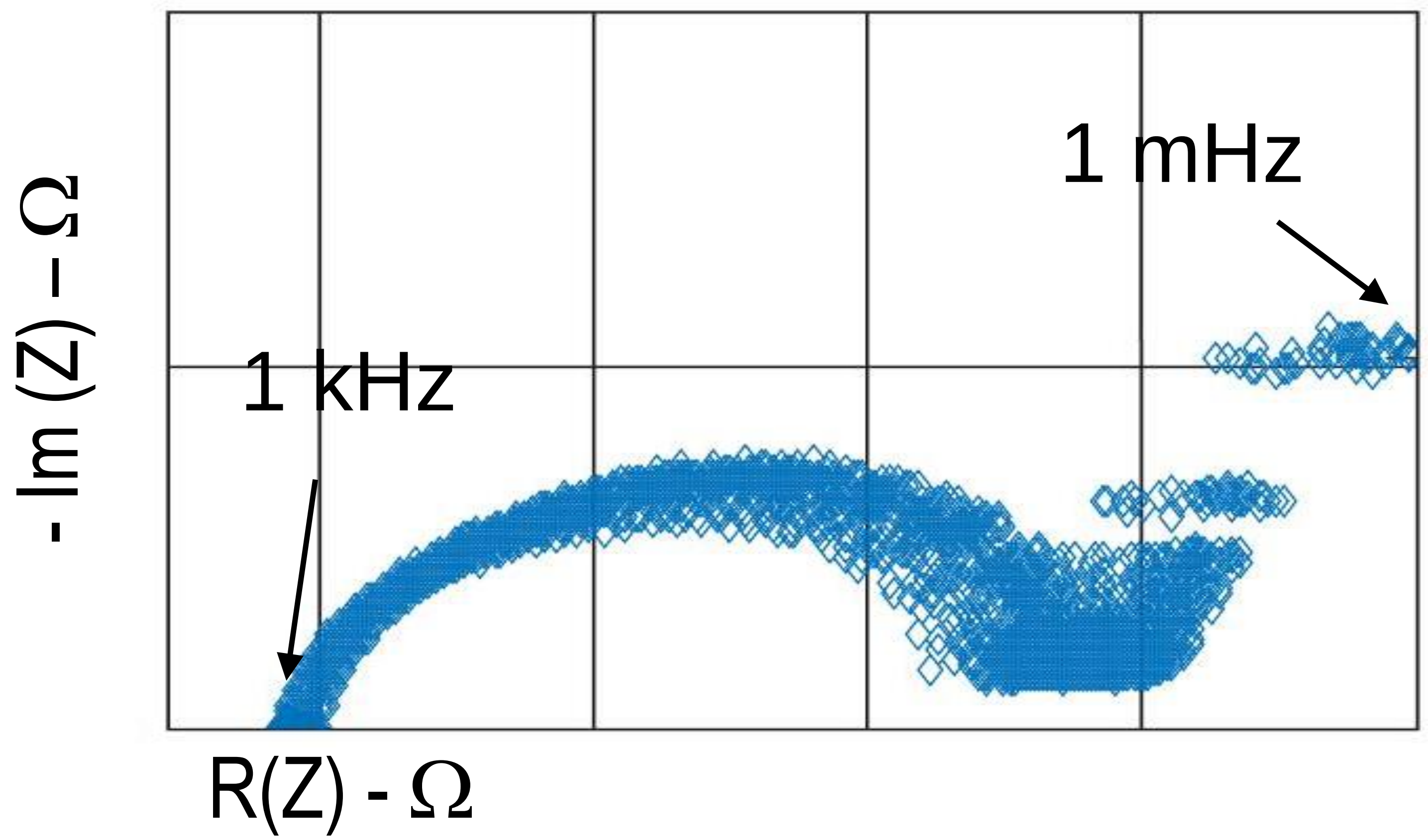
- Chemical capacity reduces by 3% to 7% after 100 cycles.
- Hence, it is very important to update Q_{max}.

Cell-to-cell variation

Manufacturer 1



Manufacturer 2

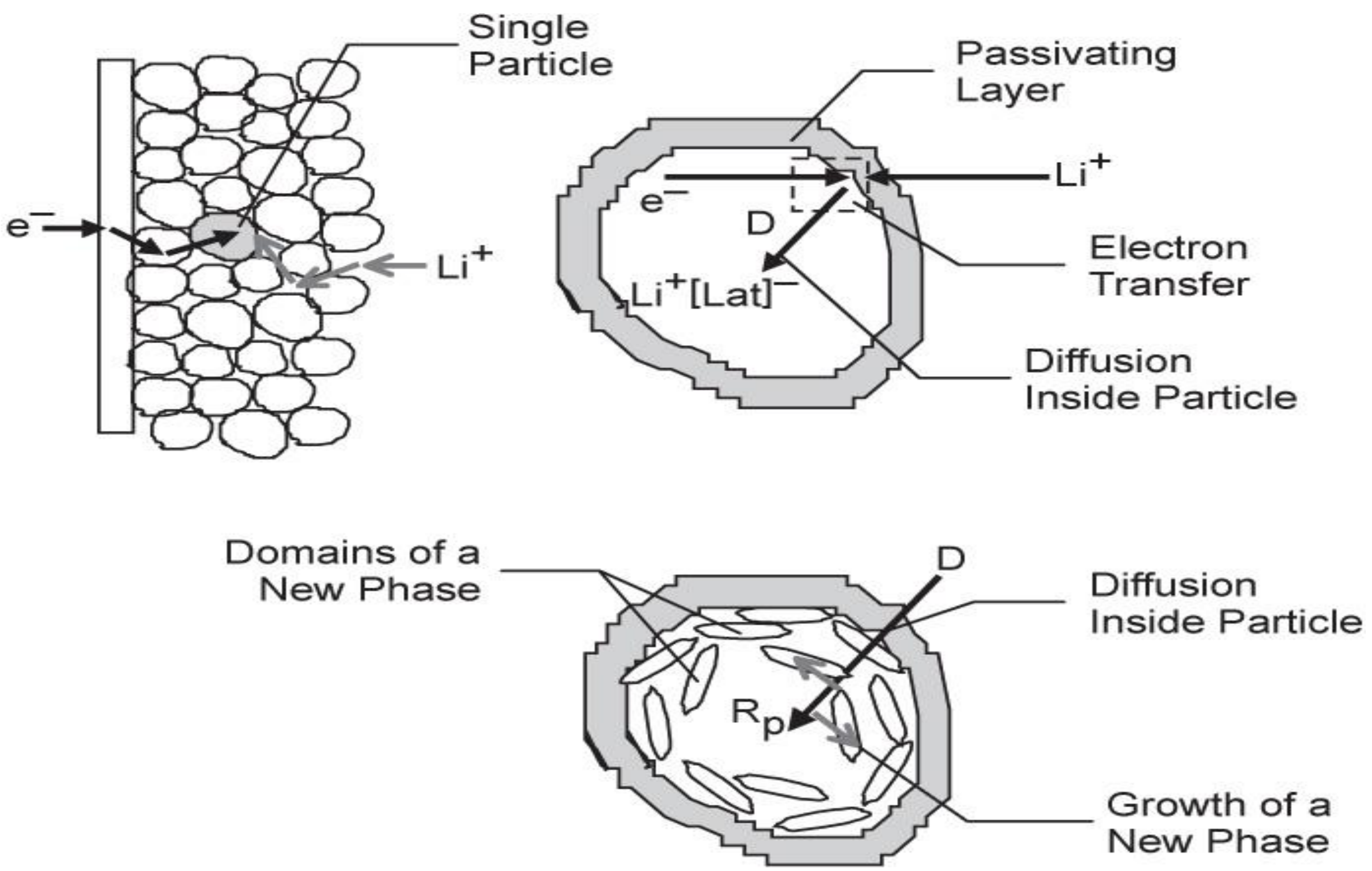


- Low-frequency (1 mHz) impedance variation: can be significant 15%.
- At a 1C rate discharge, a 40-mV difference may cause a maximum state-of-charge error of ±26%.

