Step-by-step Design Example: 1s

Battery Management Deep Dive Training

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Agenda

- **Introduction**
- **4 predesign steps**
  - Determine system requirements
  - Consider usage conditions
  - Choose a suitable gauge
  - Define test conditions
- **Bqstudio and EVM**
- **Calibration**
- **Chem id identification**
- **Data flash configuration**
- **Learning cycle and golden file extraction**
- **Evaluation Tests**
- **Conclusion**

Introduction

- Choice and correct configuration of an ideal gauge to meet an application's needs is critical to the overall success of the end equipment
- This presentation discusses a design example of a single cell battery gauge system
- The various key considerations are outlined and should act as a guide for other typical systems.

4 predesign steps

- Determine system requirements
- Consider usage conditions
- Choose a suitable gauge
- Define test conditions

Step 1:Determine system requirements

- The design example in this design walk-through will be a cell-phone application

Key Questions

- What is your accuracy target? Ex. 1% error or 25% error
- Pack-side (smart battery) or system-side?
- Power consumption of the gauge?
- Temperature range?
- Load profile
  - Constant or dynamic?
  - Long periods in standby? (Are you worried about self-discharge errors?)
  - Always charging or discharging? (Never gets a chance to relax?)
  - Battery always stays topped off? (Never gets a learning cycle?)
- How long is the battery expected to be used?
  - Do you want accuracy even after the battery is well aged?
- Gauge reporting
  - Do you only want to read State of Charge (SOC in %)?
  - Do you want capacity info (mAh)?
  - Do you want Time To Empty (TTE) or Time To Full (TTF) predictions?

Step 2: Consider usage conditions

- What factors impact usable capacity?
  - Temperature
    - Low temperature → higher impedance → less usable capacity
  - Current range
    - High current → more IR drop in cell → less usable capacity
- What conditions could make a gauge inaccurate?
  - Partial cycles
    - Never allowed to learn faded capacity
    - Coulomb counter gets off track
  - Dynamic loads
  - Long storage or standby time
- How will my battery age?
  - Why batteries degrade:
    - High cycle counts
    - Long calendar life
    - High charge rates kill cells
    - High charge voltage kills cells
    - High temperatures (even in storage) kill cells
  - What happens to old batteries:
    - Impedance goes up exponentially (result: less usable capacity)
    - Capacity fades (even for low discharges)

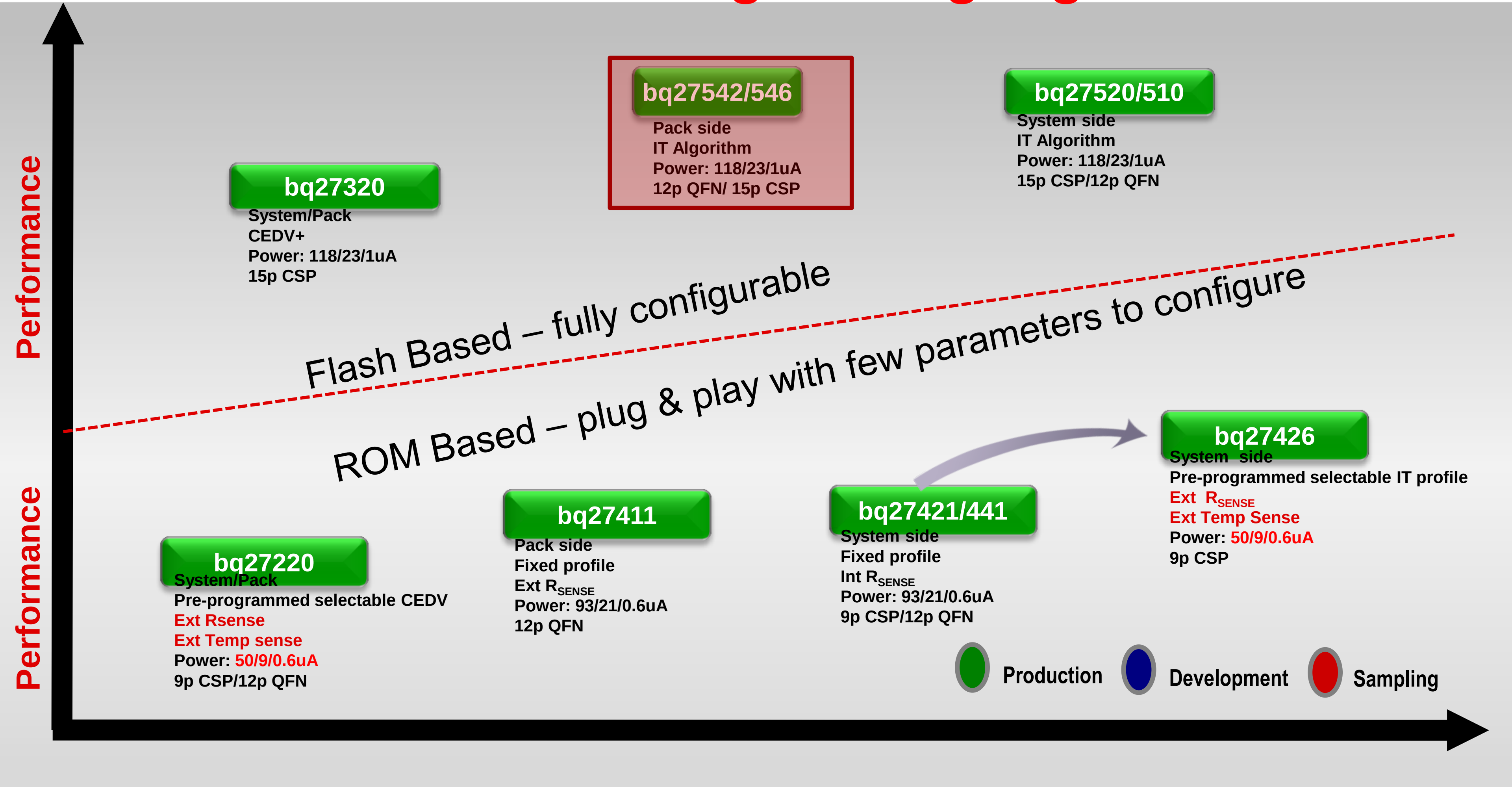
Step 2: Choose a suitable gauge

- Typical features
  - Reporting: SOC, Remaining Capacity, Time-To-Empty/Full,
  - Compensation: Can it compensate predictions for different loads (light/heavy) and different temperatures?
  - Self-discharge estimation: Can it compensate for internal self-discharge of the cell?
  - Aging: Can it compensate for or accurately gauge an aged battery?
  - Pack-side or host-side: Host side gauges might be introduced to an unexpected old or new battery. Can it handle it?

