Impedance Track™ Gauge Configuration For Dynamic Loads (EPOS)

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ABSTRACT

TI's Impedance Track algorithm for battery gauging uses load predictions to determine capacity. This application note discusses various options to tune the algorithm for dynamic loads. It is intended to help an engineer configure a TI Impedance Tracking gauge.

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1 Impedance Tracking

A battery gauge running TI's Impedance Tracking algorithm reports the Remaining Capacity (and State Of Charge) of a battery for an assumed load current. This is based on a prediction, which uses past load characteristics. The algorithm has access to three periodic measurements:

- Current
- Voltage
- Temperature

The gauge uses a model of the cell to gauge how much capacity is still available to the system until the cell's voltage reaches the system's minimum operating voltage (Terminate Voltage). While capacity is still available, this voltage will be reached sometimes in the future and as the cell's voltage is a function of load, the gauge must make a prediction based on load estimation. The capacity prediction based on load estimation is performed at various times during a discharge. The gauge will run discharge simulations from the actual depth of discharge to a predicted time when the simulated voltage will cross the Terminate Voltage threshold. The result of this simulation is a predicted Remaining Capacity. Applications with a very dynamic load profile need special considerations to achieve good gauging performance because load prediction will need to account for dynamic loads.

1.1 RM, FCC and SOC

The three main gauging results are:
- Remaining Capacity (RM)
- Full Charge Capacity (FCC)
- State Of Charge (SOC)

Remaining Capacity (RM) is the amount of charge (coulombs) that can be drawn from the battery until it is deemed empty.

Full Charge Capacity is the total amount of charge that the battery can deliver to a system for a specific set of conditions (average load, temperature).

State Of Charge (SOC) is a unit-less representation of RC relative to Full Charge Capacity. SOC [%] = 100 * RC/FCC.

A battery is deemed empty when its voltage drops below a threshold (Terminate Voltage).

1.2 Capacity Simulation

The Impedance Tracking algorithm determines FCC, RM and SOC through simulations.

FCC: This is established before discharge starts and is based on a simulation from full to empty for a specific temperature and anticipated load.

RM: The algorithm triggers simulations at various points during a discharge. Triggers are significant changes in discharge level and changes in temperature (among others). Simulations become more frequent closer to Terminate Voltage. Between simulations, the algorithm uses the coulomb counter to adjust RM.
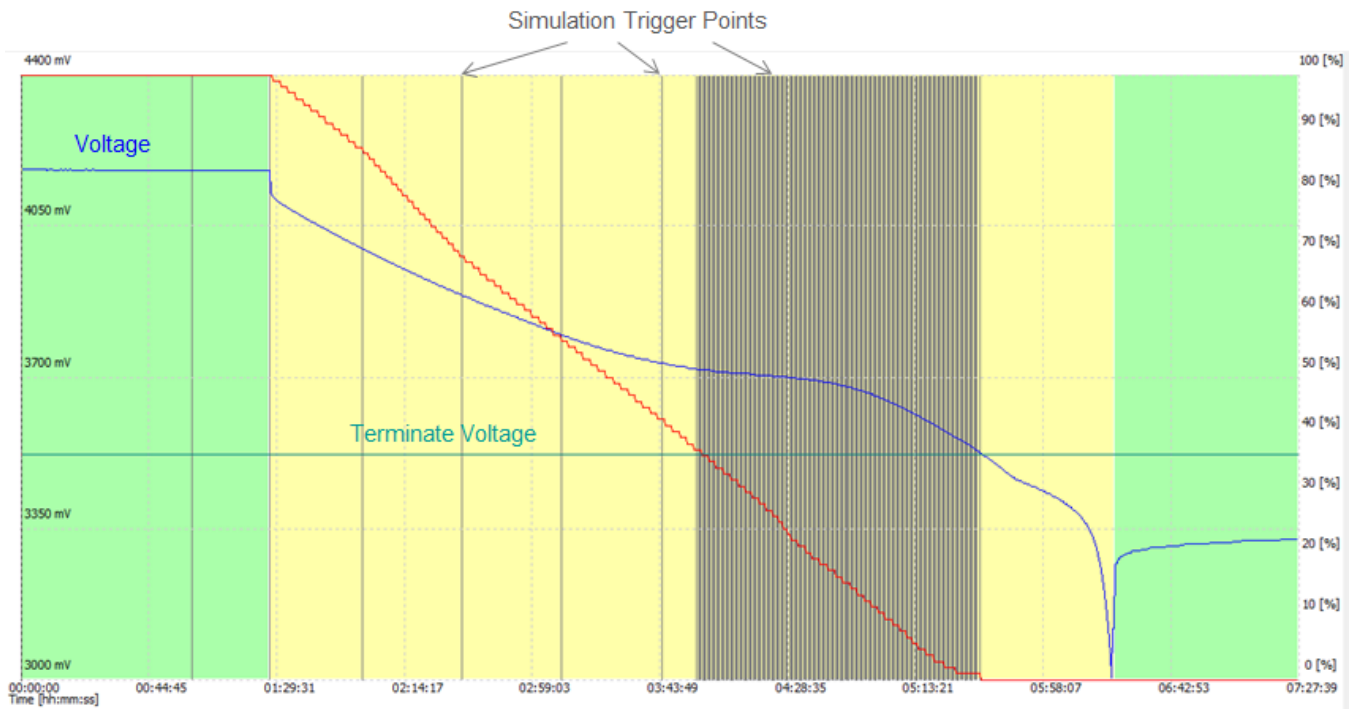
SOC: A simple equation: SOC [%] = 100 * RM/FCC

Figure 1. Discharge Example

This picture shows a typical progression of cell voltage and SOC over time during a discharge.