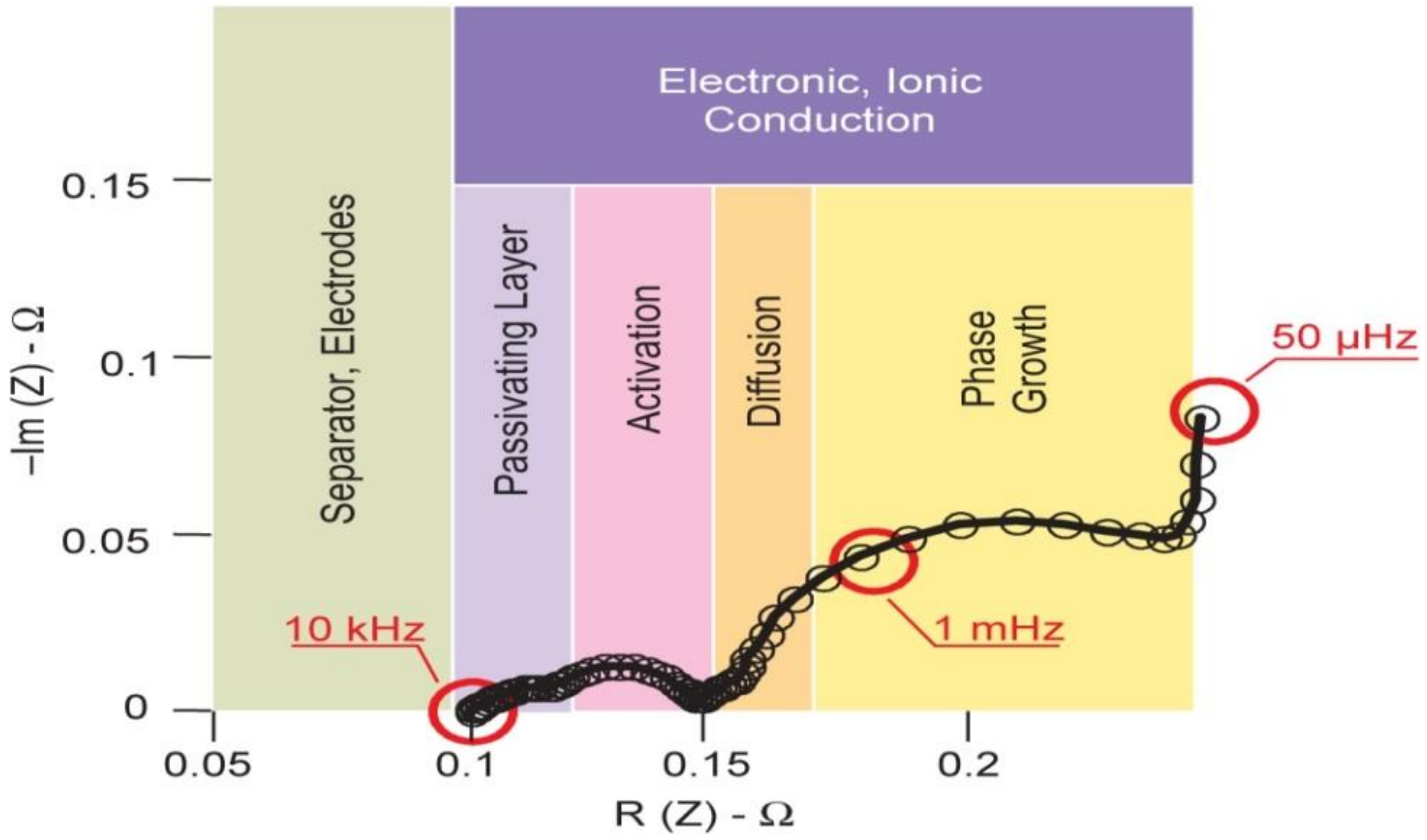
A Li-ion battery is a complex electrochemical system

The battery impedance spectrum corresponds to a complex impedance function Z(s)

Kinetic steps in Li-ion battery



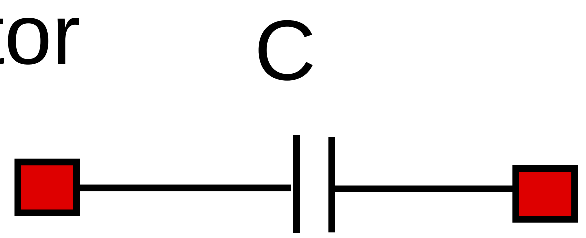
Corresponding impedance spectrum



Source: Barsoukov, E., J.H. Kim, D.H. Kim, K.S. Hwang, C.O. Yoon, and H. Lee. 2000. "Parametric Analysis Using Impedance Spectroscopy: Relationship Between Material Properties and Battery Performance." Published in *Journal of New Materials for Electrochemical Systems* 3, no. 4 (October 2000): pp. 301-308.