Step 2: Choose a suitable gauge cont’d

- Suitability of various algorithms
  - Voltage based algorithm   *SOC = f (VBAT)*
    - May be ok for very light loads and narrow temperature ranges.
    - No worries about cell self-discharge since that will be reflected in voltage.
    - Can determine only SOC (relative).
      - Example issue: % of what?
        - » 50% of a new battery may give you 1 hour of run time.
        - » 50% of an old battery may give you only 15 minutes!
    - Even worse performance if voltage profile of your cell is very flat (ex. LiFePO4)
    - ERROR could be 50-100%, especially as cells age.
  - Coulomb counting algorithm $Q = \int i \, dt$
    - Not influenced by distortions in voltage measurements.
    - Current integration hardware is very accurate.
    - Modeling for new batteries could achieve < 3-10% error.
    - Poor performance as cells age.
    - Cannot account for cell self-discharge except for modeling.
    - Learning cycle required to periodically update total capacity.
  - Impedance Track algorithm
    - Best accuracy under all conditions, even for aged cells
    - Can account for self-discharge and low-level drain by the system
    - Pack-side and host-side versions available

Discrete single cell gauge

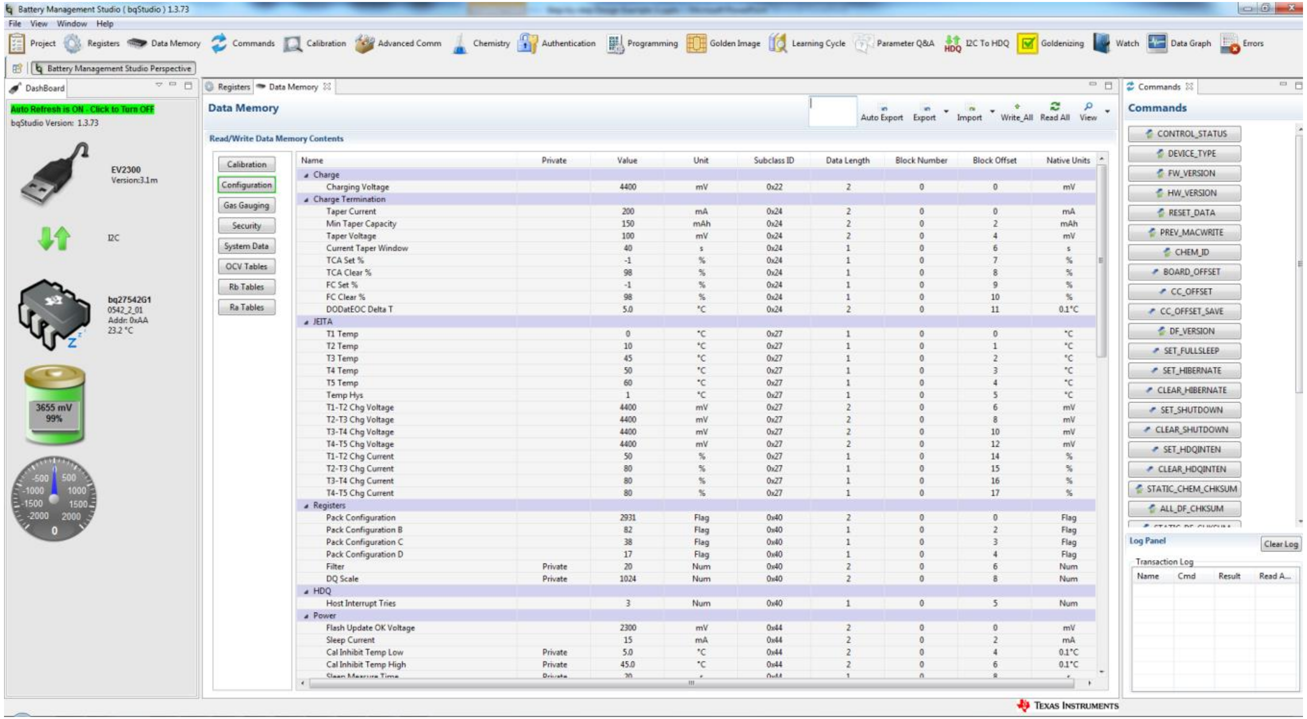


Step 4: Define test conditions

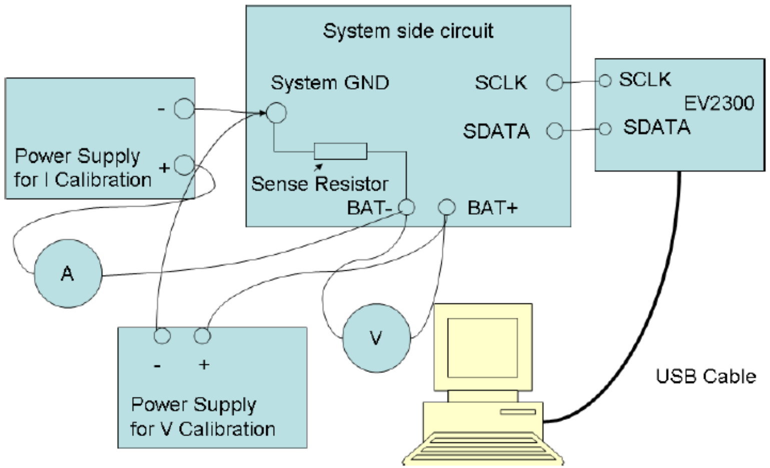
- What conditions do you want to test?
  - Nominal usage
  - Specific system operation scenarios
  - Corner cases (ex. High rate at low temperature)
- Define conditions for testing
  - Temperature?
  - Load rate & profile?
  - Test new cells then age and re-test?
    - Good way to age quickly is to cycle at high rates and high temp