The grey vertical lines denote when the gauge ran a capacity simulation during discharge.

The capacity simulation is the core of the Impedance Tracking algorithm. Every gauging result that the gauge reports is based on capacity simulations. As these capacity simulations assume a specific load, the load prediction is extremely important for accurate gauging results.

When a simulation is kicked off (by one of the triggers during discharge or when the gauge determines initial capacity), the gauge will use the built in model of the battery (ChemID) to calculate the voltage drop across the internal impedance for a predicted load. As the predicted load discharges the simulated battery, the voltage will start to drop. The simulation runs until the voltage drops below Terminate Voltage. The accumulated charge (by integrating the predicted load current) equals the capacity.

Figure 2. Capacity Simulation

This picture shows the actual progression and result of a capacity simulation. Note that this shows a predicted discharge, not a physically existing discharge. The horizontal axis is the simulation time. The vertical axis is the simulated cell voltage (based on ChemID voltage and impedance tables). Capacity result is the accumulation of simulated charges (simulated current) from starting depth of discharge all the way when the simulated voltage crosses Terminate Voltage.

The initial capacity estimate is performed with a load prediction based on parameters stored in data memory / configuration (average I/P from the previous discharge). These parameters are part of the golden image.

Initial Capacity Simulation:

FCC = Simulation Result

Remaining Capacity Simulation:

RM = Latest Simulation Result + Coulomb count

1.3 Coulomb Counting

The gauge doesn't run simulations continuously. In between simulations, the gauge uses coulomb counting to adjust RM.

Any abrupt changes in RM (for example, if the load changed significantly) after a simulation may cause jumps in reported SOC.

The gauge uses an (optional) smoothing algorithm if jumps are not acceptable (even though they reflect the true RM and true SOC).
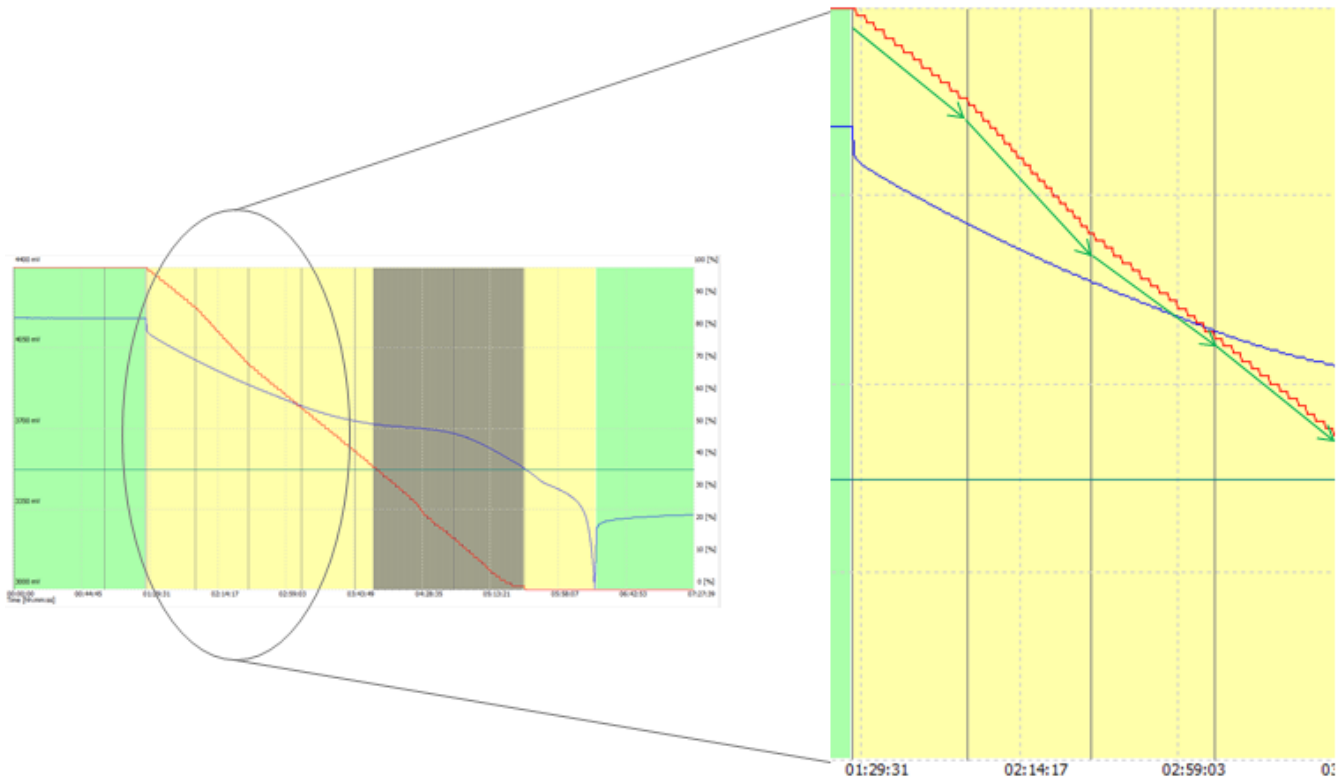

Figure 3. Coulomb Counting

The zoomed detail shows when the gauge uses the coulomb counter (delta sigma ADC) to adjust RM between simulations.

2   Load Prediction

Remaining capacity simulations use load prediction (future load) and therefore it is very import to predict the load accurately.

