![TEXAS INSTRUMENTS]

Application Report
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Impedance Track Fuel Gauge Accuracy Test for GSM Phone Applications

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ABSTRACT

The Texas Instruments Impedance Track™ (IT) fuel gauge is designed for reporting remaining battery capacity and run time accurately. To effectively accomplish this reporting a real application environment must be used for test results. The test board should be designed as similar to the real application circuit as possible. This application report outlines the procedure for implementing an accuracy test for GSM and Smart phone applications using the TI System Side Single Cell Impedance Track Fuel Gauge bq27500. The test setups, battery chemistry selection, and battery learning cycle are discussed in this report. Finally, the test results demonstrate that less than 1% remaining capacity accuracy can be achieved by the Impedance Track Fuel Gauge.

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1   Impedance Track Algorithm Background

The gas gauge algorithm uses three types of information to calculate Remaining Capacity (*RM*) and Full Charge Capacity (*FCC*):

- Chemical—Depth of Discharge (*DOD*), and maximum chemical capacity Q_{max}
- Electrical—internal battery resistance dependence on DOD, or State of Charge (SOC). SOC equals 1 minus DOD.
- External—load and temperature.

Full Charge Capacity is defined as the amount of charge passed from a fully charged state until the system Terminate Voltage is reached at a given rate of discharge (after subtracting the reserve capacity).

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> **Note:** FCC depends on the rate of discharge and is lower at higher rates and low temperatures because the cell I*R drop causes the *Terminate Voltage* threshold to be reached early.

Relative State of Charge (RSOC) is defined as:

RSOC = (RM $\times$ 100) $\div$ FCC

The algorithm differentiates between *charge*, *discharge* and *relaxation* modes of operation. See the *Theory and Implementation of Impedance Track™ Battery Fuel-Gauging Algorithm in bq2750x Family* (SLUA450) application report for additional details.

These items are updated by the Impedance Track algorithm:

- Chemical Depth of Discharge (DOD) or State of Charge (SOC = 1 − DOC)
- Q_{max}
- Resistance
- Temperature Model
- Remaining Capacity (RM) and Full Charge Capacity (FCC)

The Relative State of Charge (RSOC) Error is defined as:

RSOC Error = RSOC $_{calculated}$ − RSOC$_{reported}$

where

RSOC$_{calculated}$ = (FCC − Q_{start} − PassedQ) $\times$ 100 $\div$ FCC
and **RSOC$_{reported}$** is the RSOC reported by bq27500 Impedance Track algorithm.

Remaining Capacity Error is defined as:

RM Error = (RM$_{calculated}$ − RM$_{reported}$) $\div$ FCC

where

RM $_{calculated}$ = FCC − Q_{start} − PassedQ

and **RM $_{reported}$** is the RM reported by bq27500 Impedance Track algorithm. **PassedQ** is passed charge from the beginning of discharge to present. **Q_{start}** is the starting charge at the beginning of discharge.

1.1 References

For additional information related to this application report, see:

- *Theory and Implementation of Impedance Track™ Battery Fuel-Gauging Algorithm in bq2750x Family* (SLUA450)
- *Going to Production with the bq2750x* (SLUA449)
- *bq2750xEVM System Side Single-Cell Impedance Track™ Technology Evaluation Module* (SLUU287)
- *bqEASY for Single Cell Impedance Track™ Devices* (SLUU307)

2 GSM Phone Accuracy Test Preparation

2.1 GSM Phone Application

Unlike notebook battery applications having a relatively constant load profile, cell phones, smart phones, or PDAs (GSM, CDMA, 3G GSM or 3G CDMA communication protocol dependent) have a *pulsating* load profile. This application type always raises questions regarding, "how well Impedance Track can accurately predict the battery remaining capacity and what is the impact of the pulsating current?" In this example, a NOKIA 6106b GSM phone is used to check the Impedance Track accuracy.

As mentioned in *Theory and Implementation of Impedance Track™ Battery Fuel-Gauging Algorithm in bq2750x Family* (SLUA450) application report, the **Qmax** and **Resistance** can be updated only when certain criteria are met. There is some confusion that under a pulsating current, an accurate OCV reading may be difficult to achieve. In order to reveal the truth, this criteria should be carefully examined.

First, zero current is *not* needed for an Open Circuit Voltage (OCV) reading. Only a *low* current (that is, less than C/20 rate) is needed. This is very common in cell phone and smart phone applications when they are in standby mode. During the relaxation, a short spike current pulse does not *wake-up* the gauge from relaxation mode. The current must remain high and exceed a specified time limit for the cell to exit the relaxation mode.