Bqstudio and EVM

-bq27542/6 is the gauge choice
-bqstudio and its EVM is used for gauge evaluation and configuration



Gauge calibration



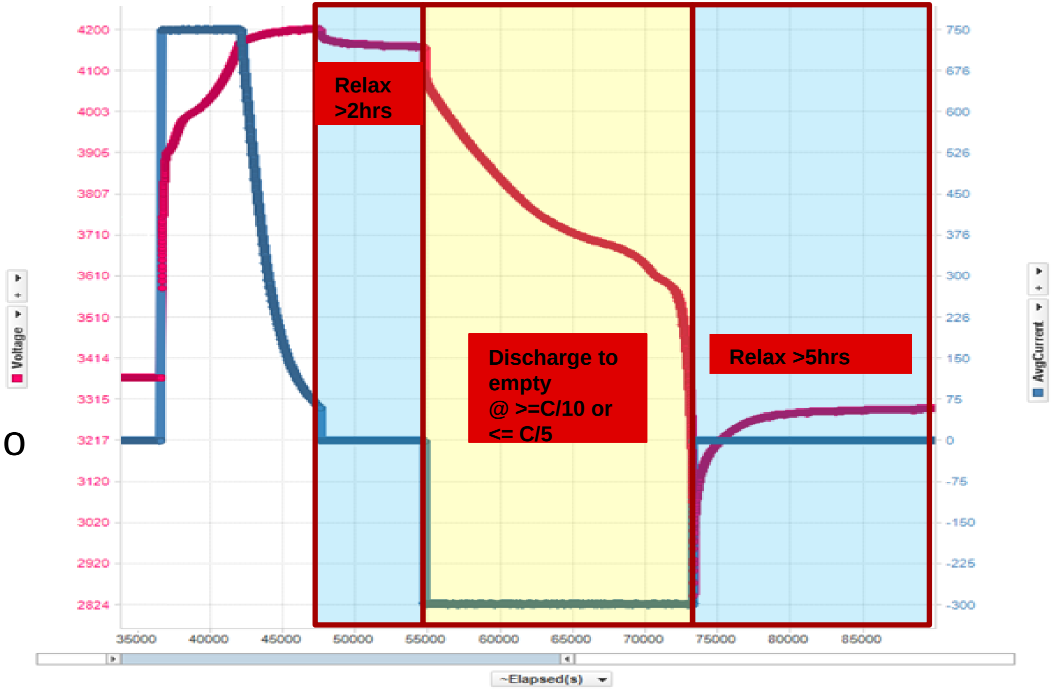
Calibrate the voltage, current , temperature measurements, cc offset and board offset

- Set up the environment as shown
- Use bqstudio to perform V,I,T and cc-offset and board offset calibration

Chem id identification using gpcchem

Identify the chem id of the battery

- Perform a relax-discharge-relax test while logging V,I,T with bqstudio
- Upload results to online tool gpcchem
- Program the best chemid returned on device using bqstudio



Data flash configuration

Configure the data flash parameter prior to learning. At minimum configure the following

- Taper current. Values between C/10 and C/20 should be used.
- Discharge current threshold. This should be less than taper current
- Charge current threshold. This should be less than taper current.
- Quit current. This determines the gauge’s relaxation state. This value should be less that dsg and chg current thresholds and less than or equal to C/20.
- Design capacity: Rated Nominal capacity of the cell
- Design voltage: Rated Nominal voltage of the cell
- Charge voltage for the different temperature levels
- Terminate voltage: minimum voltage stated in cell data sheet that the cell can be discharged to

Learning cycle and golden file extraction

Learning cycle

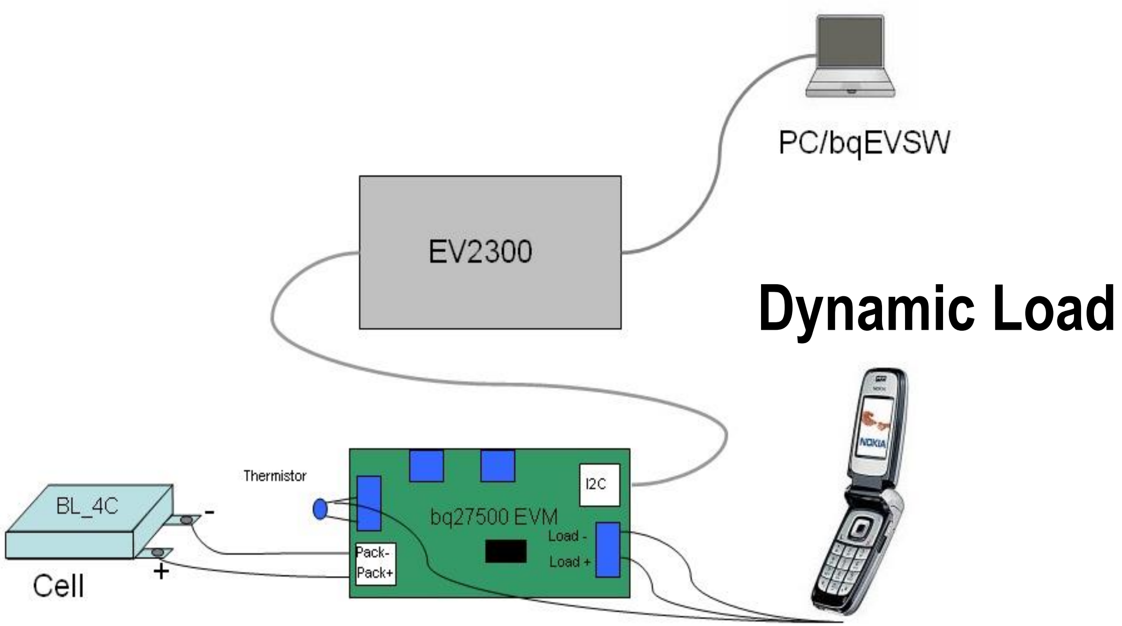
- Issue a IT enable command (0x21). Then Issue a reset command (0x41)
- Discharge to empty (terminate voltage) using a constant current value between C/5 and C/7
- Rest for 5 Hours
- Charge the battery to full(charge voltage specified in DS of cell) and make sure you taper to a value below the taper current in DF
- Rest for 2 hours (Qmax will update at this point). Update status will go from 04 to 05
- Discharge to empty using the same discharge rate as before.
- Rest for 5 hours.
- At the end of discharge, update status will change to 06

Extract golden file for mass production.