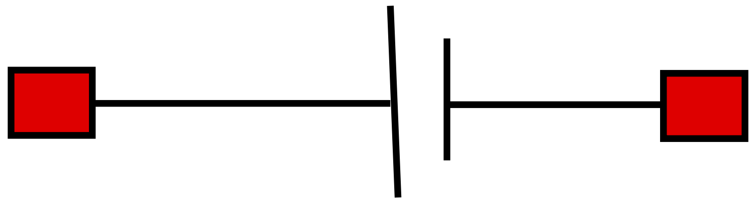
Transient response

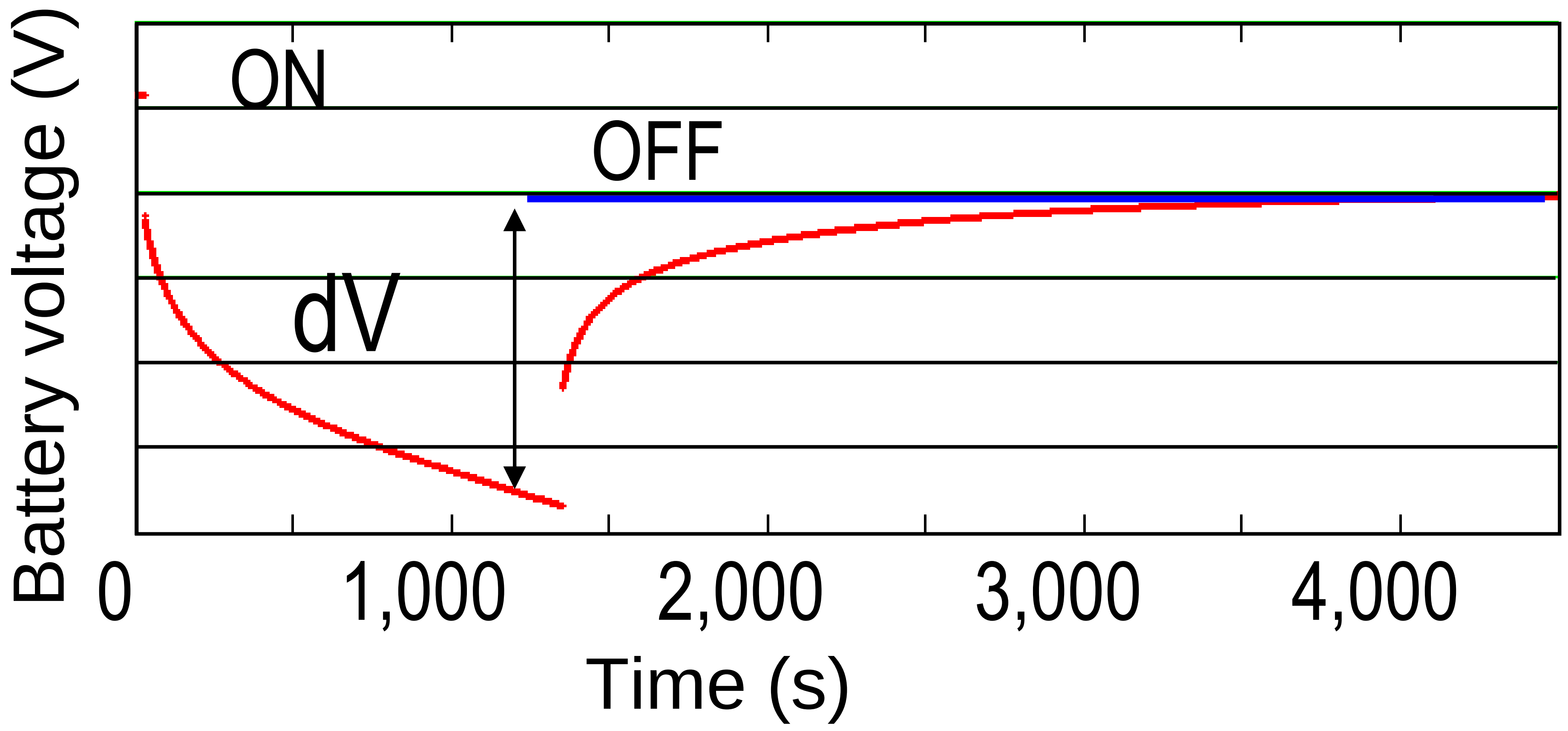
Capacitor



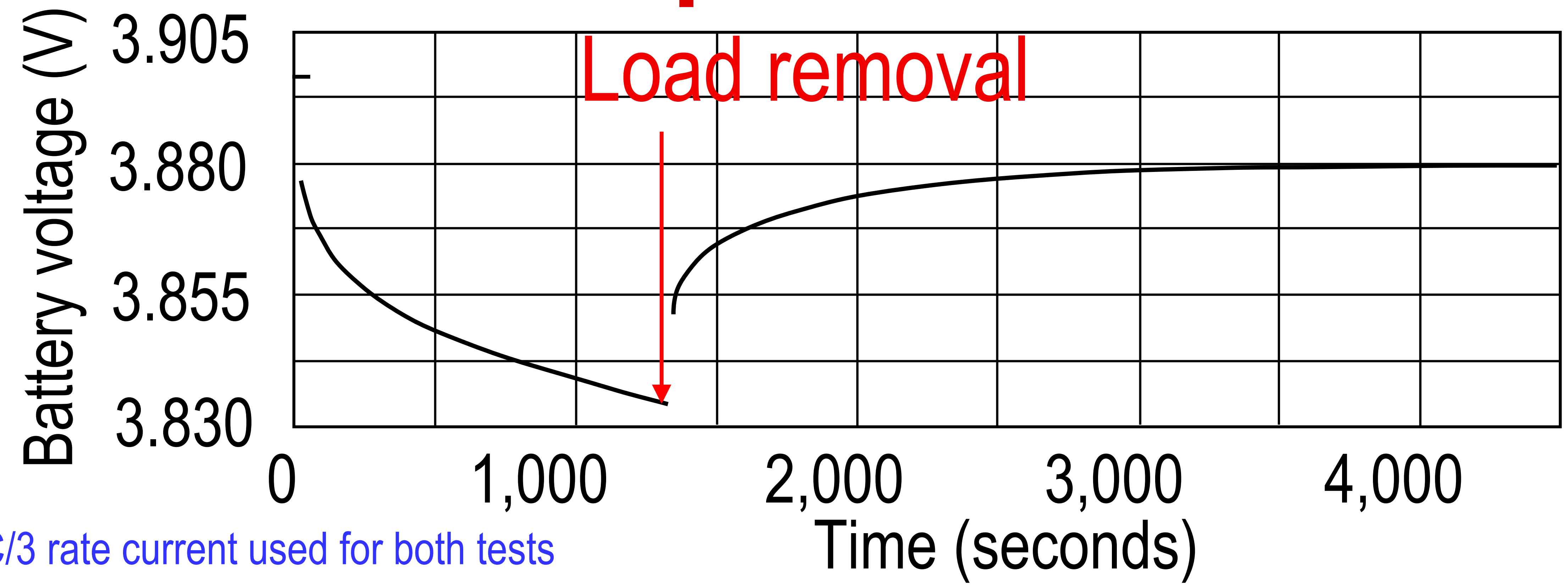
Capacitor + resistor

Battery

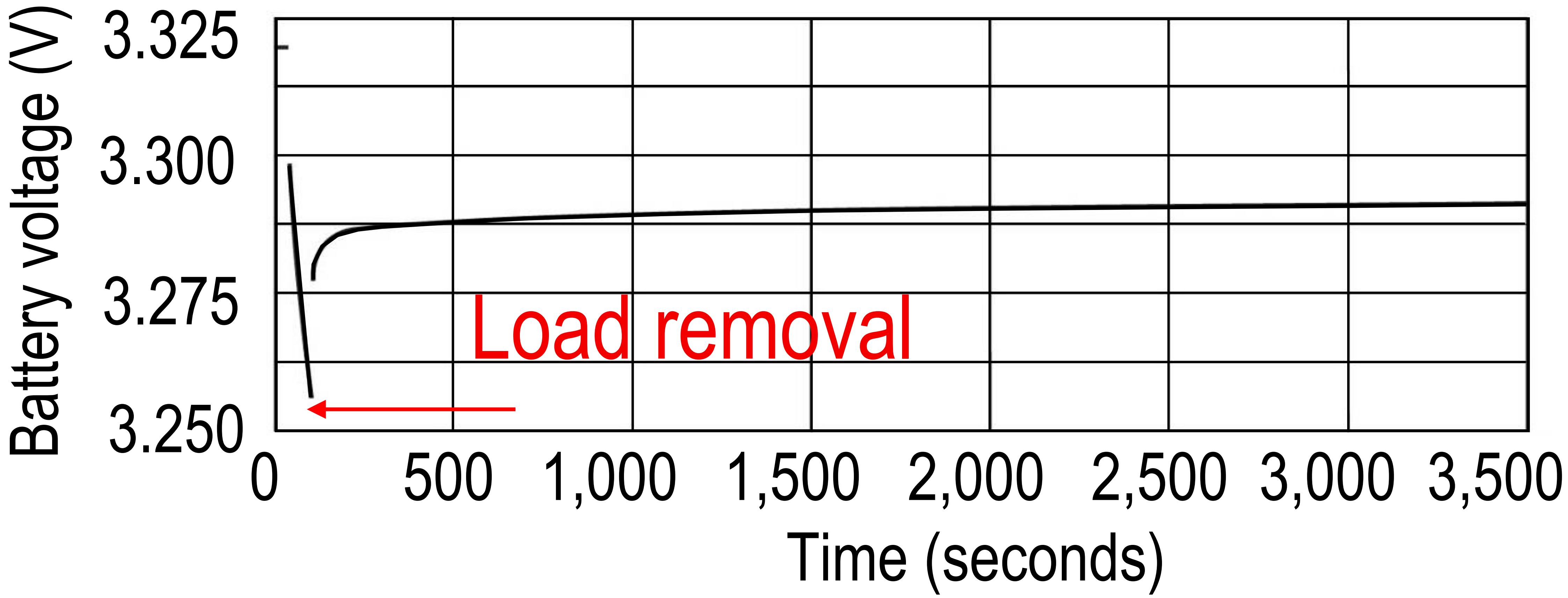




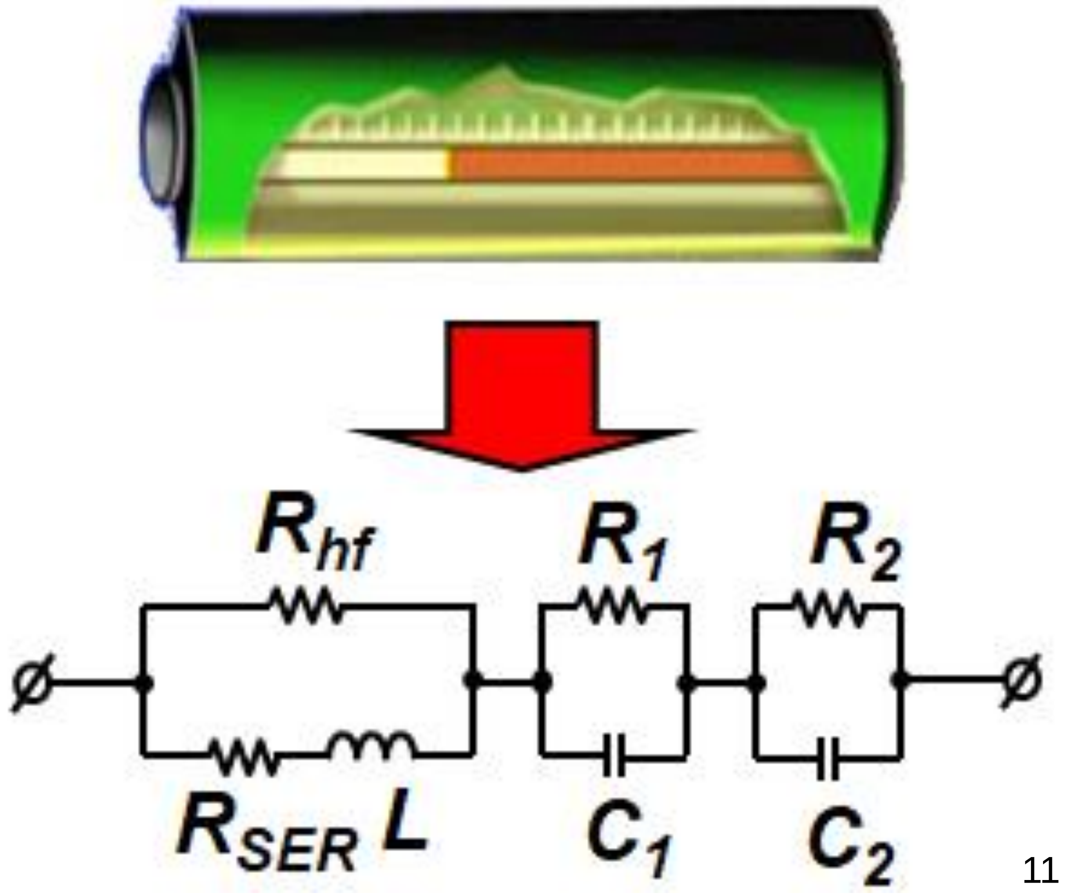
Transient response



*C/3 rate current used for both tests



- Complete relaxation takes about 2,000 seconds.
- Different voltage at different instants.
- Voltage difference between 20 and 3,000 seconds is over 20 mV.

