



Keywords: Li+, Li-Ion, battery characterization, fuel gauge, battery, fuel gauge algorithm

## APPLICATION NOTE 2412

# Characterizing a Li+ Cell for Use with a Fuel Gauge

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*Abstract: An accurate battery fuel gauge relies on knowing several characteristics about the battery behavior under differing environmental and operating conditions. To gather this needed information, the battery must be characterized under known conditions. This application note outlines a step-by-step method to characterize a battery including how to collect and then interpret the data. It also explains how to integrate the data into the evaluation software of a Maxim battery management device for use with a fuel gauge software algorithm.*

## Introduction

To accurately estimate the remaining capacity of a Li+ cell, it is necessary to know how the cell changes with temperature and various current loads. This application note outlines a method to characterize a Li+ cell, collect and interpret the data and then load the data into the evaluation software of a Maxim Battery Management device for use with the fuel gauge. The device will monitor the current flowing in and out of the Li+ cell with the Accumulated Current Register (ACR) and the fuel gauge will compare the ACR to the calculated full and empty points of the cell to determine the remaining capacity.

## Procedure to Characterize a Li+ Cell

### 1. Determine the charge and discharge profiles

The best way to characterize a Li+ cell is to create an environment as close to the actual application as possible. This includes the protection circuitry, a discharge profile consisting of the typical active and standby currents of the application, a charging profile, and the ambient temperatures that the application may experience. This requires a method to simulate the charging and discharging of the cell and the ability to vary the temperature. Typically, the temperatures used for characterization range from 0°C to 40°C in steps of 10°C. The evaluation software requires the temperature points be 10°C apart.

The active current is the typical current drawn from the Li+ cell when the application is in use by the end user. The standby current is the typical current drawn from the Li+ cell when the application is in an idle state.

The Active Empty and Standby Empty Points that are referred to by the fuel gauging portion of the evaluation software are defined as the capacity where the Li+ cell reaches the empty voltage (as defined by the user) under the load of the active current and standby current, respectively. The empty points are illustrated in **Figure 1**, which is found in Step 5. The user can define a separate empty voltage for the active current and standby current loads. The Full Point is defined as the capacity where the Li+ cell is considered fully charged by the charging circuitry. See application note 131, "[Lithium-Ion Cell Fuel Gauging with Maxim Battery Monitor ICs](#)" for details on using Maxim Battery Management devices with a fuel gauge.