Second, if a single voltage read point is taken exactly at the moment of the spike, it is ignored because the Impedance Track checks if the current exceeded a specific current threshold. If it does, Impedance Track uses the previous OCV reading.

2.2 Accuracy Test Requirements

To correctly measure and calculate the Remaining Capacity (*RM*) and Full Charge Capacity (*FCC*) to get Relative State of Charge (RSOC), (1) the battery cell chemistry must be accurately selected through battery chemistry selection cycling and (2) the battery cell resistance profile must be accurately learned through battery cell learning cycle.

Before starting all battery cycling, the Print Circuit Board (PCB) with bq27500 should be carefully calibrated. Check application report *Going to Production with the bq2750x* (SLUA449) for the correct calibration procedure.

The test setup (Figure 1) includes:

- A bq27500 EVM or any application specified test board with bq27500.
- A PC with the bq Evaluation Software properly installed.
- A PC USB interface that is connected to the EV2300 communication module.

See the *bq2750xEVM System Side Single-Cell Impedance Track™ Technology Evaluation Module* (SLUU287) application report for detailed setup requirements.

The GSM phone original BL-4C battery pack is modified. The battery cell is carefully removed from the original battery pack. The cell protection circuit board is removed to expose the positive and negative terminal. The original thermistor is discarded. For proper operation of the phone, the thermistor terminal on the phone is connected to the thermistor on test board. The battery terminals from the phone then connect to battery terminals through wires. See Figure 1 for battery cell modification and test setup.

Figure 1. Test Setup With Battery Cell
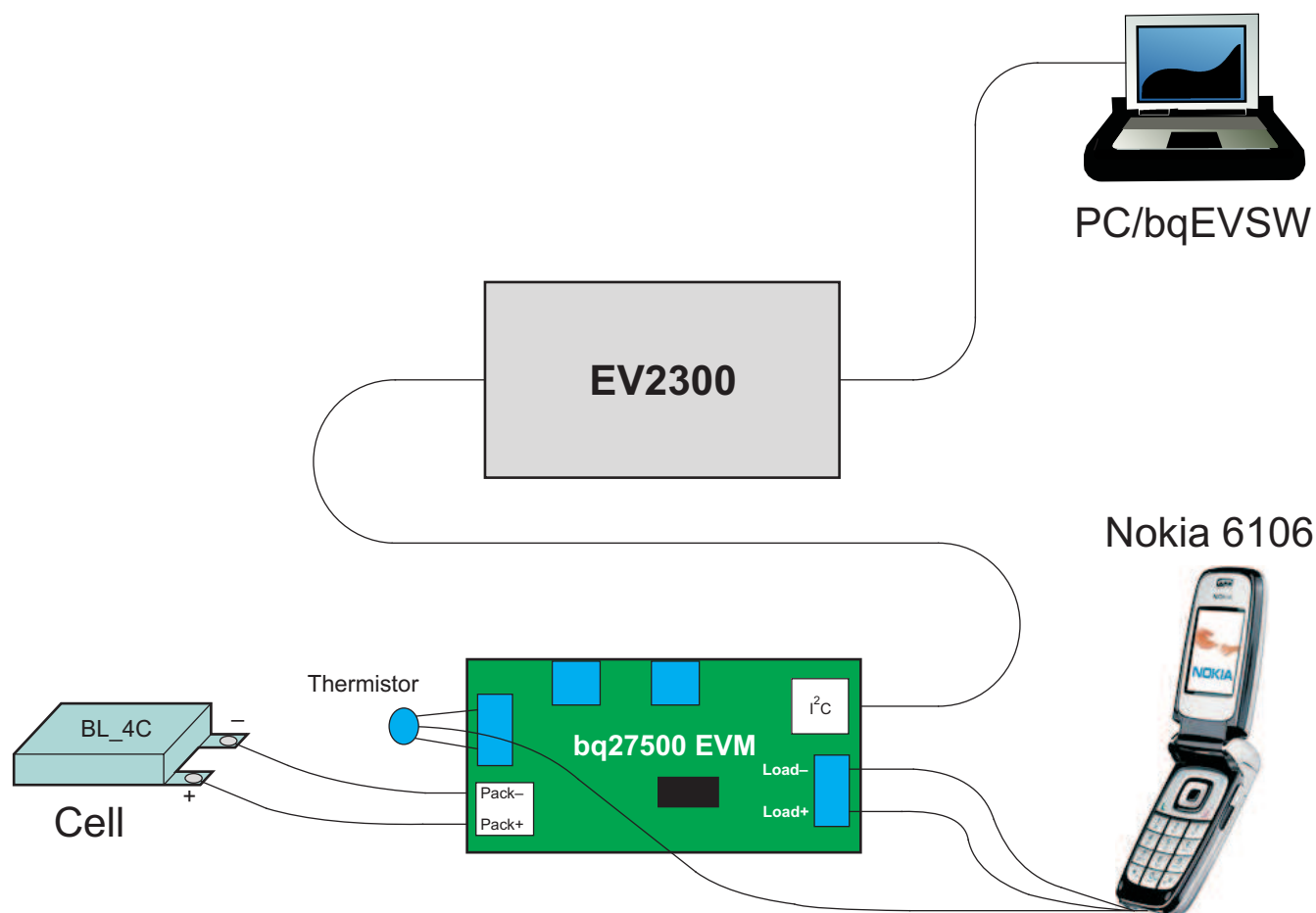
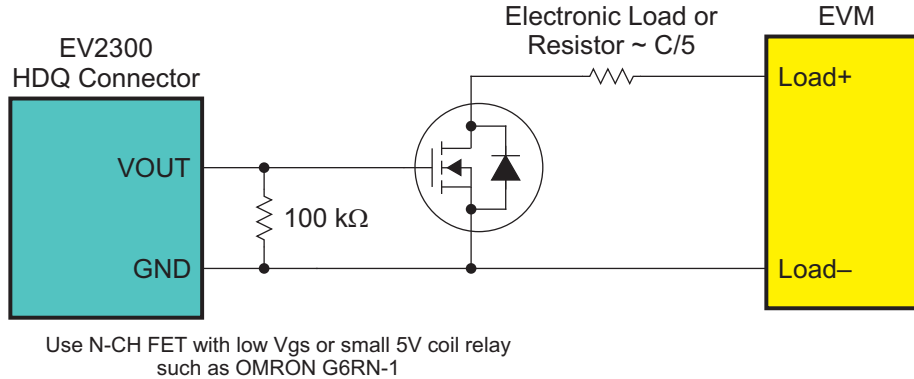## 2.3 Chemistry Selection Cycling