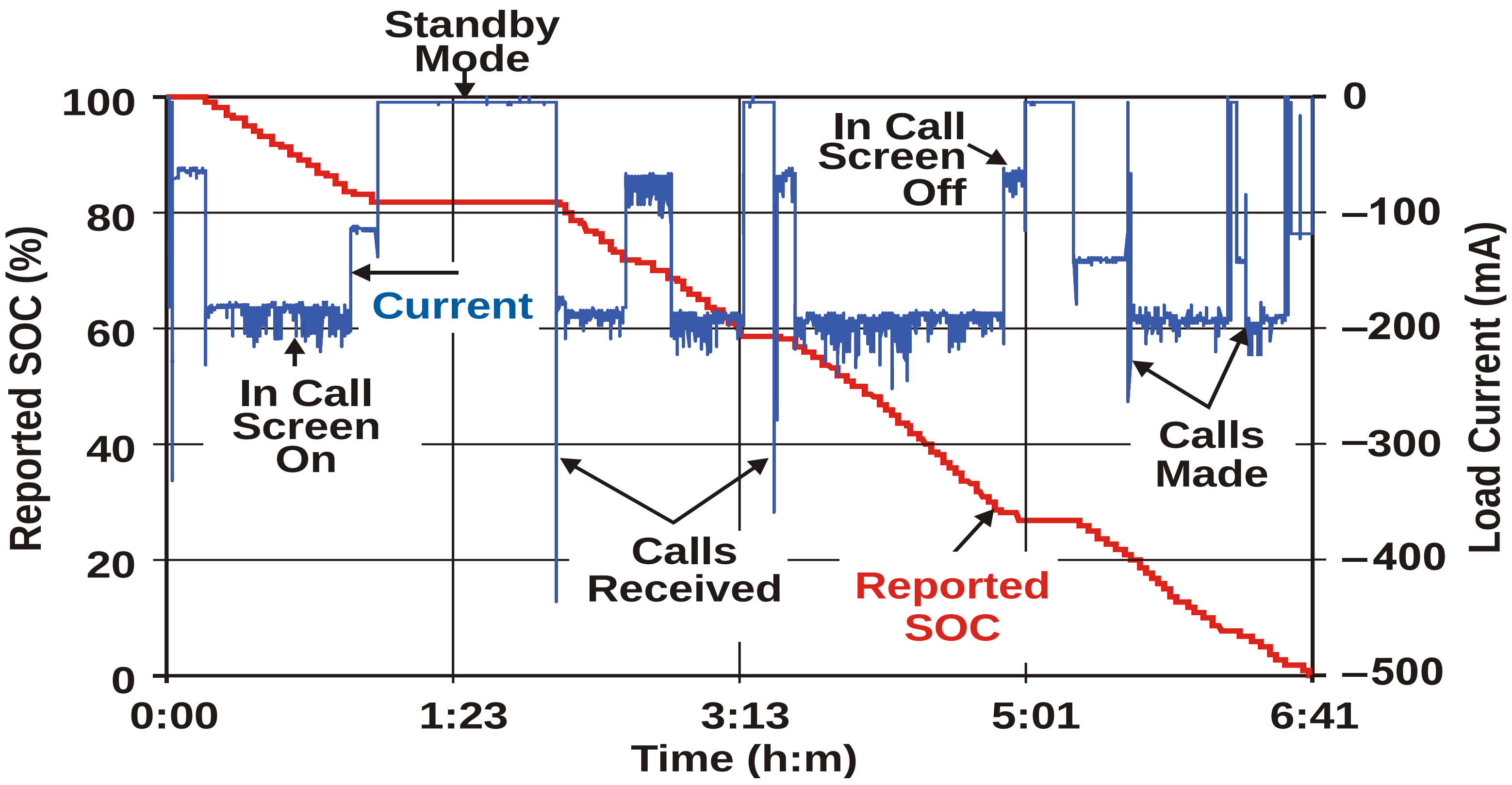
- Extract a golden srec, bqfs or dffs. You can calibrate 10 boards and program the average of the calibration parameters in your golden file .

Evaluation tests

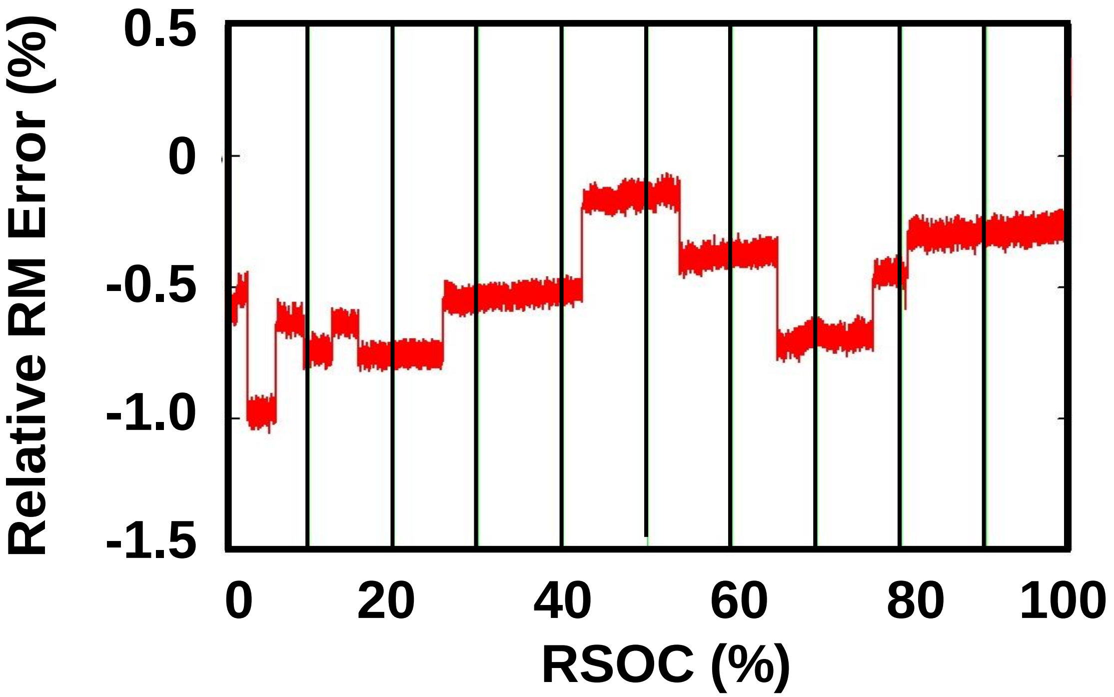
- You can set up an the actual load to perform evaluation tests as below