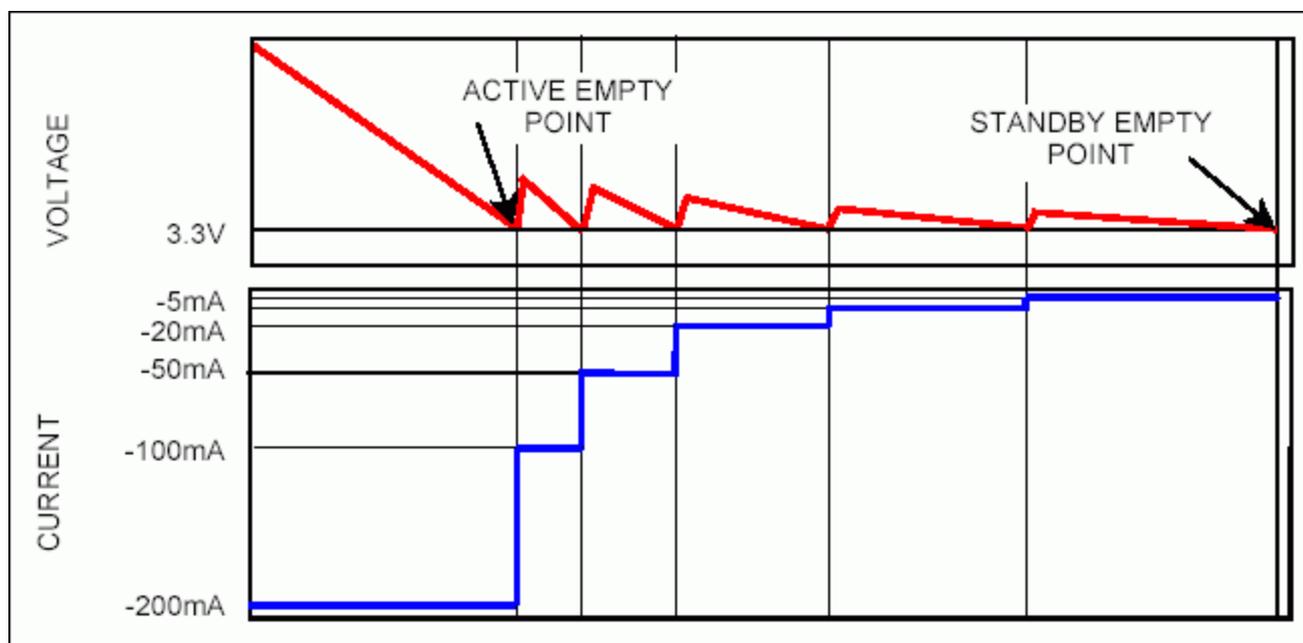


Figure 1. Voltage and current over time during a stepped down discharge.

## 2. Calibrate the offset register of the device

With the Maxim Battery Management device properly connected to the Li+ cell, as specified in the specific device data sheet, the next step is to calibrate the offset of the device. Using the evaluation software for the specific device being used, calibrating the offset is easy. Make sure there is no load on the circuit and click the Calibrate Offset button on the Meters Tab. If the evaluation software is not being used, a step-by-step method of calibrating the offset is available in application note 224, "[Calibrating the Offset Register of the DS2761.](#)"

## 3. Begin logging the data

Data can easily be logged using the evaluation software. Simply go to the Data Log Tab, set the Sample Interval to 15 seconds and click Log Data. The 15 seconds interval is recommended because it records enough data to capture all of the data points without creating a file that is too large. All the real time data will be logged to the filename specified until the Stop Logging Data button is pressed.

## 4. Cycle the cell at room temperature

An important initial step is to break-in the cell. Typically, the capacity of a Li+ cell will change by several percent during the first cycles of its life. It is recommended to cycle the cell through 20 complete charge and discharge cycles before characterizing the cell. Logging the data at this time is not required, but doing so will allow the user to monitor any additional offset in the device that needs to be taken into consideration when analyzing the final data.

## 5. Start the calibration at the highest temperature

It is recommended to start the characterization at the highest temperature because typically this is where the Li+ cell will have the largest capacity, which provides a good reference point for the rest of the data. Allow the cell to settle at the highest temperature and then fully discharge the cell to the Standby Empty Point. Next, fully charge the cell according to the application's charging profile; this will be the Full Point for that temperature. Then fully discharge the cell to the user defined active empty voltage under the active current load to find the Active Empty Point. Finally, change the load to the standby current value and continue to

discharge the cell to the standby empty voltage to find the Standby Empty Point.

To speed up the process, the user can select to step down the current from the active current load to the standby current load. Consider an example, illustrated in Figure 1, where the active current was defined to be 200mA, the standby current was defined to be 5mA, and the empty voltage was defined to be 3.3V for both. It would be acceptable to discharge the cell under the 200mA load to 3.3V to reach the Active Empty Point, and then, after allowing the cell to relax for a few seconds, place a 100mA load on the cell until the empty voltage is again reached. Continue to step down the current load to 50mA, 20mA, 10mA and finally 5mA until the empty voltage is reached and that point will be the Standby Empty Point. This will get the cell to the same point without having the extended time required to discharge the cell under a 5mA load.

## 6. Repeat at each temperature

As soon as the Standby Empty Point of a temperature is reached, go to the next temperature and begin a full charge. When the charge is completed, that will be the Full Point at that temperature. Follow that with a discharge to the Active and Standby Empty Points. Continue this process to step through all of the desired temperature points.

## Determine Data Points from the Characterization Data

The evaluation software logs the real time data to a text file in a tab-delimited format for easy import into a spreadsheet. The data can then be sorted or graphed to find the data that is needed.

## 7. Find all of the necessary data points

The user can then sort through the log file and mark all of the full points, active empty points, and standby empty points. An easy method for doing this is just to scroll through the data and look at the Current column and note changes in the current readings and place an 'x' in an unused column of the spreadsheet. For example, when the current changes from charging to discharging mark a full point, or when the active current load ends mark as an active empty point, or when the current changes from discharging to charging mark as a standby empty point. Then use the AutoFilter function of the spreadsheet application to easily view the points of interest that have been marked.