The battery cell chemistry must be carefully selected. The bq Evaluation Software provides a procedural tool called **bqEASY** that helps the user to set up the cell, based on the cell manufacturer specification and system requirements to do the chemistry selection cycle. bqEASY uses a four-point method for chemistry selection and the results are usually within 1% error of the actual chemistry learned from more sophisticated cycling system, such as the Arbin Instruments™system. TI offers the help for customer who needs to identify the cell chemistry using the Arbin Instruments system. The Arbin Instruments system takes more points when determining the cell chemistry, therefore it takes longer.

bqEASY has a chemistry database with most known chemistries that have been characterized in TI using the Arbin Instruments system. If the battery cell chemistry can not be matched to any known profiles, the battery cell needs to be sent back to TI to determine the actual chemistry through the Arbin Instruments system and a new profile can be generated.

For bqEASY to select the chemistry correctly, the cell must be charged very close to its maximum cell voltage. Normally, this is 4.2 V, before the chemistry selection cycling. The charge taper current should be less than C/100 when charging is terminated.

A programmable electronic load or resistor is also needed to generate a less than C/5 discharge rate during the discharge cycle. The chemistry selection cycle requires a controlled load profile (see Figure 2). The EV2300 HDQ port is used to periodically turn on the load using the FET or relay.

