

Design A Linear Li-ion Battery Charger For Portable Systems

Lithium-ion batteries help designers meet their goals of getting greener, whether used for storage or backup power purposes, or in highly integrated solutions to develop low-power solutions.

Energy-storage devices such as batteries continue to change how people live. Every year sees greater daily usage of battery-powered personal electronic devices. Moreover, demands for longer run times and smaller sizes are driving continuous growth in both the battery and semiconductor industries.

When the time to develop next-generation batteries takes longer than Moore's Law, the need arises for highly integrated, feature-rich ICs that deliver better performance. It's important to learn how to design with these types of ICs to simplify the development of new systems.

A battery converts chemical energy into electric potential, or voltage. If the energy can be restored, the battery is considered a secondary or rechargeable battery. Nickel-metal-hydride (NiMH) and lithium-ion (Li-ion) batteries are common in portable applications. Compared to NiMH batteries, Li-ion batteries offer a higher nominal voltage per cell, lower self-discharge rate, and energy density in mass and volume that make them attractive for powering lightweight and space-sensitive applications (Table 1).

WHY USE SINGLE-CELL LI-ION?

Li-ion batteries are relatively safe when designers use caution working with them. Table 2 shows some typical applications of Li-ion battery-powered systems. Single- and dual-cell applications comprise approximately 70% of the Li-ion battery market. Recent trends in space, cost, and weight reduction when designing small tools, digital camcorders, and similar devices are driving some dual-cell applications to become single-cell.

A single Li-ion cell can replace three NiMH battery cells in devices (Table 1, again). One advantage of reducing the number of battery cells in a system is to avoid extra design work for balancing multiple cells.

With the widely used Universal Serial Bus (USB), Li-ion batteries are able to be charged from USB ports on a majority of computers. A nominal voltage of 5 V makes the USB protocol attractive for single Li-ion cell applications. The USB specification defines the voltage drop budget in the range of 4.75 to 5.25 V for both host and/or hub, and no less than 4.45 V is allowed at the connector of host and/or hub.

Li-ion batteries typically use the constant-current constant-voltage (CCCV) algorithm for charging. When a charge voltage of 4.2 V per cell is met, the charger maintains a constant voltage until the termination condition is satisfied. A battery's voltage should be carefully designed with tolerance to avoid premature termination and hazard. The USB voltage range is well suited for simple step-down charger designs with a typical Li-ion voltage-regulation value of 4.2 V.

Two common step-down topologies are linear (low dropout, or LDO) converters and switching (buck) converters. Ideally, a switching topology offers 100% efficiency. After considering areas of power loss, efficiency may fall between 85% and 95%. Equation 1 calculates LDO efficiency:

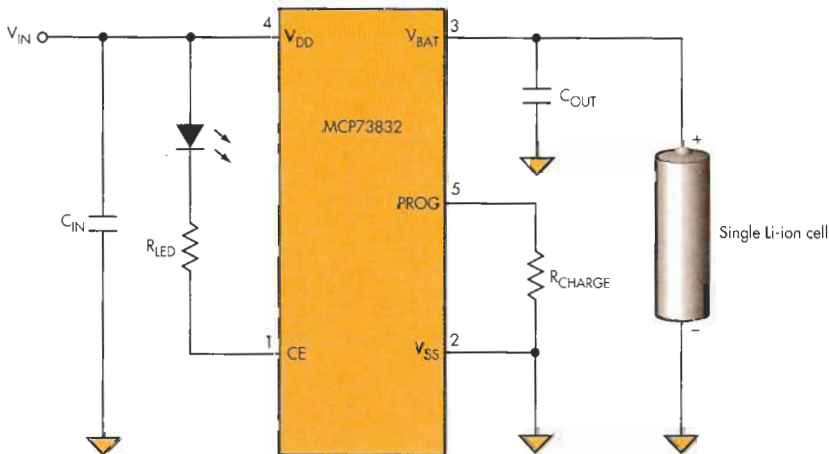
$$\eta = \frac{V_{OUT} \times I_{OUT}}{V_{IN} \times I_{OUT} + V_{IN} \times I_{GND}}$$