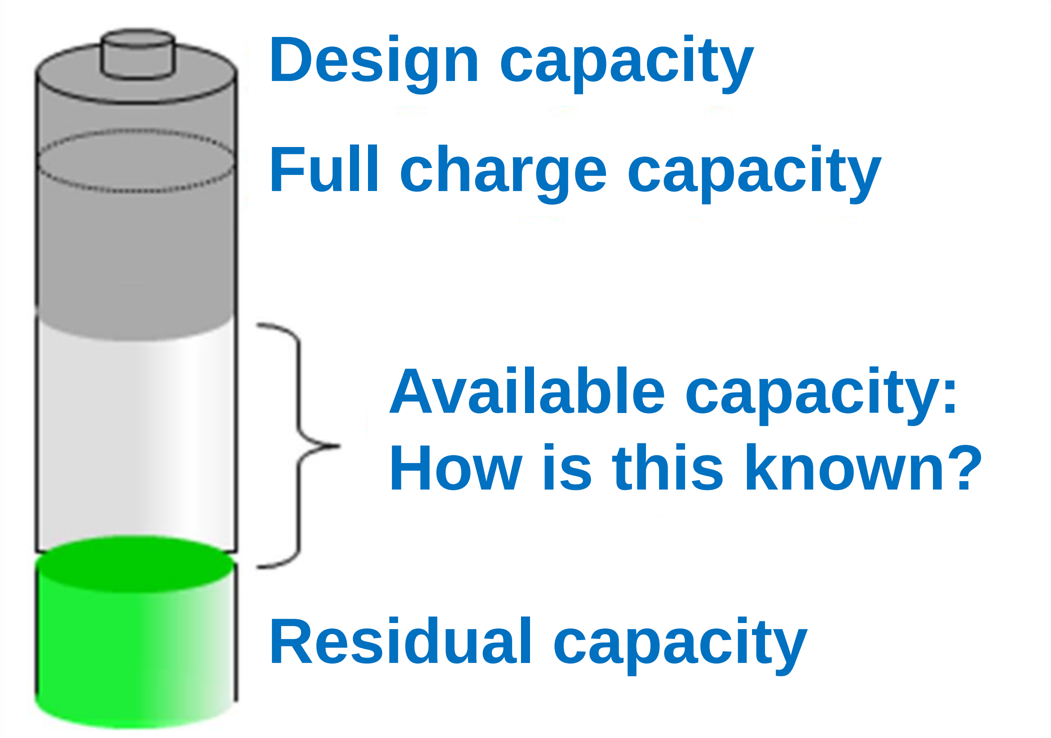


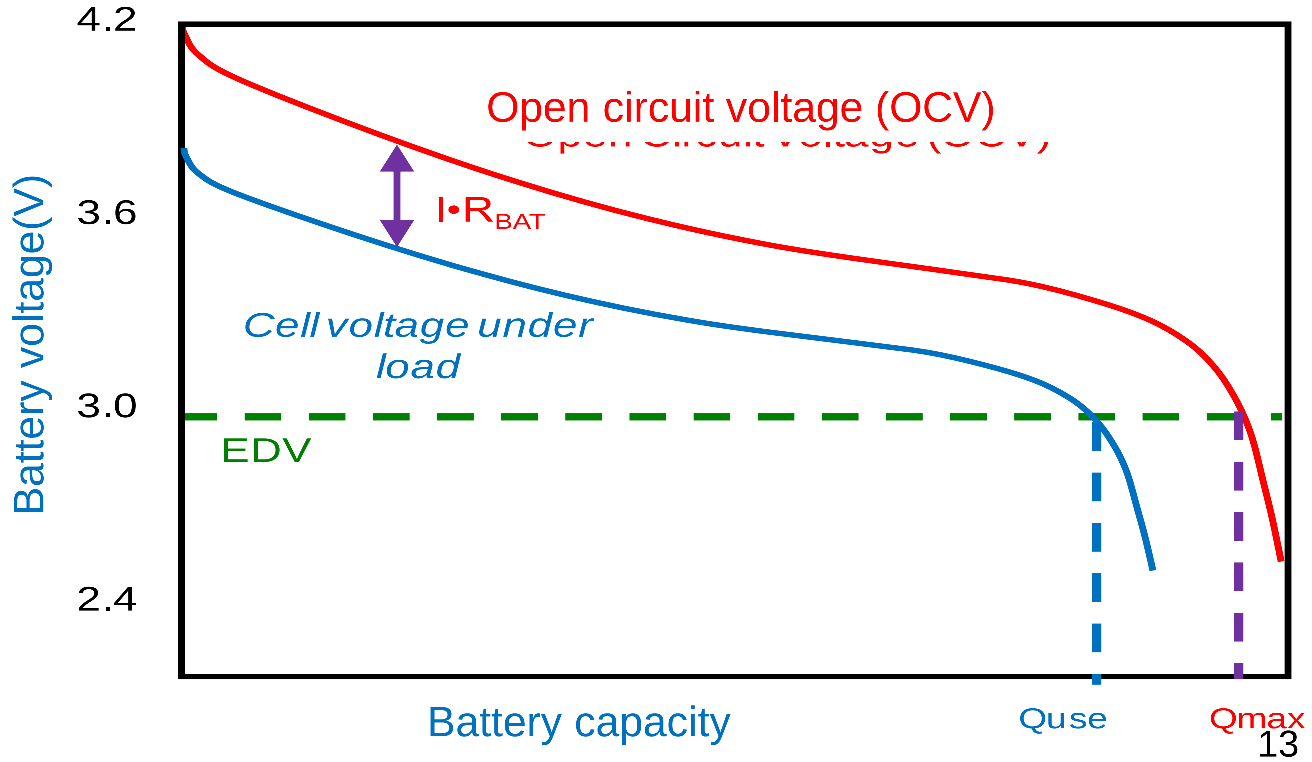
Fundamentals of gauging algorithm – Impedance Track technology

Impedance Track technology

- The Impedance Track algorithm incorporates:
  - Voltage-based gauge: accurate gauging under no load.
  - Coulomb counting: accurate gauging under load.
  - Real-time impedance updates.
  - Remaining runtime calculations.
  - State-of-health calculations.

- Uses **impedance, discharge rate** and **temperature** to calculate the usable capacity, also known as the full charge capacity.





What are the main characteristics of Impedance Track technology?

1. Chemistry table in data flash:

   OCV = f (DOD,T); R = g(DOD,T)

2. Update maximum chemical capacity for each cell:

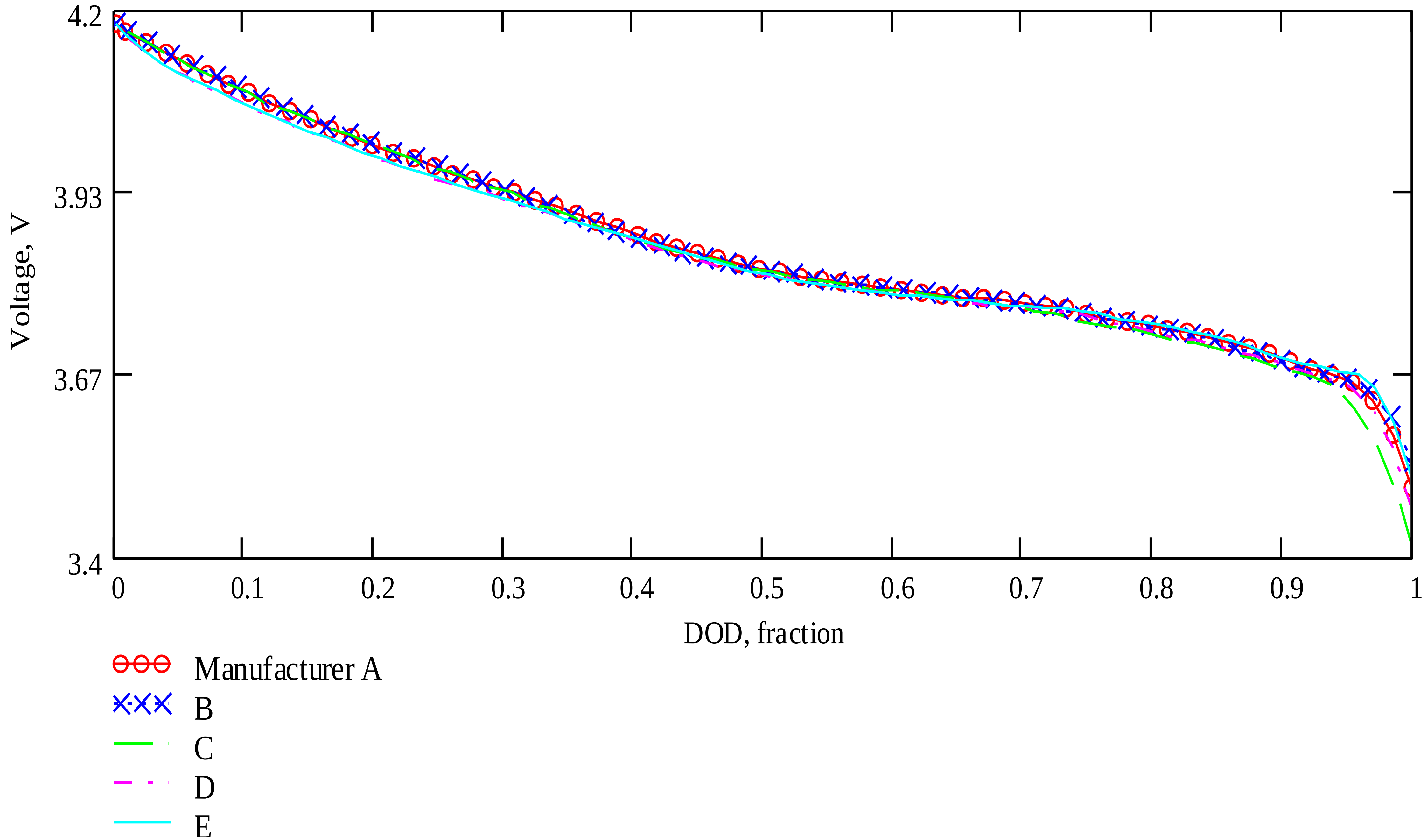
   $$Q_{max} = \frac{PassedCharge}{(DOD1 - DOD2)}$$