Figure 2. Configuration of Load Circuit

Use N-CH FET with low Vgs or small 5V coil relay
such as OMRON G6RN-1

Chemistry selection cycling will select the correct chemistry profile from the bqEASY built-in chemistry database and program these values into the bq27500 data flash for Impedance Track algorithm to use.
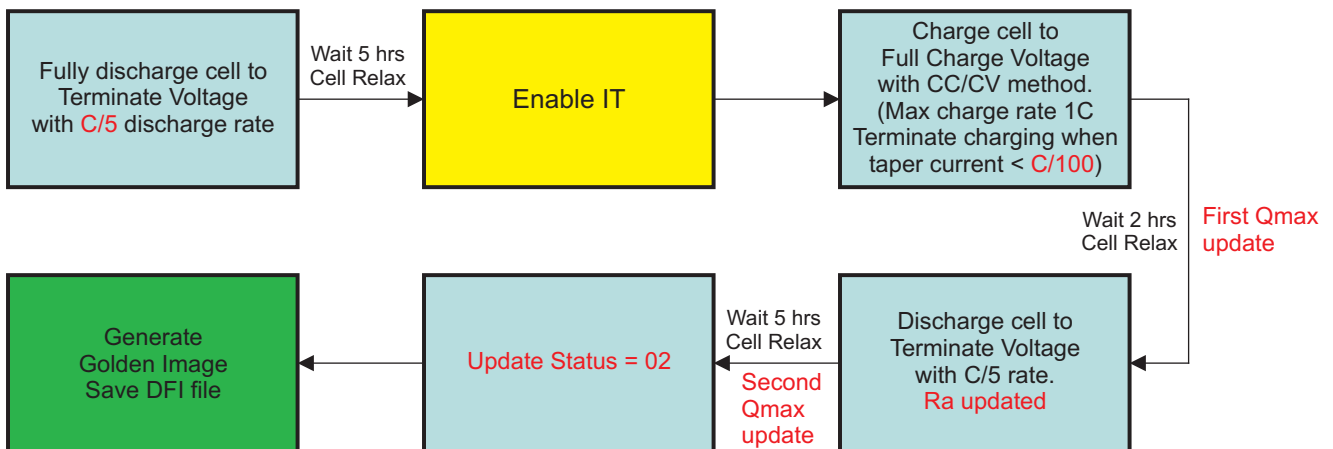
2.4 Battery Cell Learning Cycling

The battery learning cycle is used to obtain the actual cell Qmax and cell resistance value, updated based on the chemistry determined from Chemistry Selection Cycling. It is very critical that the correct chemistry be selected before proceeding with learning cycling.

A complete learning cycle consists of the procedure shown in Figure 3. Before starting the learning cycle, if the chemistry is known, the chemistry profile should be programmed into bq27500 data flash and the test board should be calibrated.

During the learning cycle, Qmax is updated twice. The first Qmax update happens after the charge cycle during the two-hour relaxation period. The second Qmax update happens after the second discharge cycle during the five-hour relaxation period. See the *Theory and Implementation of Impedance Track™ Battery Fuel-Gauging Algorithm in bq2750x Family* (SLUA450) application report for more information.

Figure 3. Learning Cycle Flow Chart

2.5 *Generate the Golden Image and Update bq27500 Flash Content*

After the cell learning cycle has completed the final five-hour relaxation, bq27500 is ready to be updated with the *golden image* (flash contents learned during the cycling). bqEASY provides the user-interface that helps you generate the golden image file and at the correct time, update the necessary flash contents with the value learned during the learning cycle. This includes updating the OCV table with correct Qmax value, updating all the resistance tables with learned resistance values, resetting the cycle count, disabling the Impedance Track algorithm for mass programming, and so forth.

Once the golden image is programmed into bq27500, the set up is ready for real application testing.

3 GSM Phone Accuracy Test and Results

The Nokia 6106 GSM phone used in this test is a registered phone. During the test, actual phone calls in and out of this phone along with applications such as playing games are carried out. The battery voltage and the discharge current are logged with time stamp. Using TI provided bq Evaluation software, the logging process can be easily implemented. The logging information is needed for post-processing to obtain the accuracy results. Depending on the battery capacity and the actual application, the total test time can range from five to nine hours. In this test, the LCD screen is frequently turned on to maximize the phone battery use.

As shown in Figure 4, the discharge current reported by the Impedance Track is being averaged by the Analog to Digital Converter (ADC) in bq27500 and by the Impedance Track algorithm. Although the GSM phone is running on GSM protocol[1] but the reported peak current is around 200 mA when the phone's LCD screen is on and only around 80 mA when the screen is off. When receiving a call, the current spike can go up to between 300 mA and 400 mA.