2.1   *Load Mode*

The gauge uses two main load prediction models ("Load Mode") that are available in data memory / configuration:

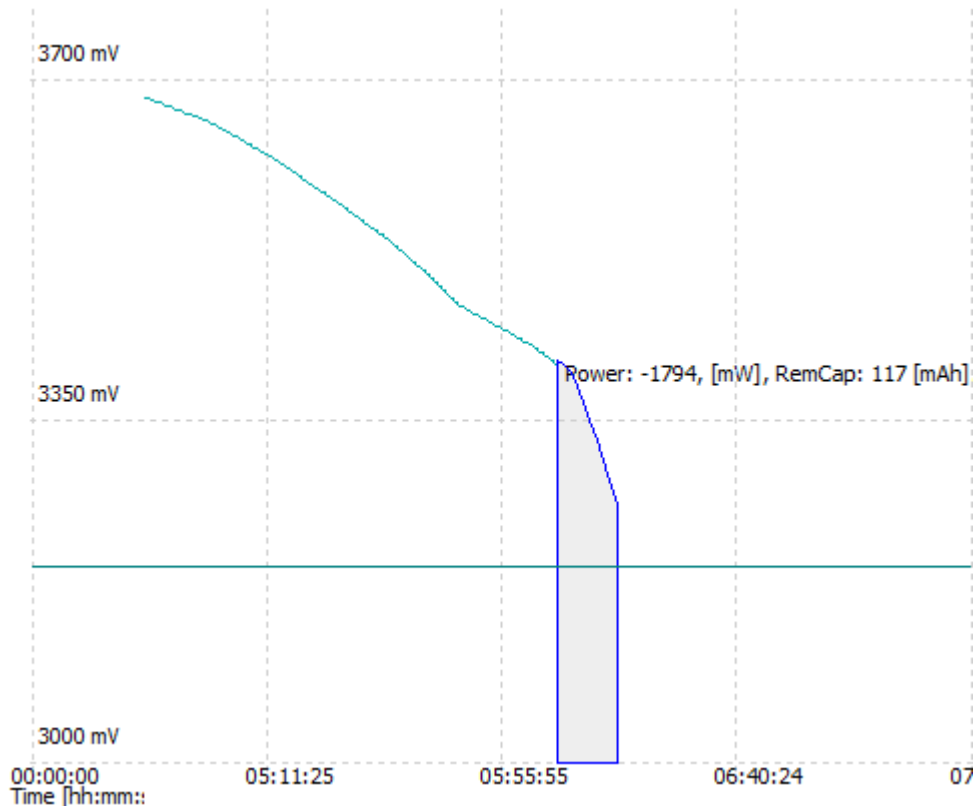1. Constant Current: Capacity simulations use a constant current, regardless of simulated battery voltage.

Figure 4. Constant Current Simulation

2. Constant Power: Capacity simulations use a variable current as a function of simulated battery voltage. The current is adjusted automatically so that the simulated power drawn from the battery is constant.
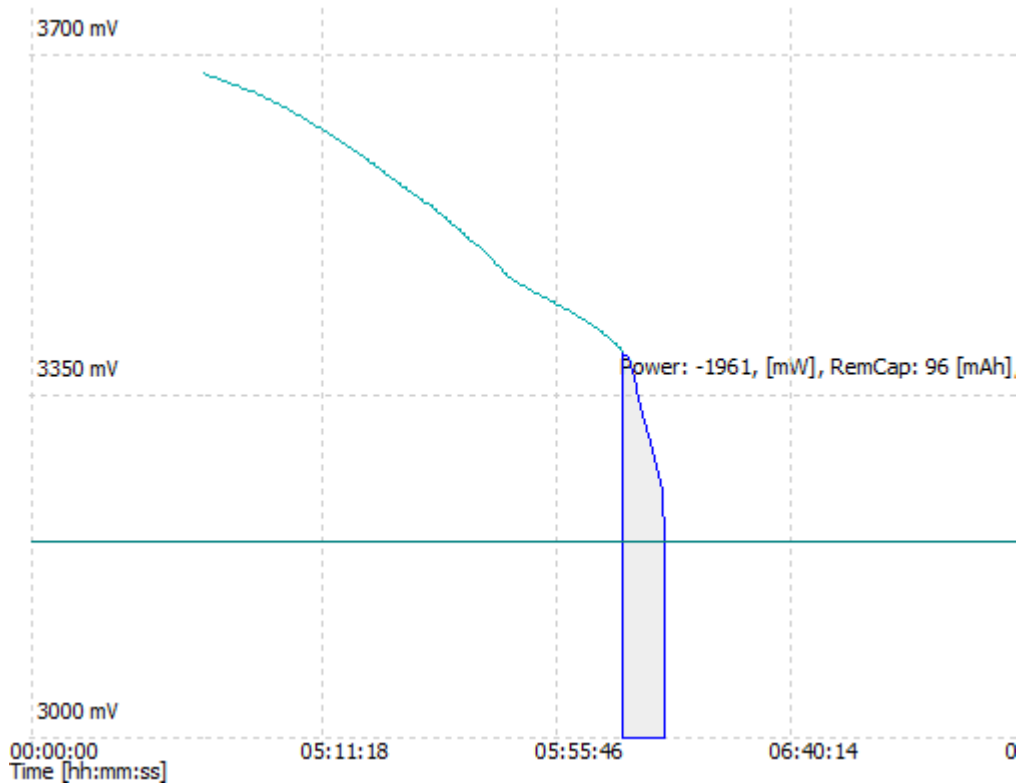

Figure 5. Constant Power Simulation

Besides choosing the Load Mode (Constant Current or Constant Power), one must also select how the gauge will determine the load for simulations.