3. Impedance learning during discharge:

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

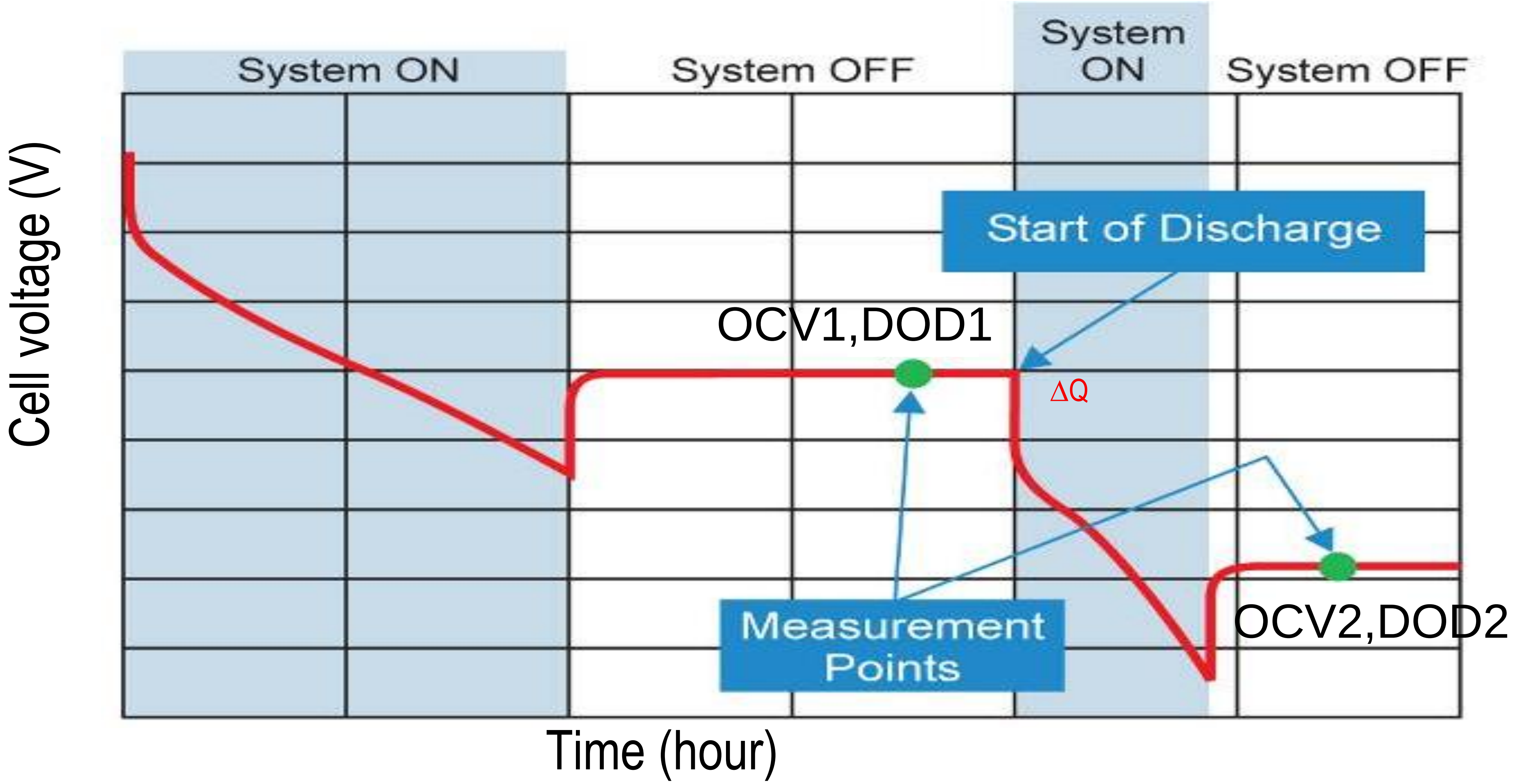
4. Run periodic simulations to update predictions of remaining and full charge capacity.

OCV



- Data flash contains the OCV tables.
- OCV profiles can be very consistent if the base cathode electrode chemistry is the same, such as LCO, NMC, LFP, etc.
- You can use the same OCV database with batteries produced by different manufacturers if the base chemistry is the same.

Measuring OCV and updating Q_{max}

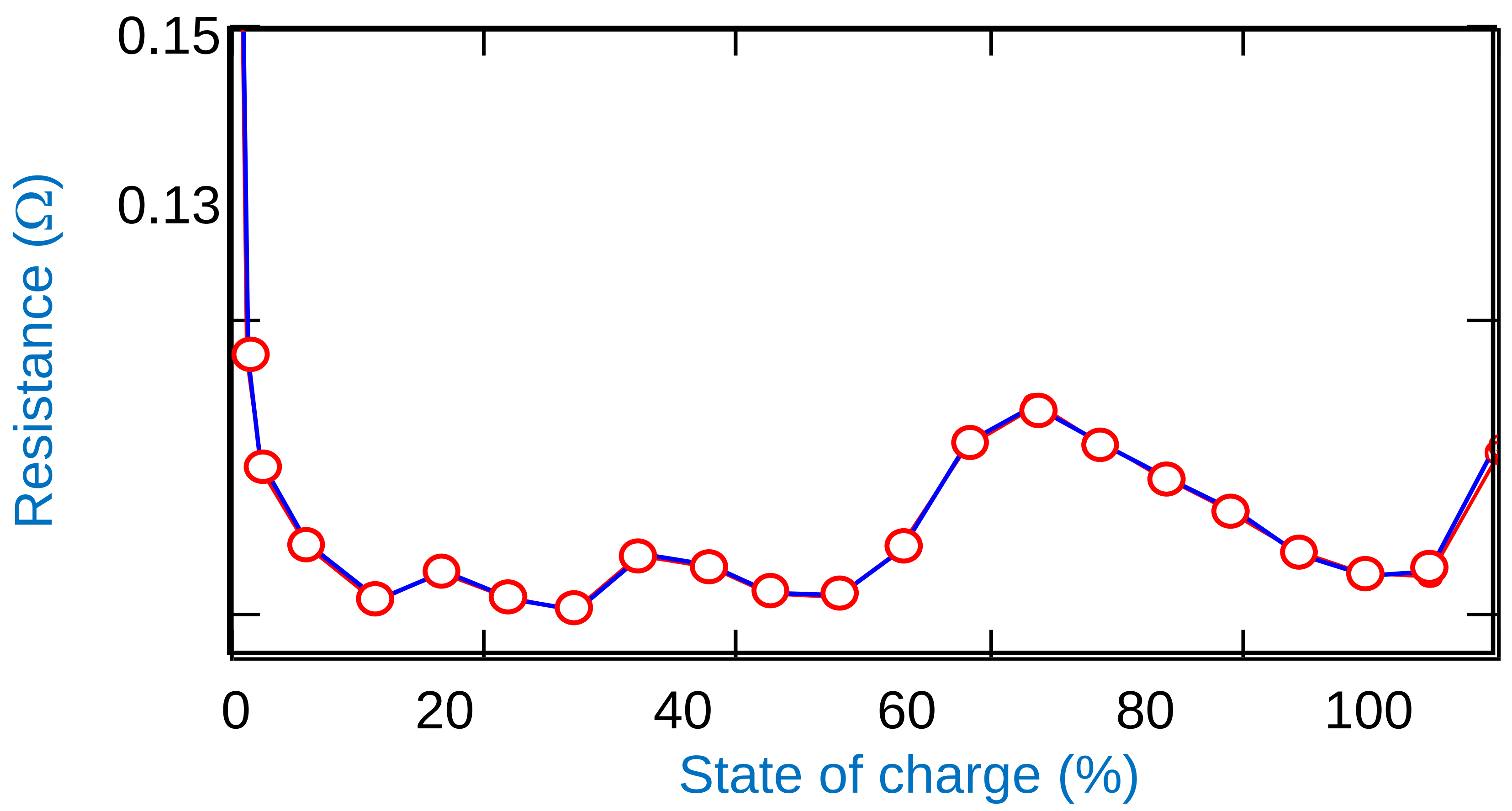


- Passed charge is determined by Coulomb counting.
- DOD1 and DOD2 computed from the measured OCV.