**Figure 4. Phone—RSOC and Discharge Current vs. Discharge Time**

t - Time - Hours:Minutes
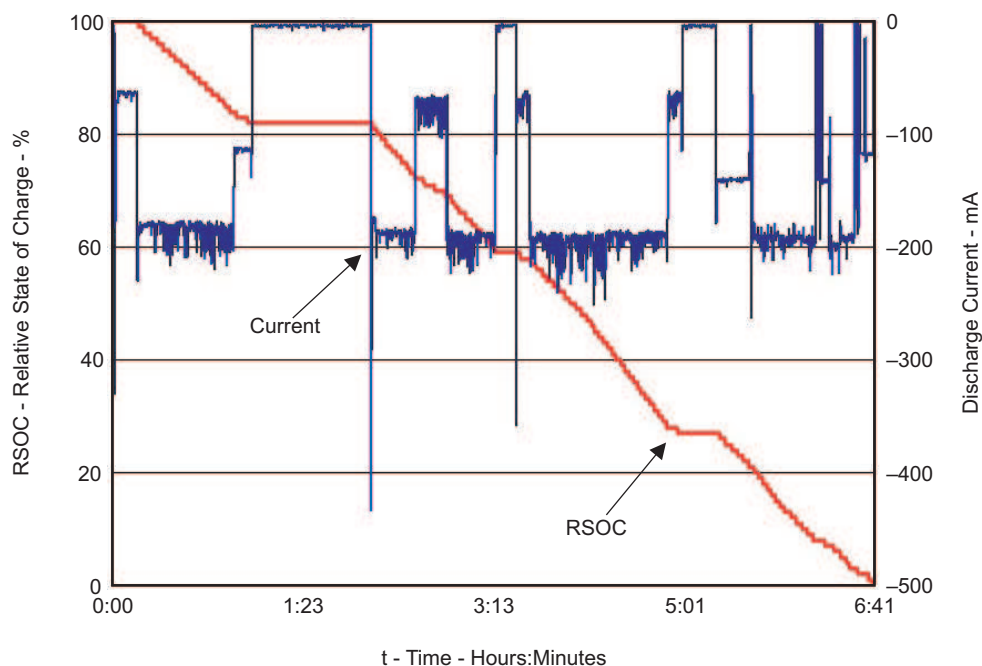
[1] GSM waveform: 1 A for 0.48 ms and 72 mA for 4.76 ms.

Figure 5. Phone—RSOC and Battery Voltage vs. Discharge Time

t - Time - Hours:Minutes
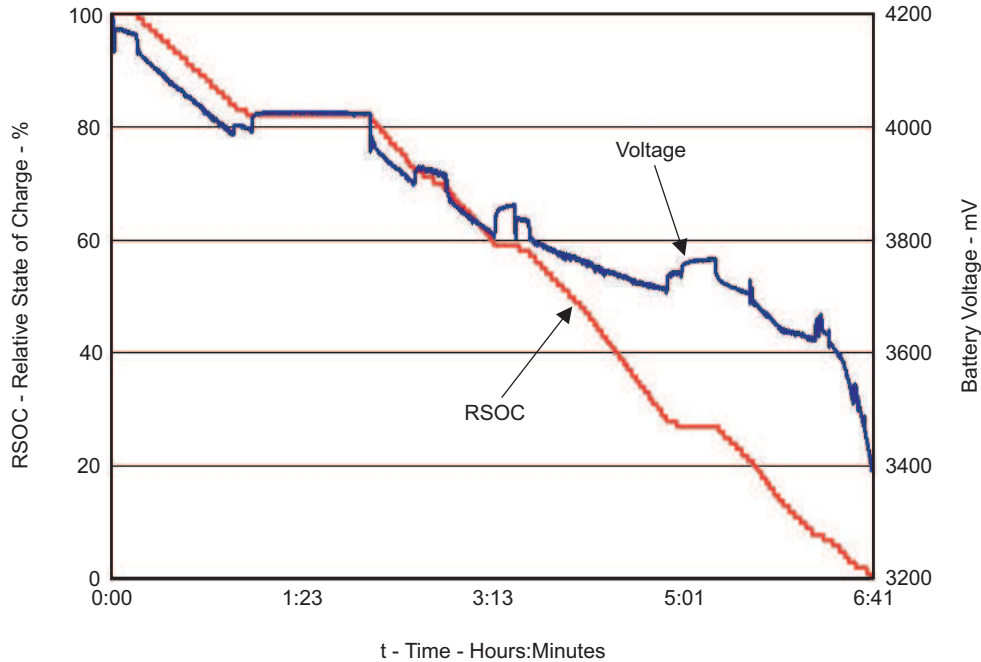
The RSOC accuracy for this particular test is calculated from the data log file and Figure 6 shows the RSOC accuracy during the entire discharge cycle. As the discharge starts, the error is about 1%, but as the phone goes into standby mode, which is around RSOC = 80%, the accurate OCV reading is taken by the Impedance Track, ir regardless of the high current spikes happening (with delay).