2.2 Load Select

The gauge uses the Load Select parameter from the data memory / configuration to predict current (or power) for simulations.

The algorithm has the following options:

- *Average discharge load from the previous discharge cycle:*
  The gauge calculates the average load from the previous discharge cycle and saves this in data memory (Avg I/P Last Run – this is also part of the golden image). Capacity simulations use this data (regardless of present load) for load prediction.
  Use this if the load profile is not known but not expected to change much between discharge cycles.

- *Present average load from the beginning of the current discharge cycle:*
  The gauge calculates the average load from the current discharge cycle and uses this for capacity simulations.
  Use this if the load profile not known but expected to change significantly between discharge cycles. This is the default setting.

- *Low pass filtered average load:*
  The gauge calculates a low pass filtered version of the average load and uses this for capacity simulations.
  Use this if the load profile is dynamic. This can lead to underestimation of capacity if the low pass filtered load is larger than the average load over the discharge cycle and lead to accelerated decrease of SOC.

- *Design Capacity / 5:*
  The gauge uses a C/5 load value for capacity simulations.

Use this if the load profile is not known.

- *User Rate:*
  The gauge uses a fixed load value for capacity simulations.
  Use this if the load profile is very dynamic (choose the max load) and if underestimation of capacity is preferred over fast changes in State Of Charge.

2.2.1 Load Select Examples, Dynamic Load

The following examples show the impact of Load Select for an application with a highly dynamic load (EPOS, where the printer is drawing a lot of current. The printer is on for short times only.):

Terminate Voltage is in a steep zone of the cell's voltage curve so capacity simulations will terminate cleanly and stable:
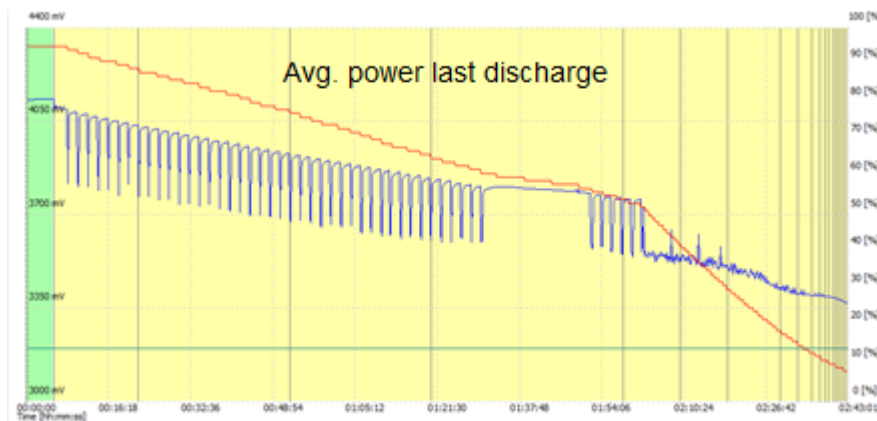

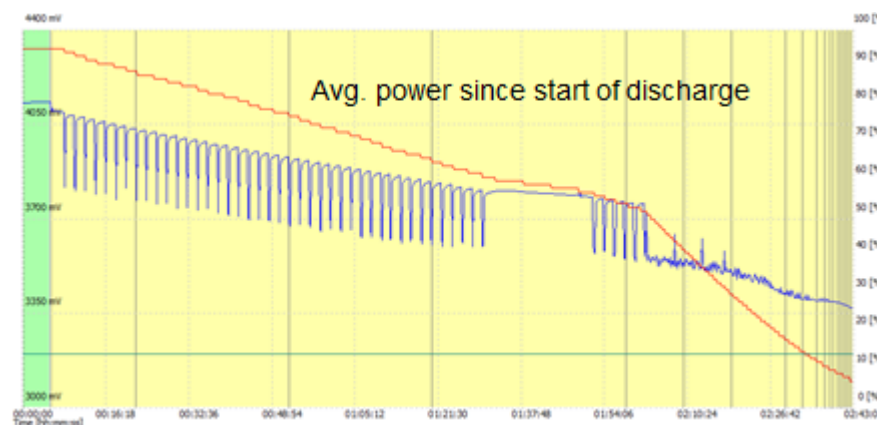**Figure 6. Avg Load Previous Discharge**
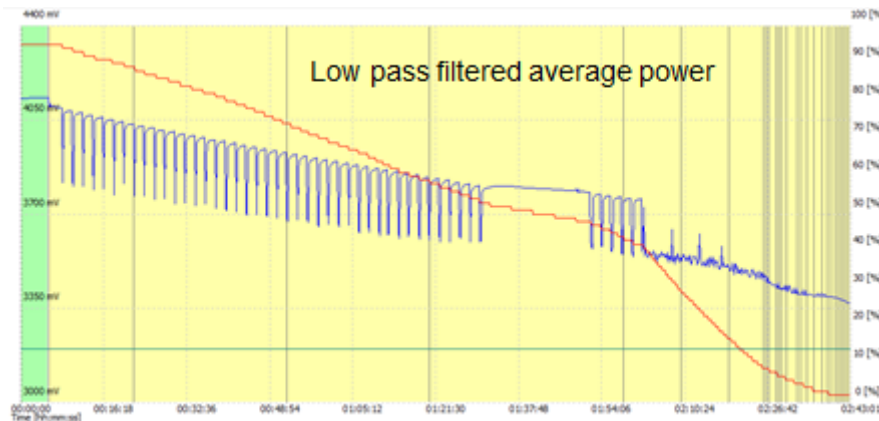