$$Q_{max} = \frac{\Delta Q}{DOD2 - DOD1}$$

Measuring and updating resistance

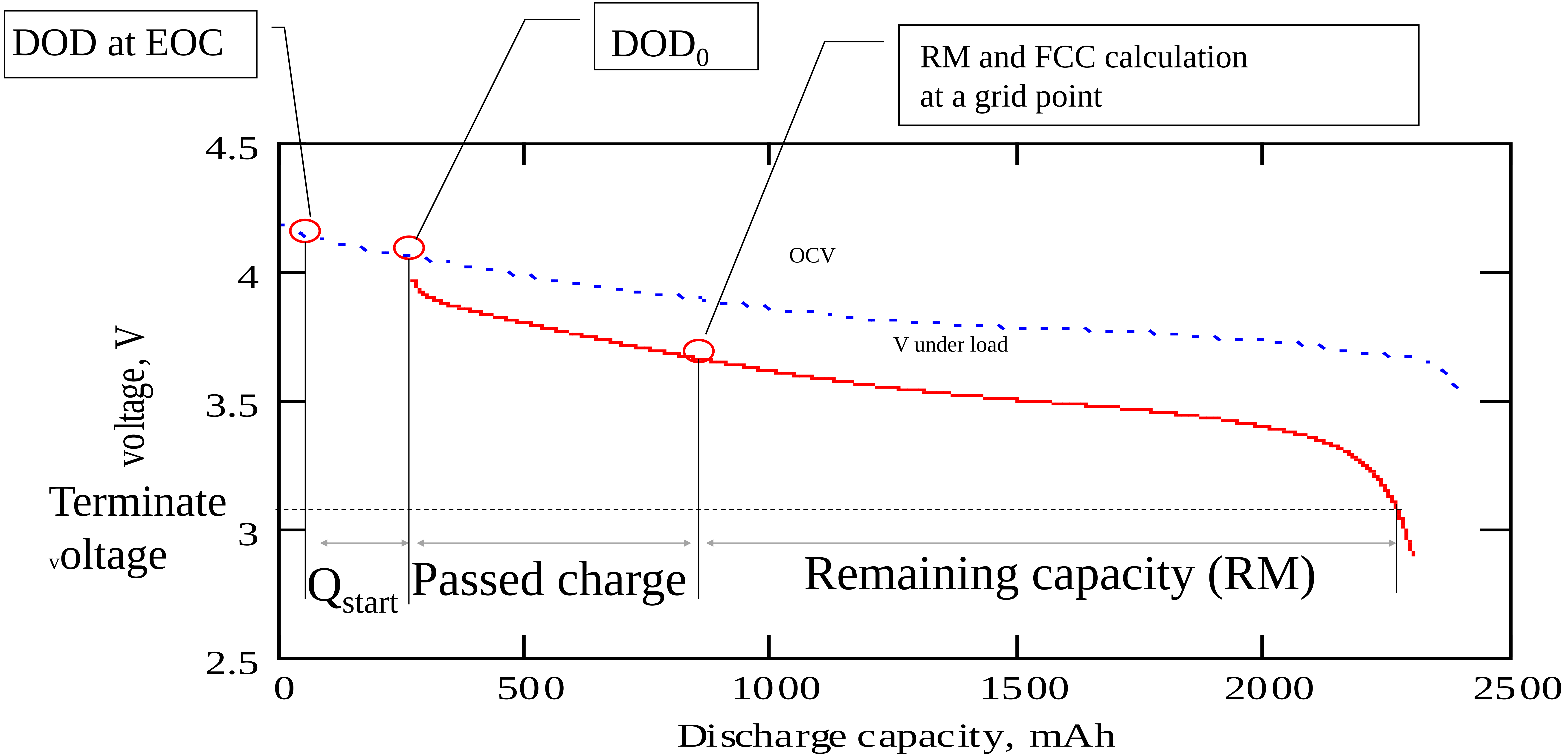
- Data flash contains a fixed table: R_a = f (state of charge, T).



- Resistance is measured in real time and R_a tables are updated:

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

Simulation to find RemCap and FCC



What are the main advantages of Impedance Track technology?

- **Dynamic learning ability**
  - Temperature variability in applications:
    - Impedance Track technology considers cell impedance changes caused by a temperature increase/decrease.
    - Impedance Track technology incorporates thermal modeling to adjust for self-heating.
  - Load variation:
    - Impedance Track technology will keep track of voltage drops caused by high load spikes.
- **Aged battery**
  - Impedance Track technology can adjust for changes in usable capacity caused by cell aging.
- **Increased run time**
  - A lower terminate voltage can be used with an Impedance Track technology-based gauge.
- **Flexibility**
  - Cell characterization.
  - Host system does not need to perform any calculations or gauging algorithms.

Impedance Track technology gauging configuration

Impedance Track gauge configuration

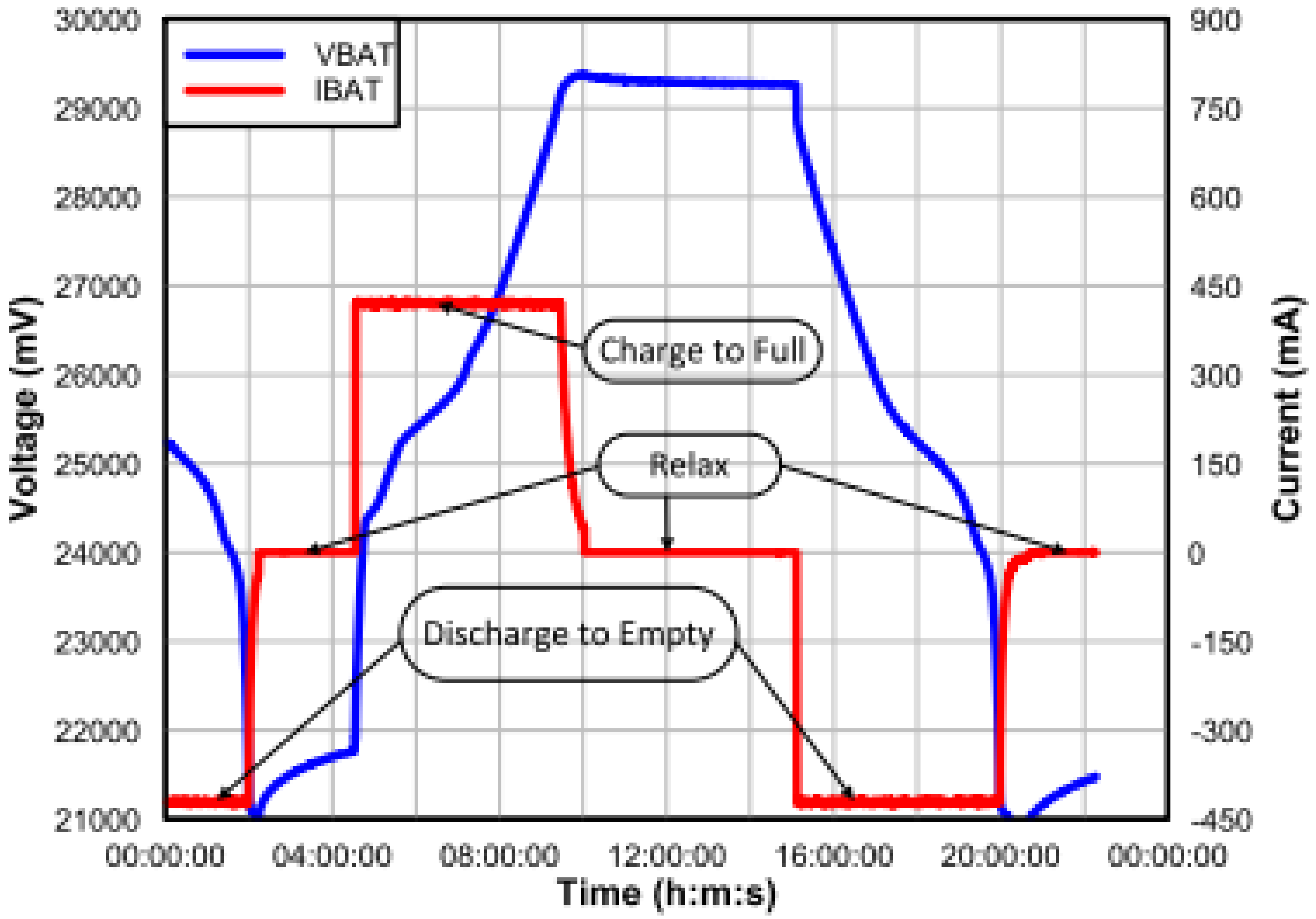
- The best performance from Impedance Track technology-based gauges can be obtained through the correct configuration:
  - Determine and program the correct ChemID.
    - Create relax-discharge-relax logs and use the gauging parameter calculator (GPC) GPCCHEM selection tool to identify a close match.
    - If no match, send cells to TI to characterize and create a new ChemID.
  - After programming the ChemID, perform a learning cycle (optimization cycle) to learn the R_a and Q_{max} values and finalize the golden image.