Figure 6. Phone—RSOC Accuracy vs. RSOC

RSOC - Relative State of Charge - %
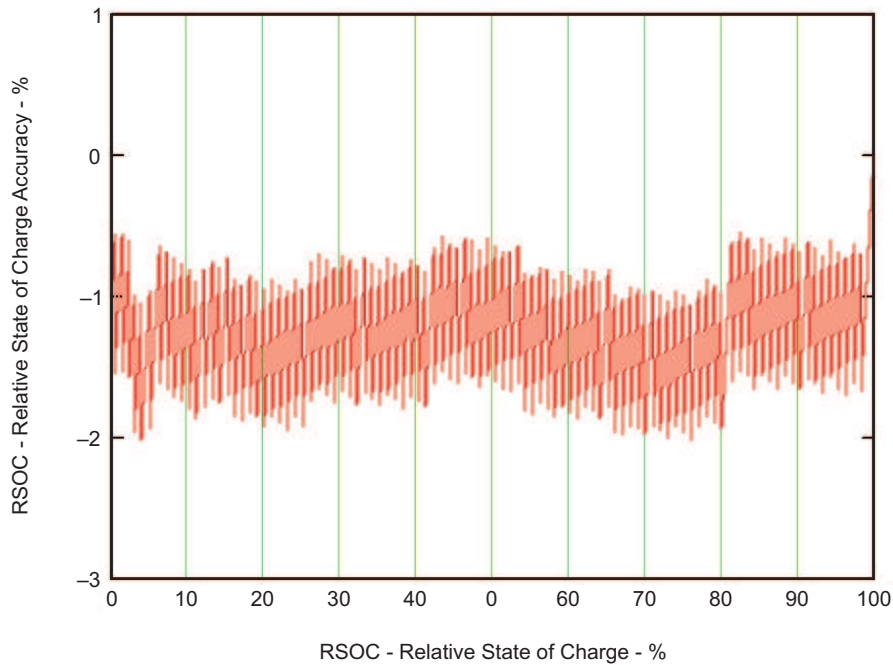
This test has proved that the Impedance Track algorithm works as expected even for pulsating load profile. The high current spike does not affect Impedance Track accuracy.

The Remaining Capacity accuracy is calculated. This is one of the critical parameters that can predict the actual run time of the cell phone. As shown in Figure 7, the RM accuracy is within 1%. During the entire application cycle, the Impedance Track algorithm has made multiple RM adjustments based on the load current, the battery temperature, and so forth. The bq27500 has very accurately reported the remaining capacity with less than 1% error during the entire discharge cycle.

Figure 7. Phone—Remaining Capacity Accuracy vs. RSOC
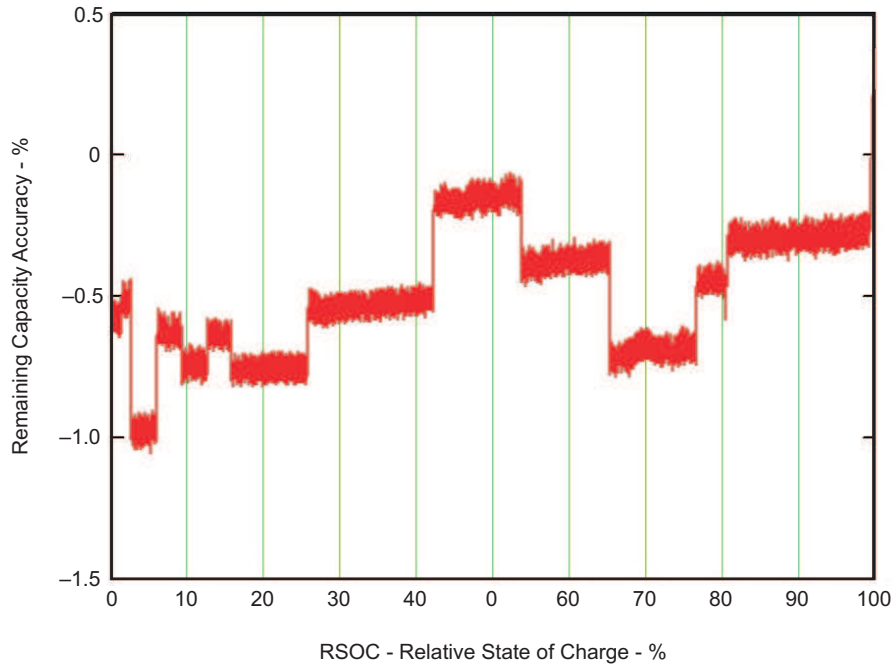
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