GSM phone test: reported SOC and current



Fuel-gauge test results with a smart phone



- Up to 99% accuracy at room temperature

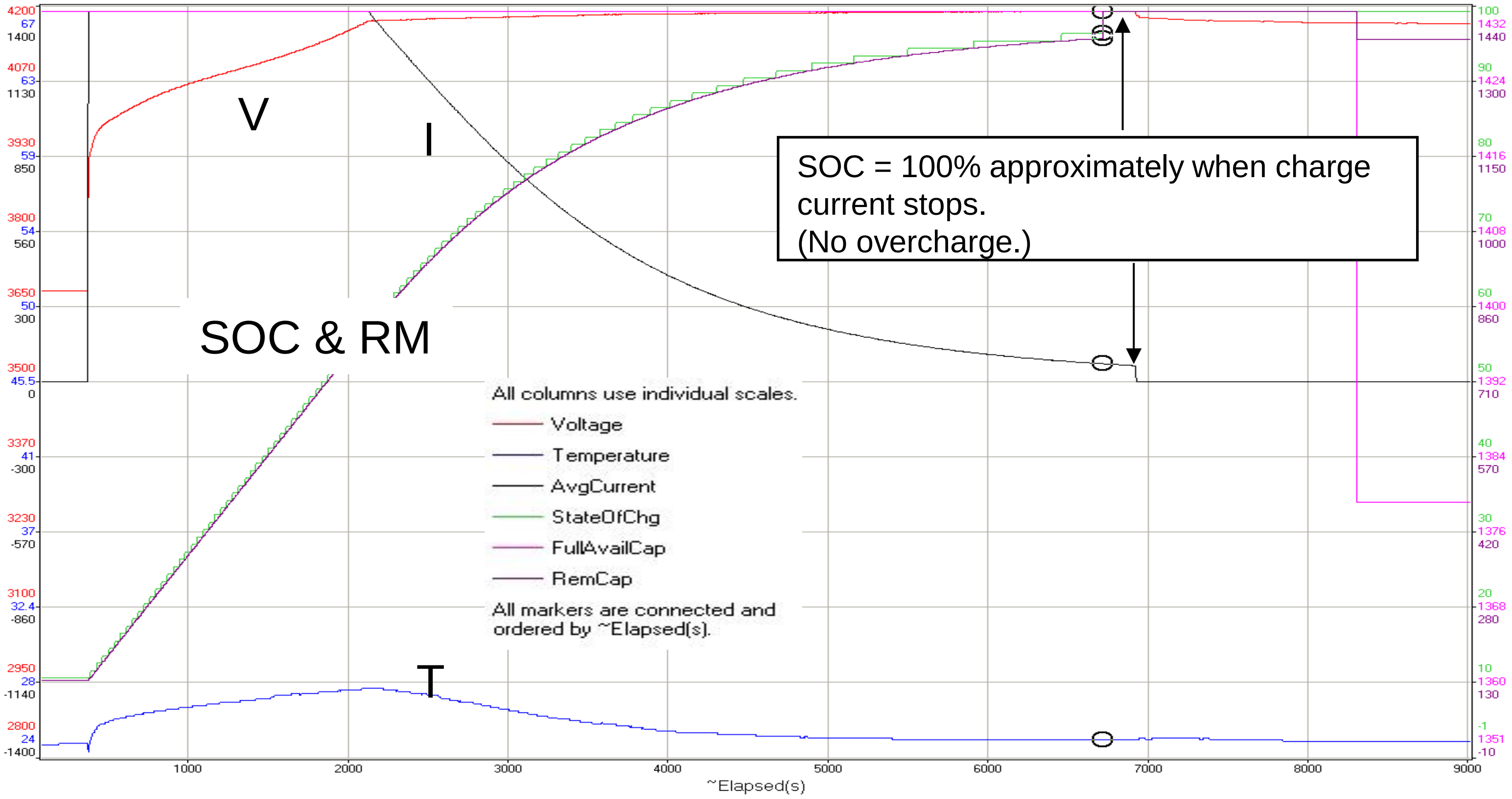
Accuracy Evaluation

- Simple inspection
- Detailed error calculations
- Common sources of error

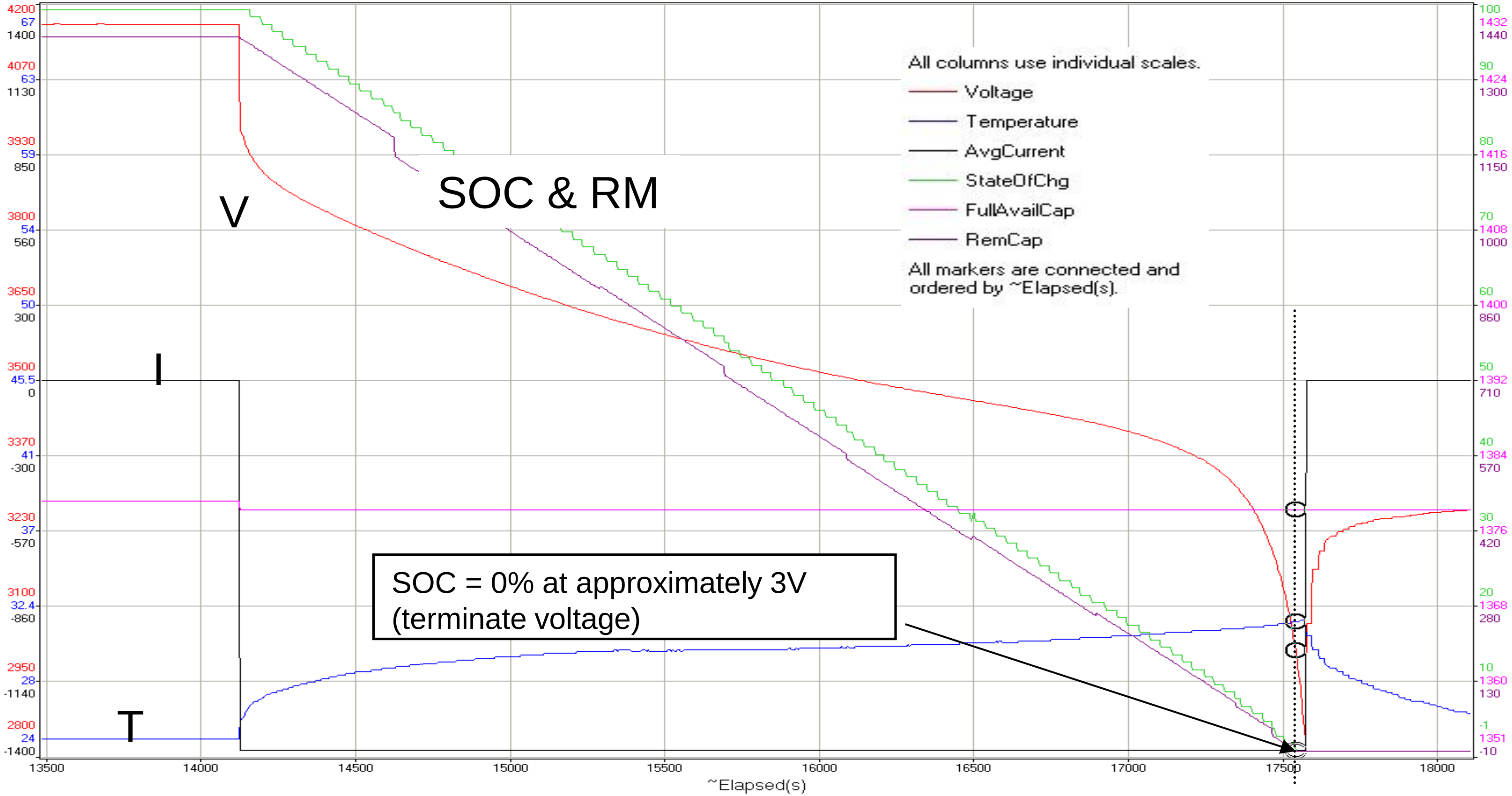
Simple inspection

- Log gauge data every 1-10 seconds
- Import to spreadsheet and plot voltage, SOC, current, etc.
- Inspect
  - Does it report 0% at or near your true terminate voltage?
    - If not, by how much capacity and/or run-time was it off?
  - Does it look smooth or have large jumps?
- Very subjective and difficult to gauge relative error magnitude