**Table 1** shows an example of data that was collected by the DS2761 in characterizing a Li+ cell with the data points of interest filtered out and labeled. The charging profile used in this example was a constant current charge of 900mA until the voltage reaches 4.2V. Then the cell was charged at a constant voltage of 4.2V until the current tapered below 70mA, which was defined to be the Full Point. The Active Empty Point was defined to be 3.0V under a 350mA load. The Standby Empty Point was defined to be 2.7V under a 3mA load. The cell was characterized at 40°C, 30°C, 20°C, 10°C and 0°C.

If the data was logged during the cycling of the cell in Step 4, the empty points can be compared to see if there is a trend, either increasing or decreasing, which would indicate some offset in the current readings. Because the cycling is done at a constant temperature, the empty points should all line up if the offset is completely cancelled out. If an offset were detected, it would need to be included in the data as an offset added to the ACR column to get an accurate characterization of the Li+ cell.

**Table 1. Characterization data for Li+ cell**

Time	Voltage	Current	Temperature	ACR	Mark	Label
1:13:26 AM	3.25	918.317	40	62.38	x	Start
2:12:41 AM	4.158	480.817	40	927.97	x	Break
2:41:34 AM	4.197	68.688	39.75	1032.7	x	Full
5:26:54 AM	3.035	-345.297	40.125	81.19	x	Active Empty

7:36:03 AM	2.757	-2.475	39.875	71.04	x	Standby Empty
8:35:50 AM	4.163	440.594	30.125	930.2	x	Break
9:06:28 AM	4.197	69.307	30	1032.2	x	Full
11:50:18 AM	3.006	-344.678	30.375	94.06	x	Active Empty
1:44:11 PM	2.757	-3.094	30.125	80.69	x	Standby Empty
2:45:07 PM	4.168	376.856	20.125	929.95	x	Break
3:18:54 PM	4.197	69.926	21.125	1031	x	Full
6:00:16 PM	2.987	-345.297	20.625	110.15	x	Active Empty
7:46:43 PM	2.757	-3.094	20.5	90.1	x	Standby Empty
8:51:04 PM	4.177	306.312	10.375	928.71	x	Break
9:29:26 PM	4.197	70.545	10.5	1028.5	x	Full
12:06:02 AM	2.962	-346.535	10.875	130.94	x	Active Empty
2:01:00 AM	2.757	-3.094	10.75	100.5	x	Standby Empty
3:16:05 AM	4.182	230.817	0.625	919.06	x	Break
4:00:59 AM	4.197	69.926	0.5	1019.3	x	Full
6:28:55 AM	2.943	-350.248	1.25	161.63	x	Active Empty
9:18:10 AM	2.777	0	0.875	113.61	x	Standby Empty

## 8. Determine the capacity data points

The data used to determine the full and empty points of the Li+ cell at the different temperatures will be the data from the ACR column of the log file. The full and empty points are relative data points and need to be referenced to one fixed data point. The Standby Empty Point at the highest temperature is selected to be the reference point because it is typically the lowest point the ACR will reach during a characterization (this point is highlighted in Table 1). Therefore, all readings will be greater than this point to make for easy data storage.

**Table 2** shows the ACR readings at each point of interest taken from Table 1. The Standby Empty Point at 40°C is selected to be the reference point, so all ACR readings should have 71.04mAhrs subtracted from them to determine the other full and empty points. The simple table of full and empty points relative to the Standby Empty Point at 40°C is shown in **Table 3** and can be easily entered into the evaluation software to be stored in the device.

**Table 2. Full and empty points extracted from Table 1**

Temperature	0	10	20	30	40
Full	1019.3	1028.5	1031	1032.2	1032.7
Standby Empty	113.61	100.5	90.1	80.69	71.04
Active Empty	161.63	130.94	110.2	94.06	81.19

**Table 3. Full and empty points referenced to standby empty point at 40°C**

Temperature	0	10	20	30	40
Full	948	957	960	961	962
Standby Empty	43	29	19	10	0
Active Empty	91	60	39	23	10

## 9. Determine the break point

A data point that will be of interest for estimating the charge time remaining is the break point. The break point is used to approximate the ACR curve during a charge with 2 lines, as illustrated in **Figure 2**. The break point is selected by the user to be the point where the ACR curve "breaks" over so that the 2-line approximation has the least error.