Figure 7. Avg Load Since Start of Discharge

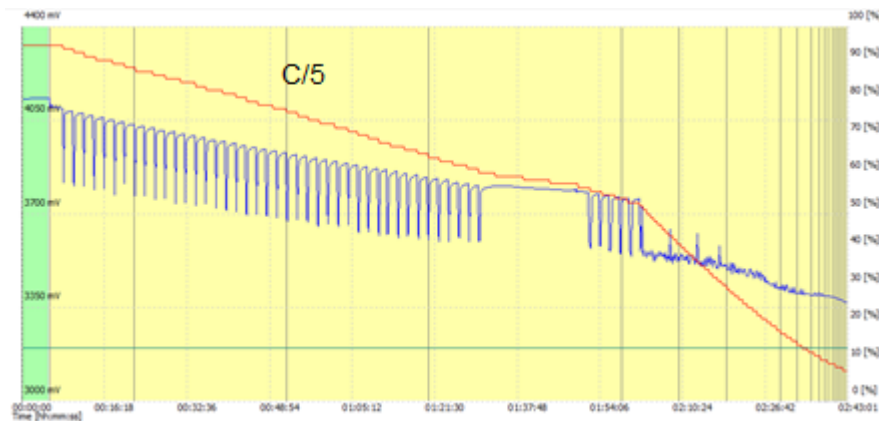**Figure 8. Low Pass Filtered Average Load**

Figure 9. C/5 Load

3 Highly Dynamic Load Example (EPOS)

Some applications have a load profile that is very challenging for battery gauging.

One example is handheld Electronic Point Of Sale (EPOS) devices that have a printer which operates in short bursts during the day but long periods at the end of the day.

The load from the EPOS electronics except for the printer is fairly low (for example, C/10) with the load from the (thermo) printer exceeding this significantly (for example, 2C).

Here is the gauging result with poor capacity prediction due to a configuration that is not adequate for the dynamic load of the application:

Figure 10. SOC Jump

During discharge, the load changed dynamically between around C/10 (EPOS display and keypad) to 2C (short bursts of printer activity). At the end of discharge, the printer is turned on continuously, which drastically changes the load profile right when load prediction is the most critical for gauging performance. Because the average load was a lot smaller than the final load, the gauge over-estimates capacity, which results in a sudden drop in SOC when the cell voltage drops below Terminate Voltage.

There are two problems with this particular example:

1. Terminate Voltage should be in the steep zone of the loaded cell voltage. This will allow the simulation to terminate accurately and stable. If the Terminate Voltage shifts into the flat zone of the loaded cell voltage, a small change in simulated voltage will cause a big change in simulated capacity.

2. Inadequate Load Select for this application.

3.1 Terminate Voltage and Flat Zone

It is very important that the Terminate Voltage that the gauge uses for capacity simulations is in the steep zone of the simulated, loaded cell voltage.

Very high loads, like 2C in this example, may shift the Terminate Voltage before the drop off of the simulated, loaded cell voltage at high depth of discharge. This can lead to large changes in simulated capacity for small changes in simulated voltage (and hence it can impact the quality of the simulation result):
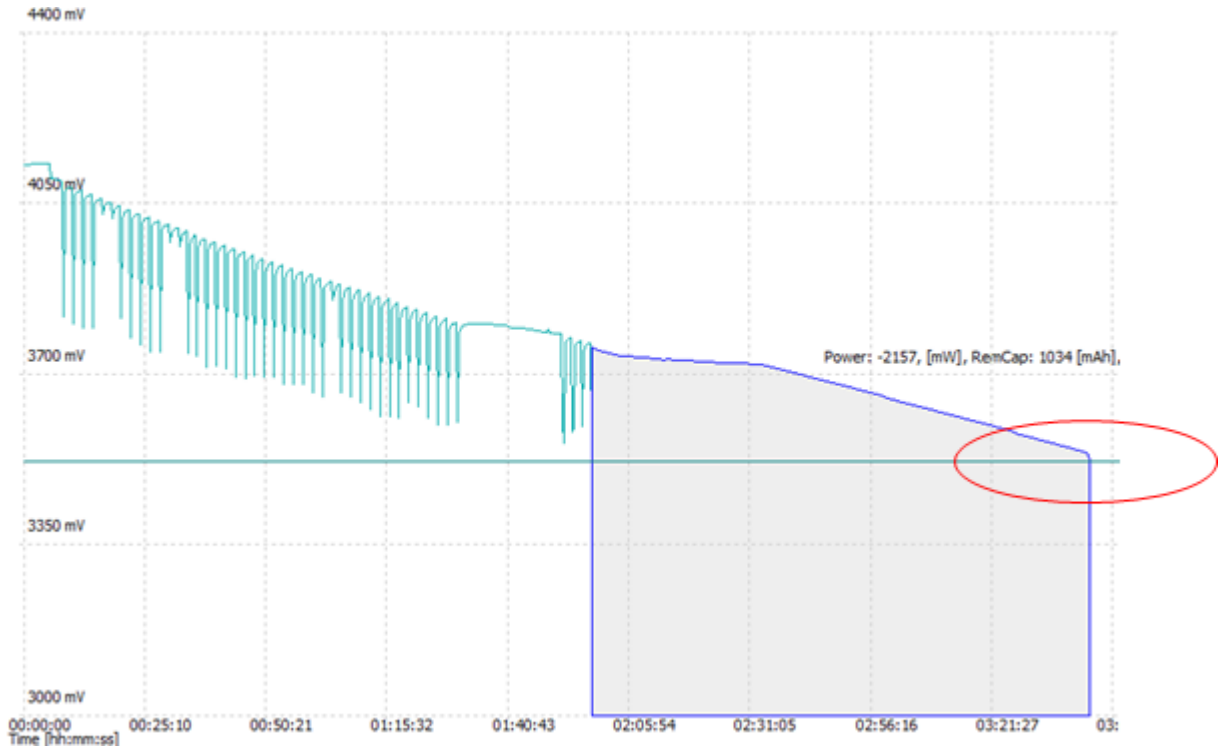
Figure 11. Flat Zone Simulation Termination