Example: inspect a 25ºC charge at 1C rate



Example: inspect a 25ºC discharge at 1C rate



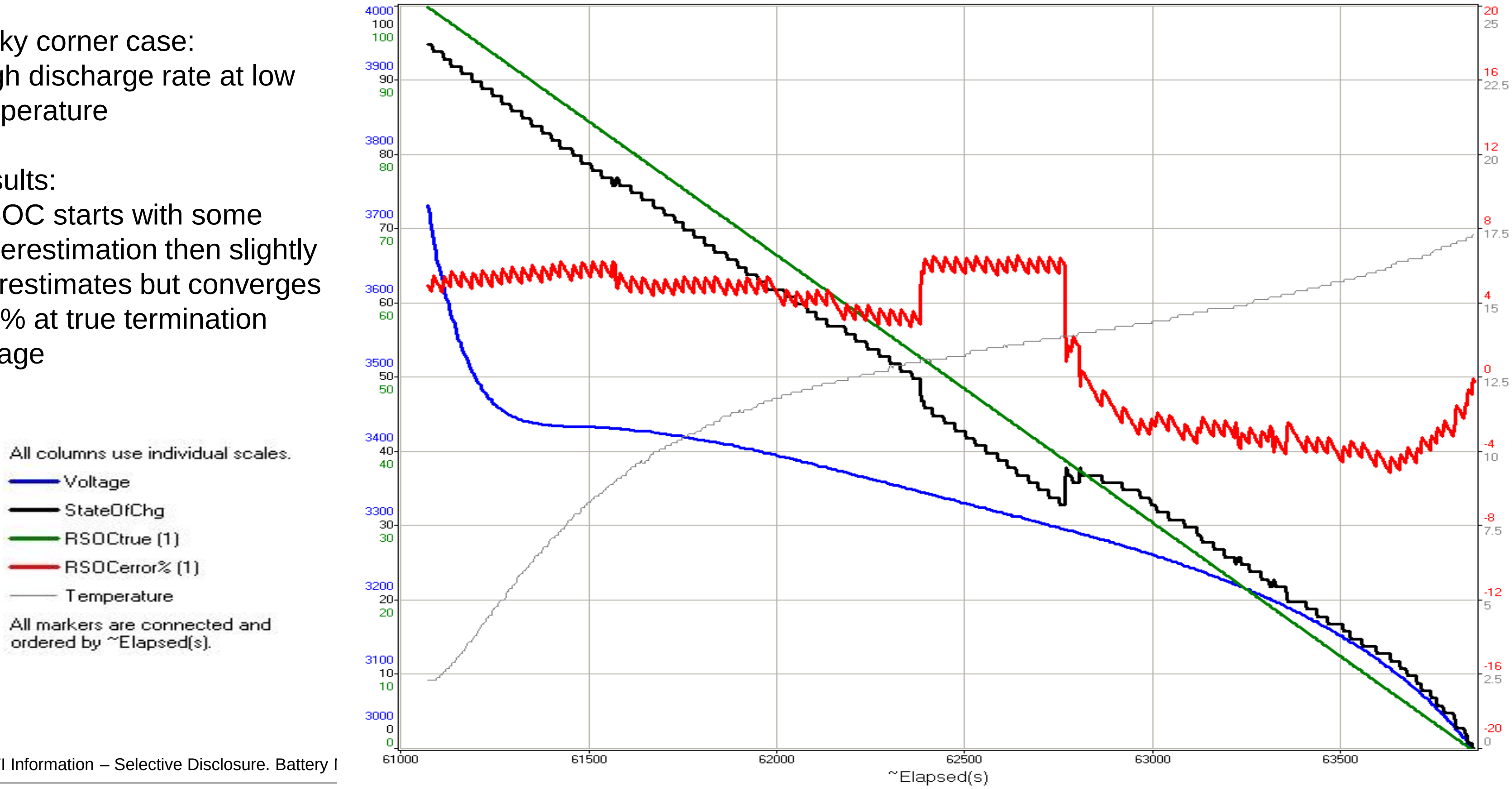
Detailed accuracy calculations

- Log gauge data every 1-10 seconds & import to spreadsheet
- Calculate a new column: Q_integrated = rolling sum of current_reading*time_since_last_log_point
  - Start from full condition
- Calculate FCC_true = Integrated capacity from fully charged state down to termination voltage
  - Simple integration: capacity = constant current * total discharge time from full to terminate voltage
  - If using varying load, you need to calculate each log point Current*Tdelta and keep a rolling sum.
- Calculate a new column: Qrem_true = FCC_true – Q_integrated
  - True remaining capacity at any point (mAh)
- Calculate a new column: RSOC_true = Qrem_true / FCC_true