Before performing the learning cycle

- Make sure to enter the correct values for the following parameters:
  - Design capacity.
  - Design voltage.
  - Charge term taper current.
  - Discharge (Dsg) current threshold.
  - Charge (Chg) current threshold.
  - Quit current.
  - Term voltage.

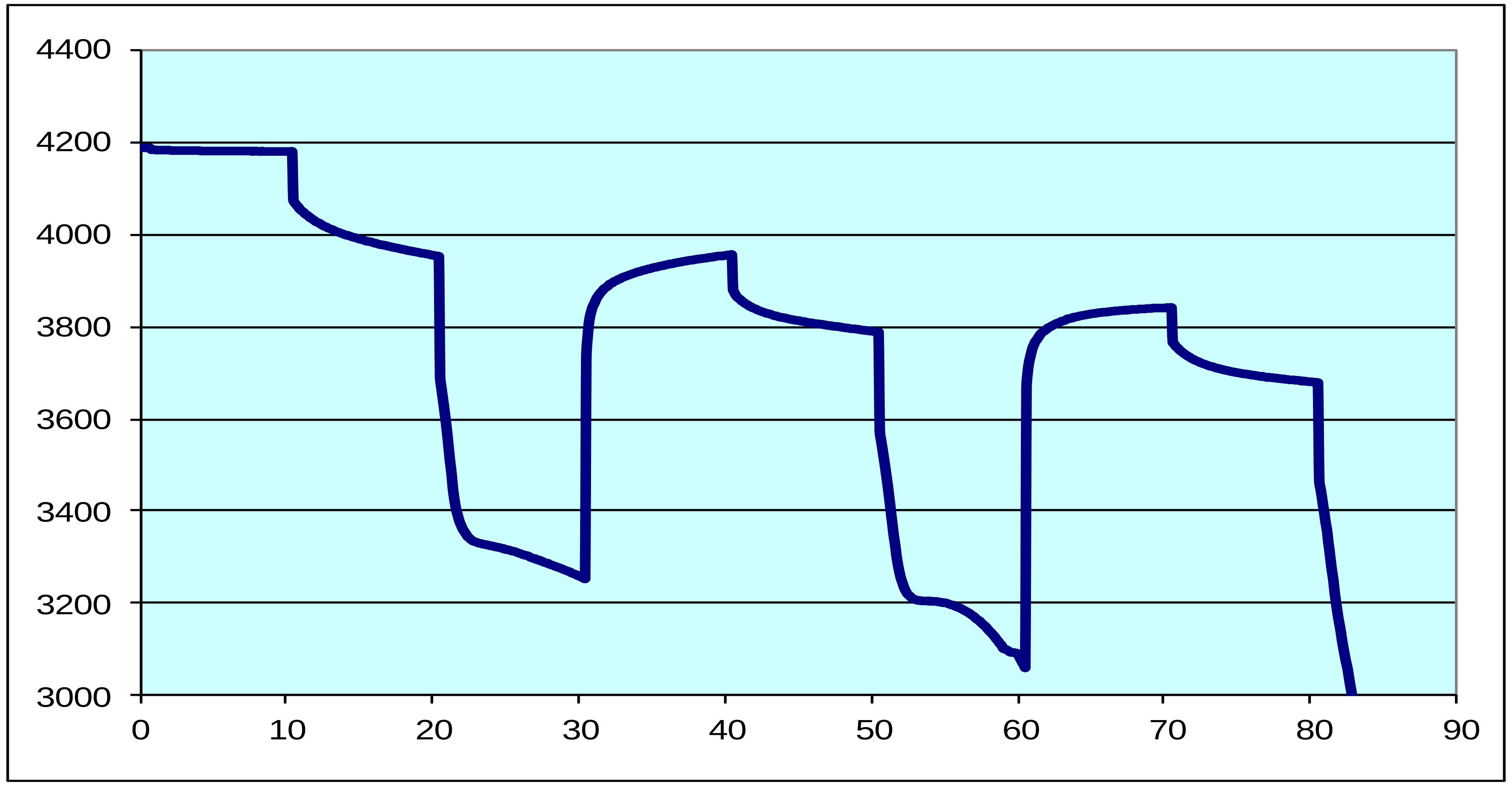
Learning cycle procedure

- Discharge battery to empty.
- Relax for at least 5 hours:
  - Enable Impedance Track algorithm (0x21).
  - Update status changes from 00 to 04.
- Charge battery to full.
- Relax for at least 2 hours:
  - Q_{max} updates at this point.
  - Update status changes to 05.
- Discharge battery to empty using rate between C/10 and C/5:
  - Resistance tables update during the discharge cycle.
- Relax for at least 5 hours:
  - Update status changes to 06.



http://www.ti.com/lit/an/slua903/slua903.pdf

How to improve performance for dynamic loads



- Symptom:
  - Gauge jumps to 0% when the load current suddenly increases.
- Possible causes:
  - Voltage dropped below terminate voltage with heavier current.
  - Gauge updates prediction with new heavier load and expects that “empty” will be reached immediately.

Fuel gauge configuration: Load mode

- Do **not** increase terminate voltage as a further guard band!
- If possible, lower the terminate voltage. Trust Impedance Track technology!
- **Change Load Mode and Load Select to another option.**

Load mode = 0

- Gauge will use a constant current load for simulations.

Load mode = 1

- Gauge will use a constant power load for simulations.
- Most systems use switched-mode DC/DC converters.
- As the battery voltage decreases, the current draw will increase to maintain constant power ($P = I \times V$).

Fuel gauge configuration: Load select

- **Load select** tells the gauge what load to assume for simulations.

  – If **load mode = 0 (constant current):**
    - 0 = Avg I Last Run
    - 1 = Present average discharge current (average over entire discharge)
    - 2 = Current
    - 3 = AverageCurrent
    - 4 = DesignCapacity/5
    - 5 = AtRate (mA)
    - 6 = User-Rate-mA

  – If **load mode = 1 (constant power):**
    - 0 = Avg P Last Run
    - 1 = Present average discharge power
    - 2 = Current x Voltage
    - 3 = AverageCurrent x Average Voltage (average over entire discharge)
    - 4 = DesignEnergy/5
    - 5 = AtRate (10 mW)
    - 6 = User-Rate-mW

How to improve performance at low temperatures

Symptom:

- State of charge jumps to 0% at low temperatures.

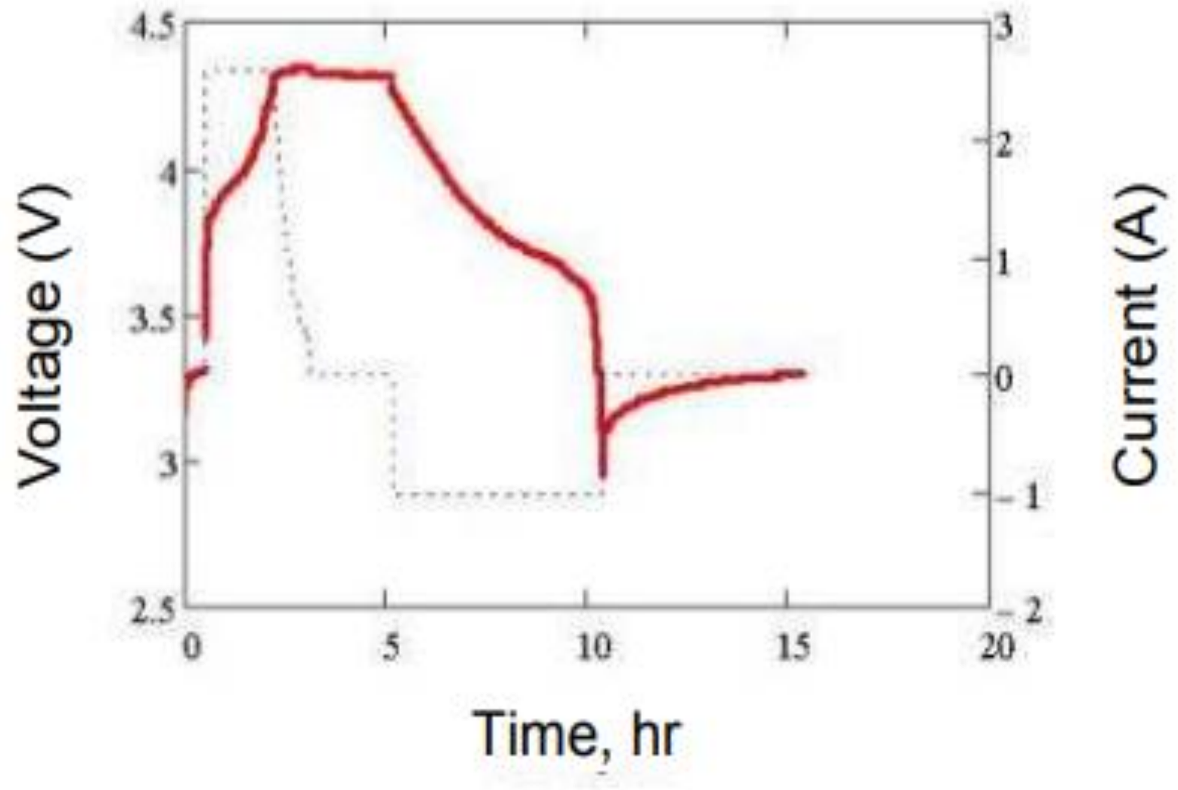
Possible causes:

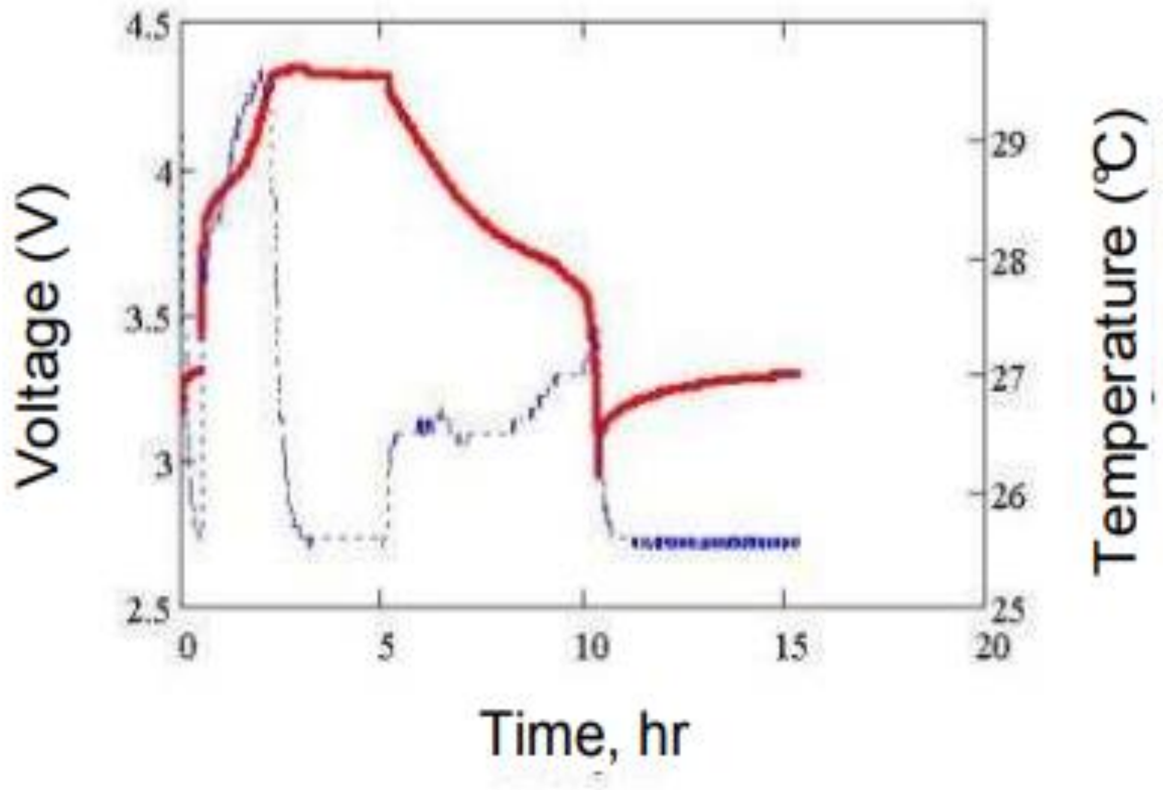
- Incorrect R_bL values or thermal model parameters, or both.

Resolution:

- Perform an R_bL tweak test to get the correct R_bL and thermal model parameters using the online GPC tool.

R_bL-tweak test procedure



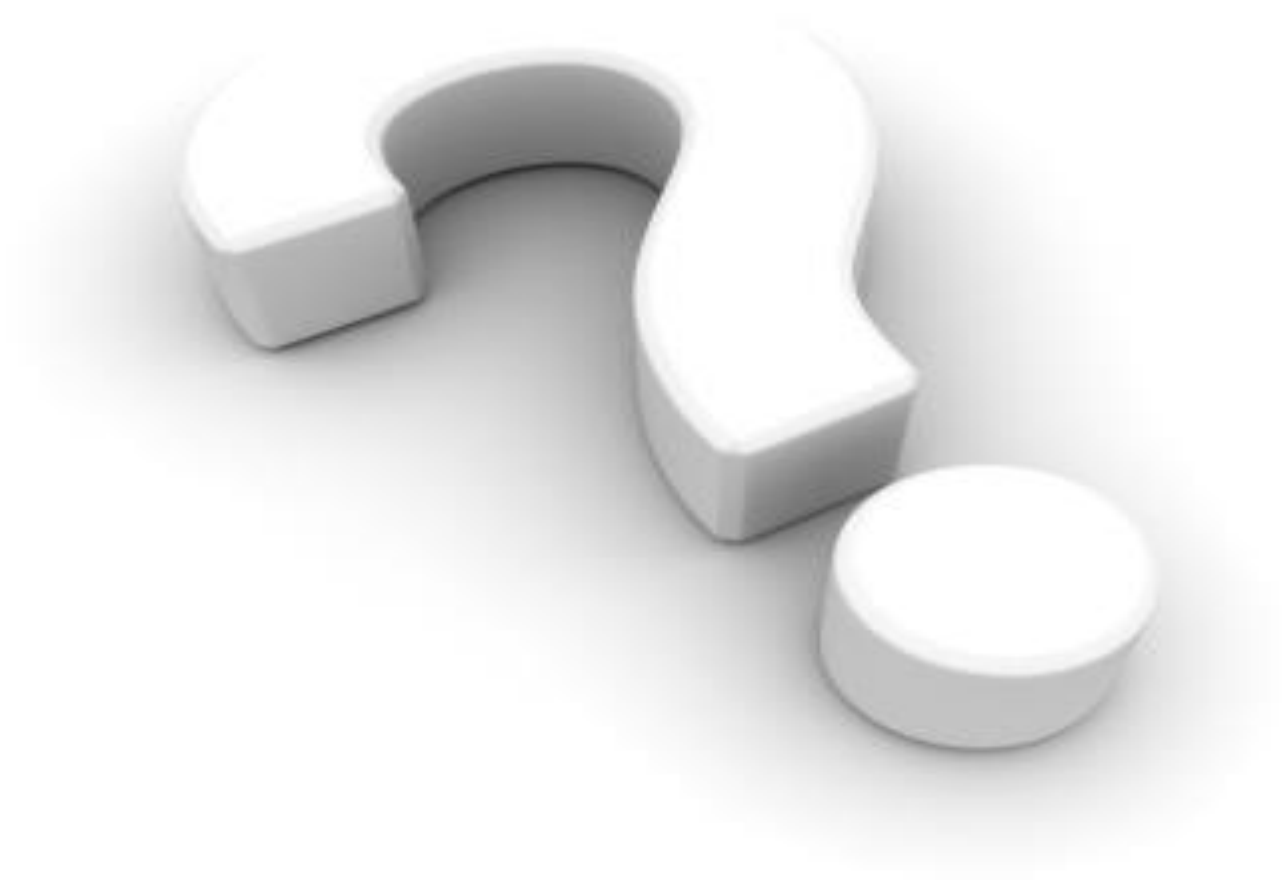


1. Perform charging at room temperature and let the battery relax for 2 hours.
2. Set the discharge temperature to 25°C. Wait 1 hour until pack reaches thermal equilibrium.
3. Discharge the battery at a system-typical high rate down to the minimal cell voltage. Let the battery relax for 5 hours to reach full equilibrium OCV.
4. Go to step No. 1 and repeat all steps, with the temperature set to 0°C in step No. 2.

For more details, see http://www.ti.com/lit/ug/sluubd0/sluubd0.pdf.

Summary

- Gauging is extremely important for extended battery run times.
- Accurate modeling of the battery, particularly the battery resistance, enables accurate prediction of the usable capacity (full charge capacity).
- Impedance Track gauges have the ability to handle a wide variety of battery operating conditions, such as varying temperature, varying loads and age.
- Correct configuration is essential in obtaining the best performance from the gauges.



Questions