3.2 Inadequate Load Select

The default setting for Load Select can be inadequate if the load changes significantly which can cause the predicted load to be incorrect:
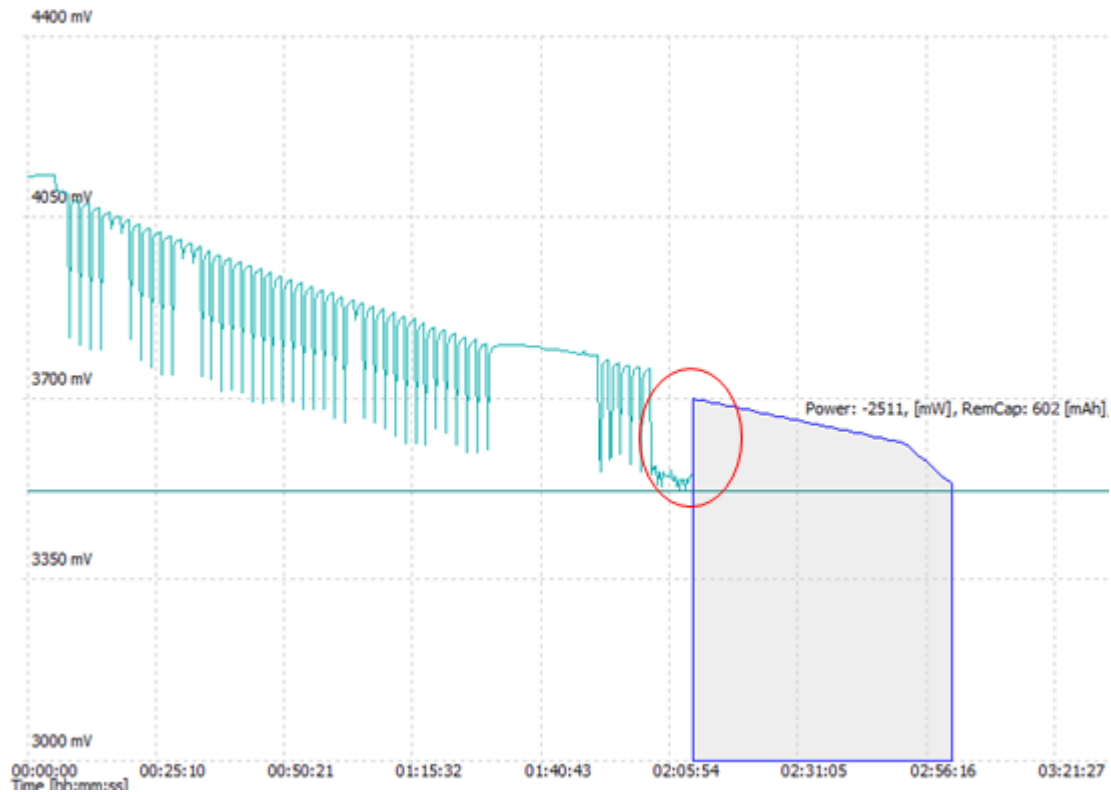
Figure 12. Simulated Voltage Mismatch

The gauge uses the average load since start of discharge in this example. While this is a good choice for most applications, it will not work well for this example and cause a mismatch in predicted capacity vs. true capacity. The simulation shows that the gauge overestimates simulated voltage because it underestimates the load, hence there is a gap between actual voltage and simulated voltage as indicated by the red ellipse in this picture.

3.3 Solutions

Changing Load Select will eliminate the jump in SOC for this application at the expense of underestimating capacity in possible other uses cases where the load is not significantly increased close to end of discharge.