  - True relative state of charge (%)
- Calculate a new column: Qrem_error = (Qrem_true – Qrem_gauge) / FCC_true
  - Qrem_gauge is “Remaining Capacity” in IT gauge log files
- Calculate a new column: RSOC_error = (RSOC_true – RSOC_gauge)
  - RSOC_true is “State of Charge” in IT gauge log files
- Plot voltage, Qrem_true, Qrem_gauge, Qrem_error
- Plot voltage, RSOC_true, RSOC_gauge, RSOC_error
- Summarize in table showing
  - % error at the point of 15% true SOC
  - % error at the point when termination voltage is reached
  - Max % error

Extreme RSOC analysis: 1C discharge at 0°C

Tricky corner case:
-High discharge rate at low temperature

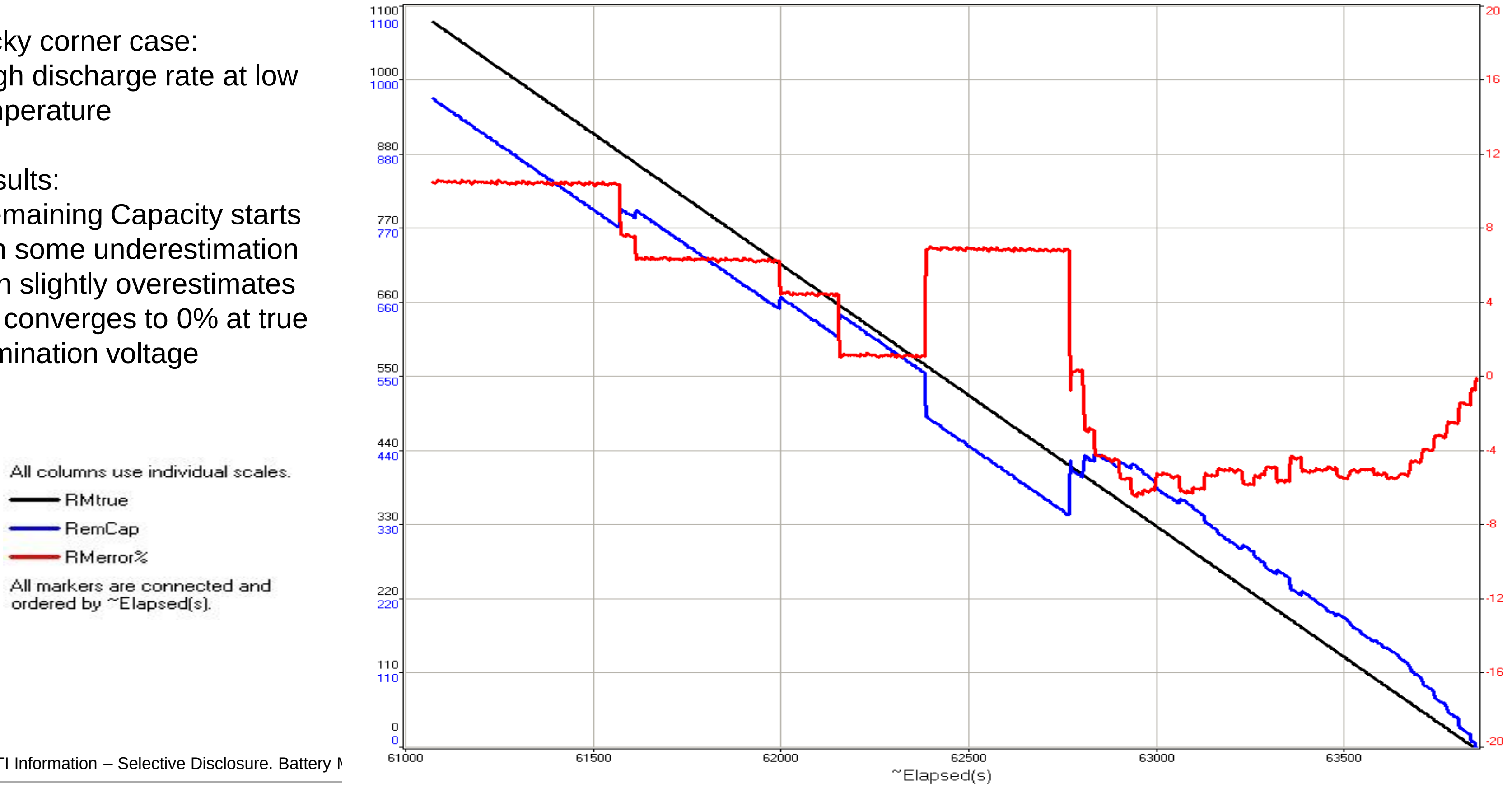
Results:
-RSOC starts with some underestimation then slightly overestimates but converges to 0% at true termination voltage