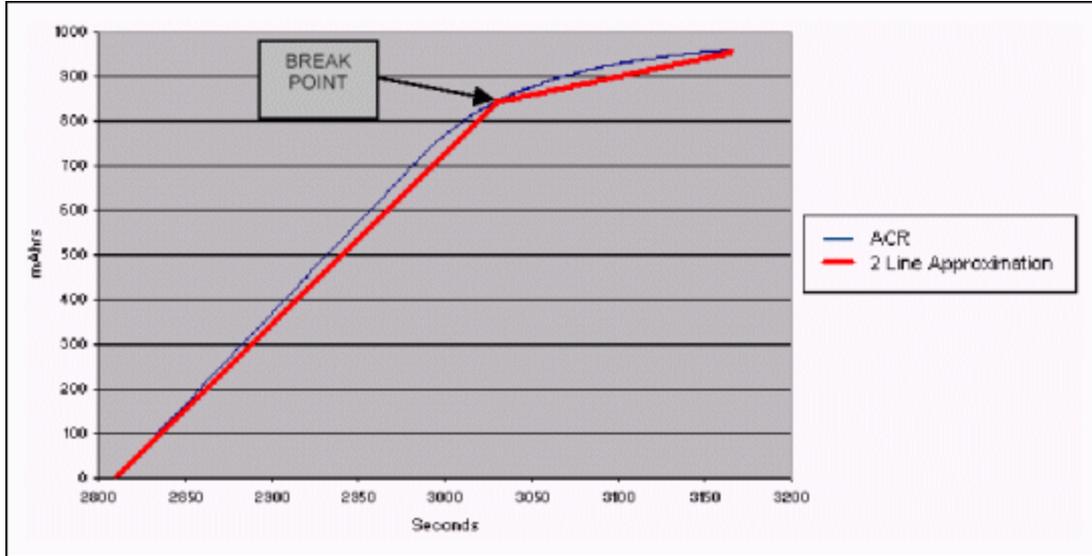


Figure 2. ACR and 2-Line approximation over time during a charge at 20°C.

The easiest method for determining the break point is to graph the ACR over time during a charge and visually determine where the curve breaks over. It is recommended to select the ACR curve from the middle temperature and use that break point for all temperatures. The break point will be stored as the number of mAh/hrs less than the full point. In Figure 2, the break point is approximately 100mAh/hrs less than the full point.

### 10. Determine the charge time estimation data points

The break point and the minutes from empty to full and the minutes from the break point to full at each temperature are required for the FuelPack algorithm to return an accurate estimation of the charge time remaining. It is necessary to go back through the data and mark all of the break points. This can be done by simply finding the full point and going back the number of mAh/hrs that were selected as the break point in Step 9.

From the data in Table 1, take the timestamp for each standby empty point at the previous temperature (which is when the charge started), the break point, and the full point as shown in **Table 4**. Table 4 also shows the ACR at each of the data points. Then use those timestamps to calculate the minutes between empty and full and the break point to full at each temperature as shown in **Table 5**. The fuel gauging algorithm of the evaluation software only allocates enough EEPROM for 3 temperatures worth of charge data, so data at 0°C, 20°C, and 40°C should be written to the device.

**Table 4. Timestamps for standby empty, break, and full points at each temperature**

Temperature	0		20		40	
	Time Stamp	ACR	Time Stamp	ACR	Time Stamp	ACR
Standby Empty	2:01:00 AM	100.5	1:44:11 PM	80.69	1:13:26 AM	62.38
Break	3:16:05 AM	919.06	2:45:07 PM	929.95	2:12:41 AM	927.97
Full	4:00:59 AM	1019.06	3:18:54 PM	1031	2:41:34 AM	1032.7

**Table 5. Data points needed for charge time remaining estimation**

Temperature	0	20	40
Empty to Full (minutes)	120	95	88
Break to Full (minutes)	45	34	29
Break Point (mAhrs)	100		

## Program Data to Device and Begin the Fuel Gauge

### 11. Program the device with the appropriate data

Use the evaluation kit to program the device with the data from Table 3 and Table 5. Manually enter that data into the text boxes of the Fuel Gauging Data sub-tab of the Pack Info Tab, as shown in **Figure 3**, and click the Write button (not shown). The data will be written to the scratchpad of the device and then copied to EEPROM.