The simplest method is to change the Load Select from the default (average load from start of discharge) to a static, user defined load that is close to the maximum load.
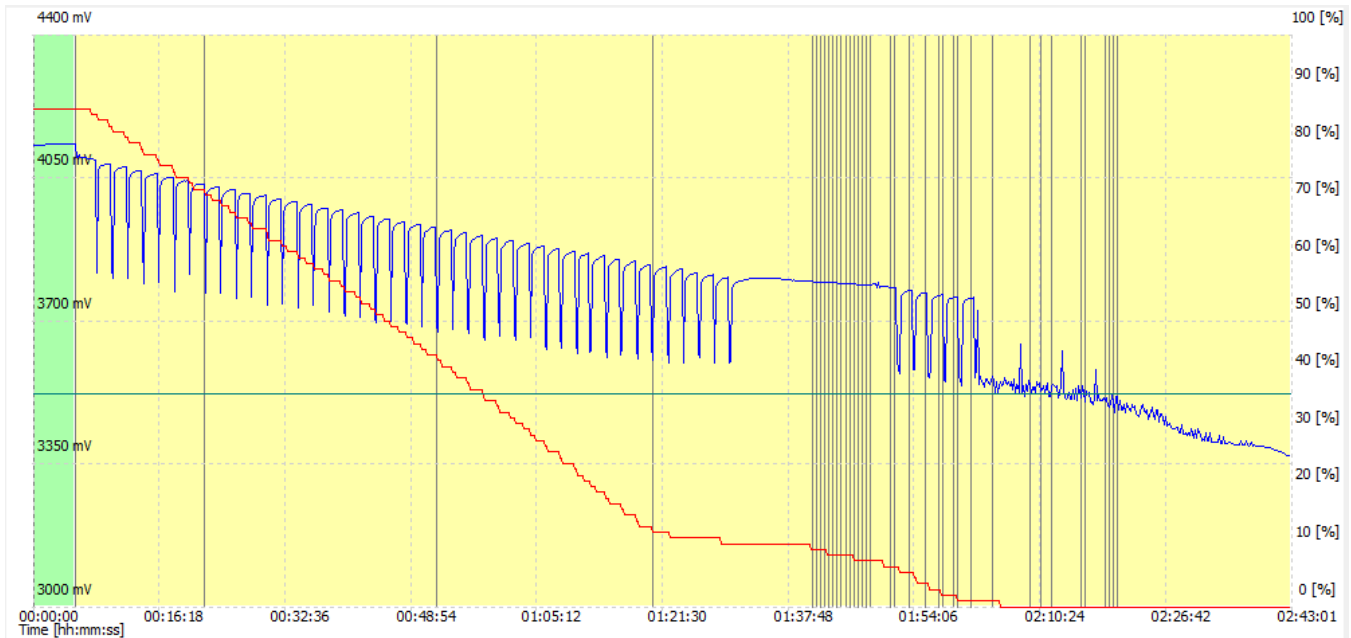
Here is an example for a user defined load (1.5C):

Figure 13. User Defined Load

The gauge will underestimate capacity during the earlier parts of the discharge because the actual average load is significantly less than the user defined load (C/2 vs. 1.5C). It will eliminate the jump in SOC at the end of discharge but gauging performance in general is poor due to the severe underestimation of capacity for most of the discharge.

An alternative approach is to improve simulation stability by shifting the Terminate Voltage threshold into the steep part of the simulated, loaded voltage and subtracting excess capacity with the Reserve Capacity parameter.

This application requires the gauge to report 0% SOC at a cell voltage of 3500 mV. This is high enough for the simulated, loaded voltage to shift into the flat zone. Changing this to 3200 mV and subtracting excess capacity (500 mAh) allows for better simulation and capacity predictions:

Terminate Voltage = 3200 mV
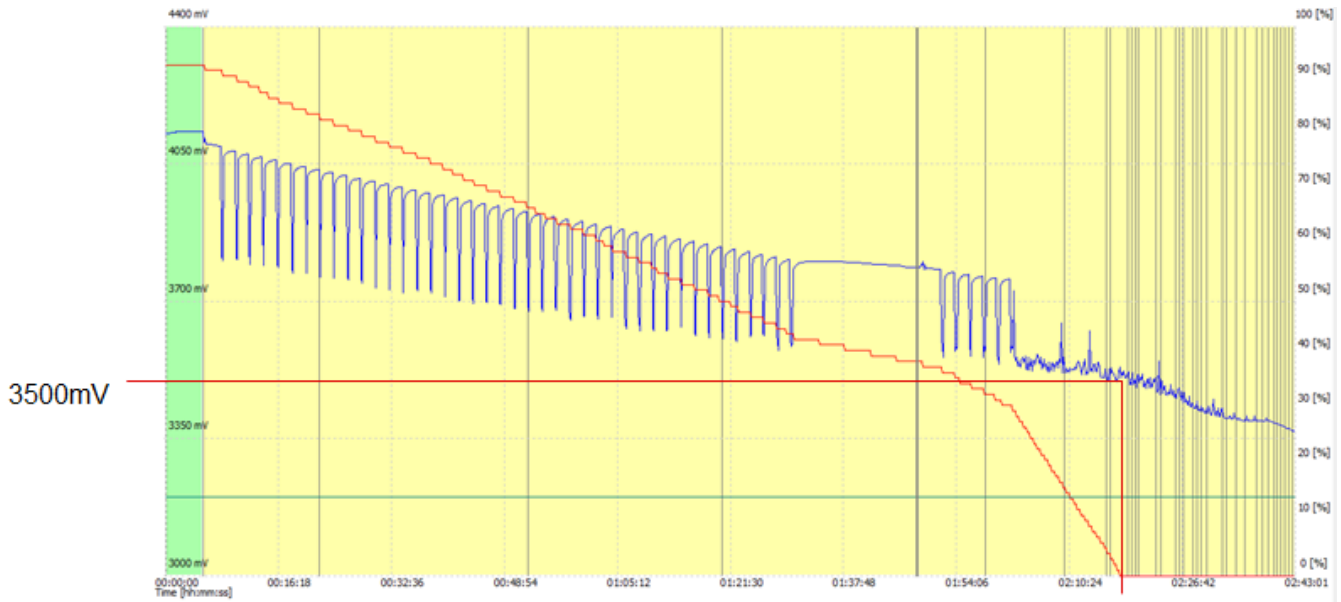
Reserve Capacity = 500 mAh