When I_{GND} is much smaller than I_{OUT} , it can be ignored. Thus, the efficiency of an LDO-based Li-ion battery charger can be simplified to the ratio of V_{OUT} to V_{IN} :

$$\eta_{CV} = \frac{4.2 \text{ V}}{5.0 \text{ V}} = 84\%$$

$$\eta_{BAT=3.0 \text{ V}} = \frac{3.0 \text{ V}}{5.0 \text{ V}} = 60\%$$

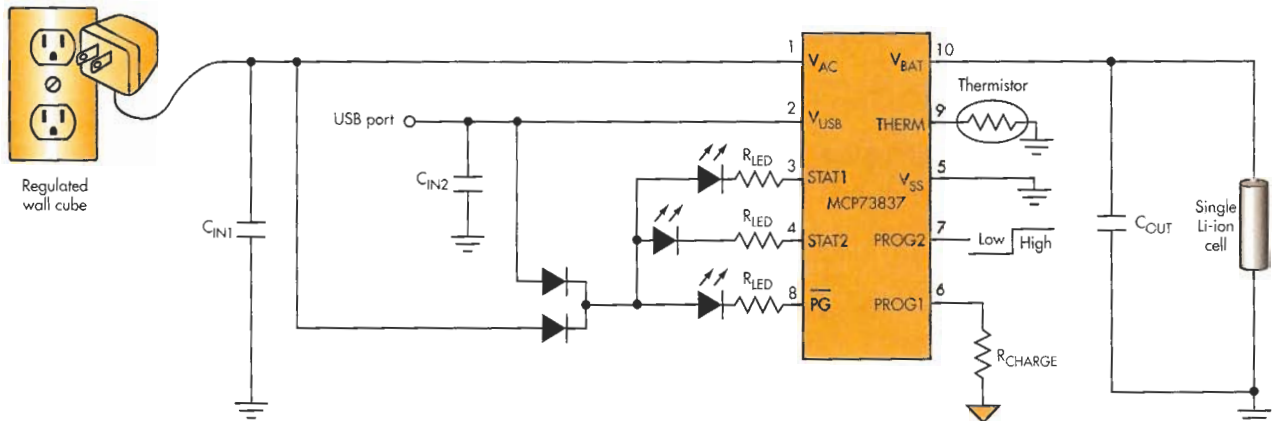
During a typical constant-current (CC) charging mode, the efficiency moves from



1. To operate, a typical baseline Li-ion battery charger typically needs an input capacitor, output capacitor, and programming resistor.



BRIAN CHU, senior applications engineer, Analog and Interface Products Division, received a BSEE and MSEE from the University at Buffalo, the State University of New York.



2. This dual-input Li-ion battery charger, which offers three different charge-current settings, can seamlessly switch between a wall wart (ac-dc adapter) and a USB port.

60% to 84%. The efficiency will stay at 84% for the constant-voltage (CV) charging mode. Thus, an LDO topology works well in single-cell Li-ion battery-charger designs when the input voltage is about 5 V.

An LDO topology also reduces cost by omitting inductors, and it avoids electromagnetic interference (EMI) challenges associated with switching topologies. But, if a fast-charging current above 1 A is required, a switching topology should be considered. Equation 4 presents a power-dissipation calculation that illustrates this:

$$\begin{aligned}
 P_{\text{DISSIPATION}} &= I_{\text{CHARGE}} \times (V_{\text{IN}} - V_{\text{OUT}}) \\
 &= 2 \text{ A} (5 \text{ V} - 3 \text{ V}) = 4 \text{ Watts}
 \end{aligned}$$

In this example, a battery-charging current of 2 A and a battery voltage of 3 V

are selected to show the worst condition in CC mode. An input voltage of 5 V is selected to simplify the calculation. When designing a system, the worst condition that's based on a given tolerance should be considered.