	0C	10C	20C	30C	40C
Full Charge	948	957	960	961	962
Standby Empty	43	29	19	10	0
Active Empty	91	60	39	23	10

Charging	0C	20C	40C
Empty to Full (minutes)	120	95	88
Break to Full (minutes)	45	34	29
Break Point (mAhrs)	100		

*Figure 3. Load the data needed for fuel gauging into the evaluation software.*

### 12. Synchronize the ACR

A final step to accurately report the capacity of a Li+ cell is to synchronize the ACR of the device to the capacity of the cell. A simple way to do this is to fully charge the Li+ cell according to the charge profile of the application and then set the ACR to the Full Point at that temperature. In order to do this with the evaluation software, start the fuel gauge by clicking the Start Fuel Gauging button on the Fuel Gauging Tab, as shown in **Figure 4**. When the charge is complete, click the Full button on the Fuel Gauging Tab and the ACR will be in sync with the capacity of the cell.

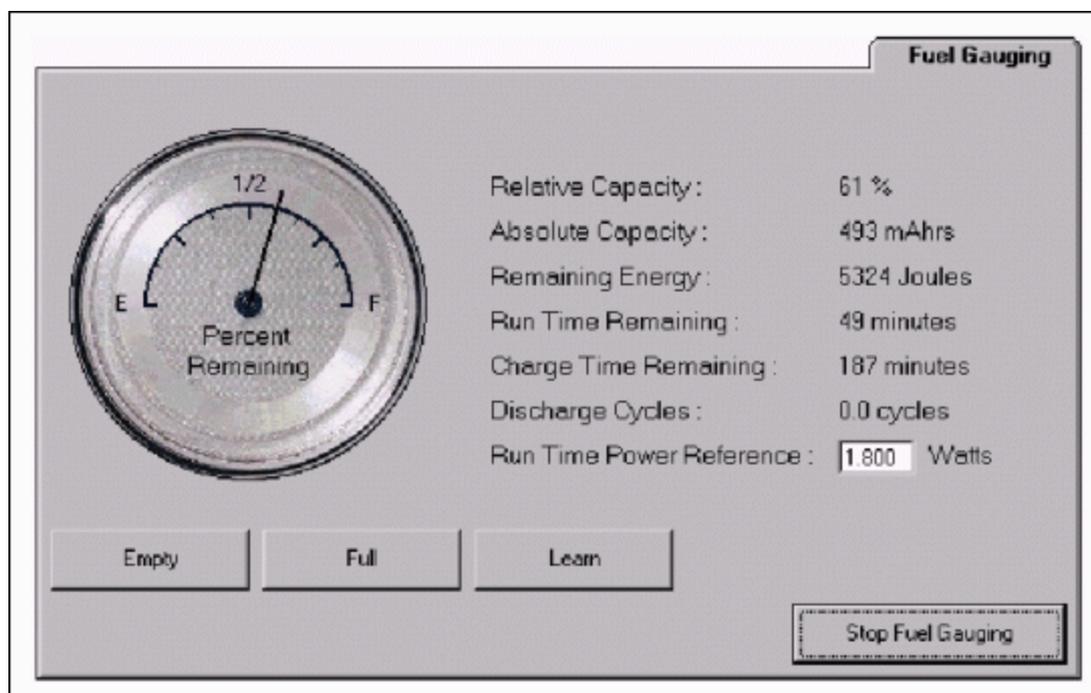


Figure 4. Fuel gauging tab of the evaluation software.

For more details on the data provided by the fuel gauge, refer to application note 131, "[Lithium-Ion Cell Fuel Gauging with Maxim Battery Monitor ICs.](#)"

## Summary

The Maxim fuel-gauging algorithm provides an accurate means of tracking the capacity of a Li+ cell as the cell is charged and discharged by the application. This requires knowledge of the capacity of the cell and how it will behave under the various loads and temperatures that the application may experience. Once the characterization data is collected and stored using the evaluation software provided by Maxim, the fuel gauge will accurately estimate the remaining capacity of the cell.

### Related Parts

[DS2761](#)

High-Precision Li+ Battery Monitor

### More Information

For Technical Support: <http://www.maximintegrated.com/support>

For Samples: <http://www.maximintegrated.com/samples>

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