Figure 14. Reserve Capacity and Lower Terminate Voltage

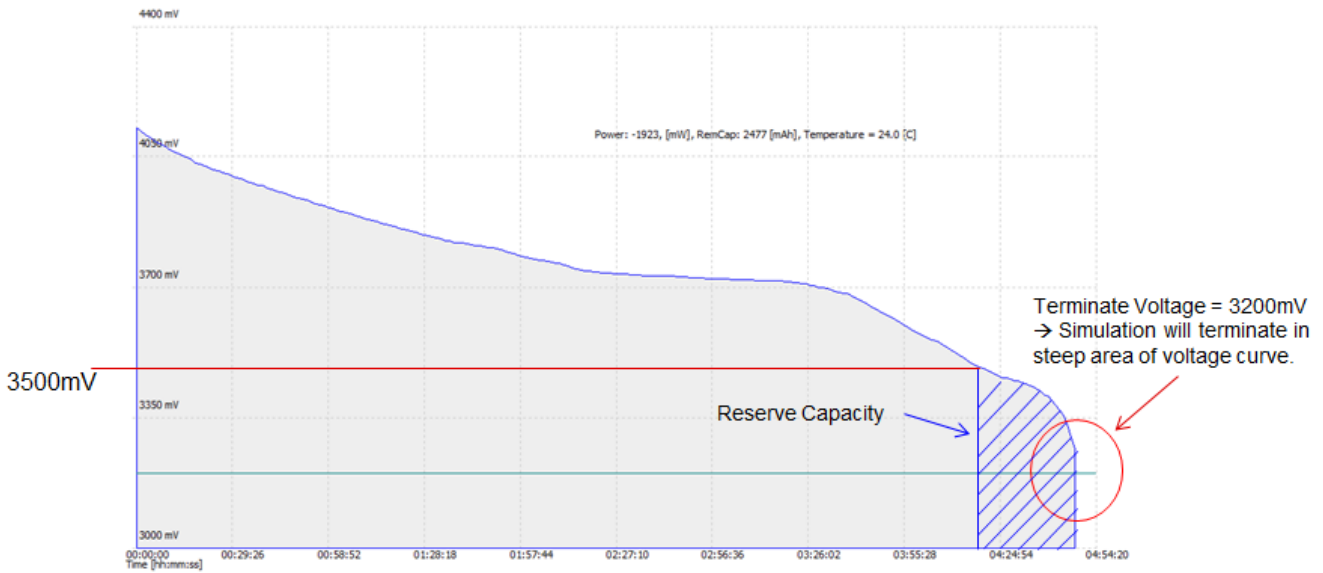Note that the effective voltage where the gauge hits 0% SOC is 3500 mV

Figure 15. Capacity Simulation

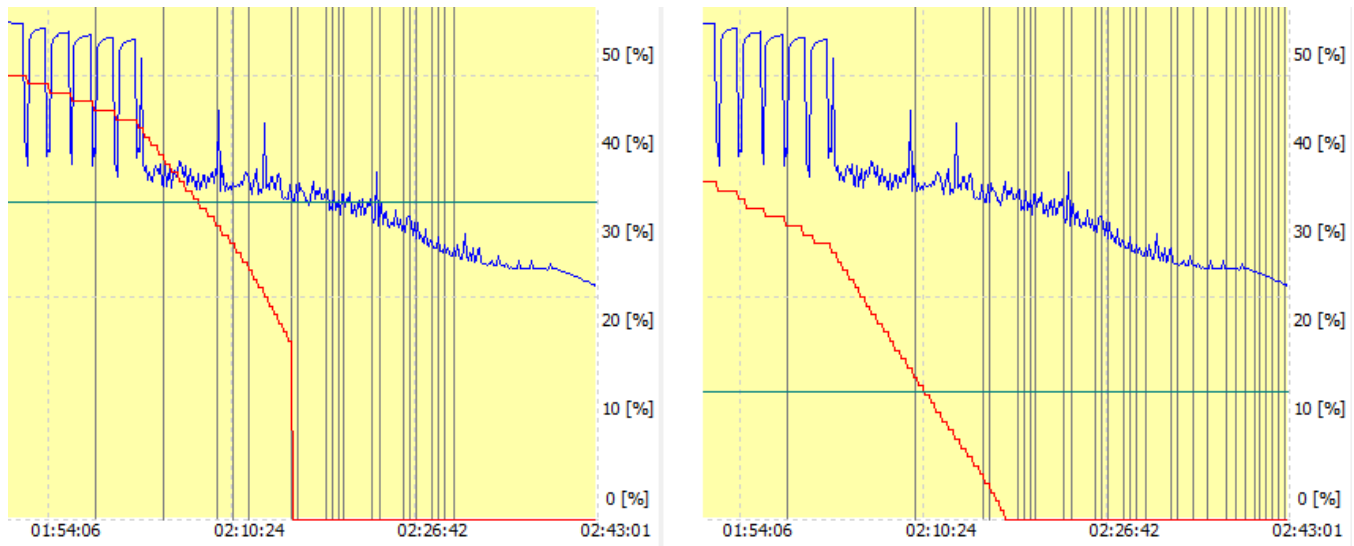Comparison between original configuration and optimized configuration:

Figure 16. Before and After Optimization

A good approximation of adequate Reserve Capacity can be determined by analyzing a constant current discharge with a typical high load for the application:

Integrate the charges passed between the desired Terminate Voltage (for example, 3500 mV) and the lowered Terminate Voltage (for example, 3200 mV, or any voltage in the steep zone and greater than 3000 mV) and use the result for Reserve Capacity.

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