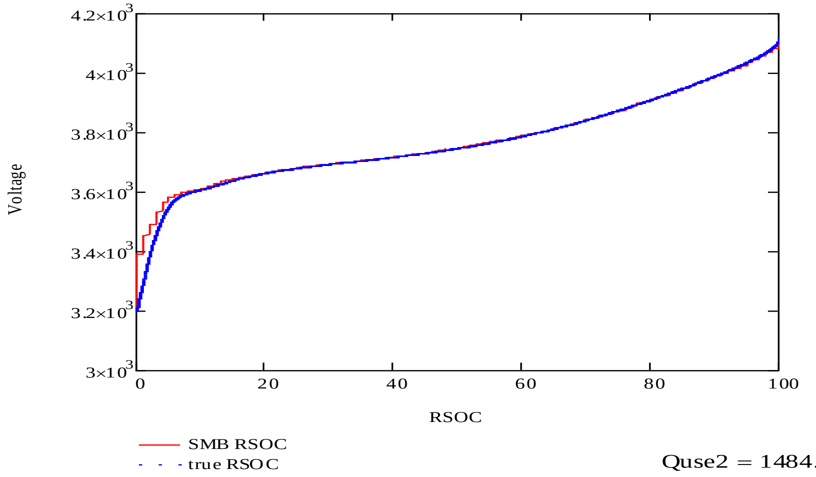
Extreme RemCap analysis: 1C discharge at 0°C

Tricky corner case:
-High discharge rate at low temperature

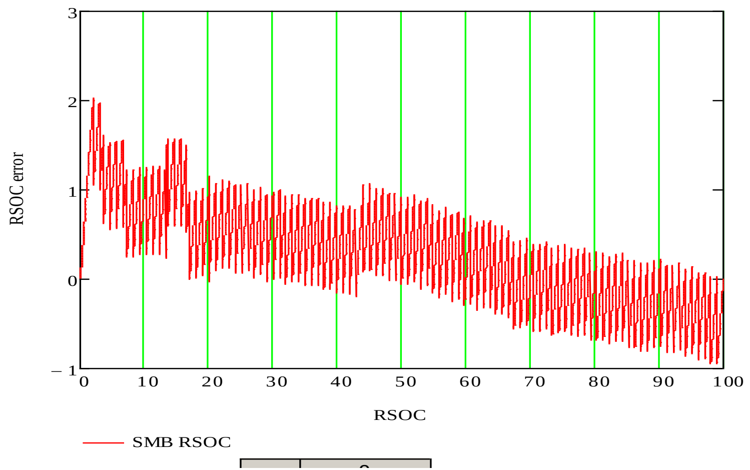
Results:
-Remaining Capacity starts with some underestimation then slightly overestimates but converges to 0% at true termination voltage



True vs reported RSOC

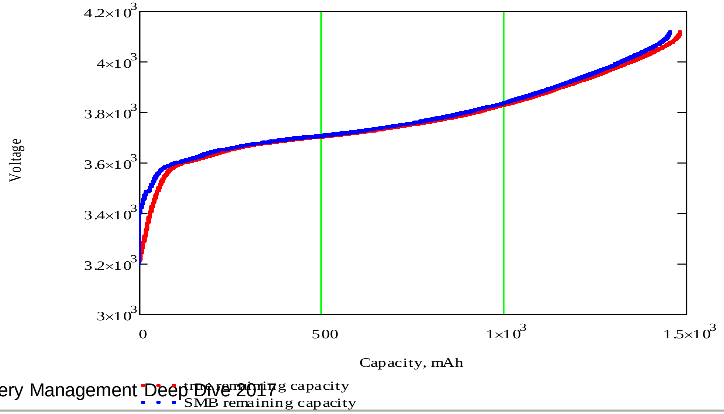


RSOC accuracy

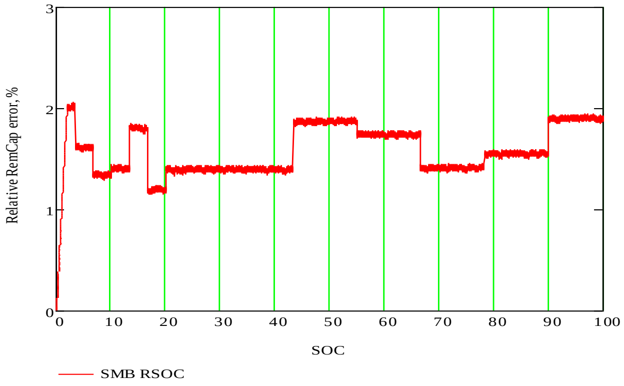


Quse2 = 1484.9975

Remaining capacity



Relative RemCap error



Example Mathcad analysis

Common sources of error

- Wrong or skipped calibration
- ChemID or modeling parameters not correct for actual cell in use
- Golden file not optimized: skipped or bad learning cycle leads to wrong initial Qmax and resistance values
- Temperature error: make sure thermistor is actually attached to the cell during test
  - It needs to know the cell temperature, not the ambient temp.
  - Cells typically self-heat during discharge.
- Gauge not allowed to accurately measure starting capacity
  - Ex. Attach unrelaxed cell so gauge uses wrong starting voltage to calculate initial SOC
  - Ex. Charge or load is present when gauge is initialized or cell is attached
- Thermal modeling:
  - Bare cell at low temp will not heat up much
  - Typical system will be enclosed and have more self-heating
  - Does your gauge handle either situation or does it need configuration of thermal modeling parameters?
  - Symptom: large temperature changes during test may result in inaccuracies and/or capacity jumps unless gauge is configured to handle it
- Selecting wrong LoadMode (constant current or power) and LoadSelect for application
- Avg I/P Last Run in dataflash not initialized to expected rate to be used in test
- Overcharging or undercharging cell by charging at high or low temperatures
- Significantly overcharging by tapering to a lower current than gauge is configured to use for full charge detection
- Using old firmware version: TI is always continuously improving the IT algorithm to better handle corner cases or odd usage conditions!

Conclusion

- The key considerations when designing a single cell battery gauge system was analyzed.
- Gauge performance is closely associated with the algorithm implemented and the correct configuration.
- This design walk through can be expanded to work with any single cell gauge application

Questions?