Even for a 35°C/W thermal-rated 4- by 4-mm quad flat no-lead (QFN) package, it's difficult to dissipate 4 W:

$$35^\circ\text{C/Watt} \times 4 \text{ Watts} = 144^\circ\text{C}$$

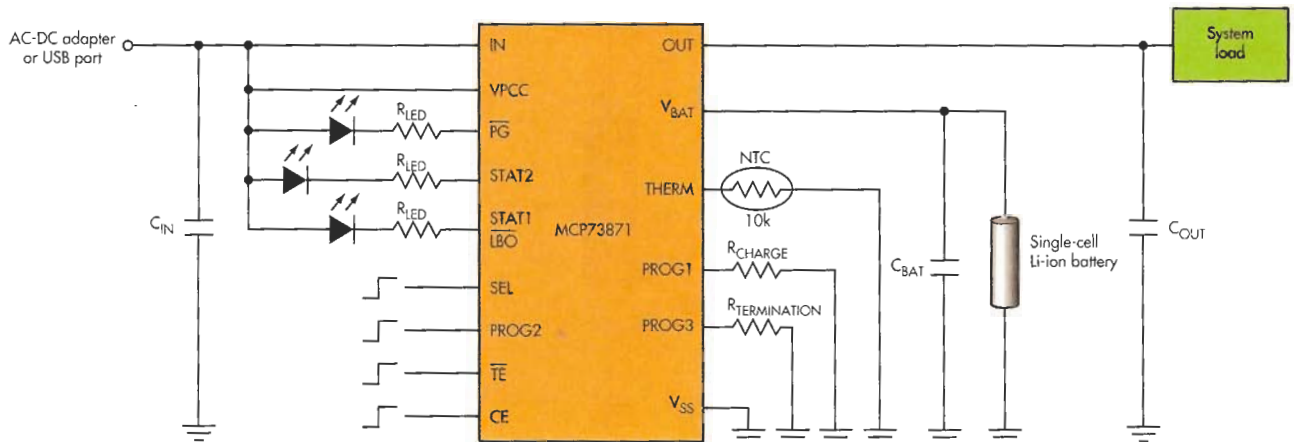
A room temperature of 25°C with an additional 144°C introduces a temperature of 169°C in a system. A junction temperature of 169°C is over the thermal-shutdown threshold of a typical die temperature. Well-designed Li-ion charging-management ICs should include thermal feedback that reduces the charge

current when temperature begins to rise to threshold levels.

BASELINE LINEAR LI-ION BATTERY CHARGERS

Baseline linear Li-ion battery chargers are usually low-cost and have a low pin count and low passive-component requirements. They're often available in packages such as SOT-23, MSOP, and DFN. With the maturation of semiconductor technology, most baseline linear battery chargers are fully integrated. The typical pin count ranges from five to 10 pins.

Charging a Li-ion battery safely is usually the primary and only goal for baseline chargers. No fancy features are required. Figure 1 depicts a simple five-pin battery charger that requires a minimum of three components to operate—an input



3. Power-path management features can switch between power sources in this system load-sharing Li-ion battery charger.

Table 1: NiMH Vs. Li-ion Battery Characteristics

Cell type	Nominal voltage (V)	Energy density (Wh/L)	Energy density (Wh/kg)	Self-discharge (%/month)	Cycle life (charge/discharge)
Li-ion	3.6	500	160	10	500
NiMH	1.2	250	80	30	1000

Note: These values are for reference only. Actual battery parameters may vary depending on the choice of materials, the manufacturer, and testing conditions. Advanced NiMH and Li-ion batteries are not discussed here.

capacitor, an output capacitor, and a programming resistor. Additional pins may be available for functions such as extra status indicators, power-good indicators, battery temperature monitoring, timer, and logic current control.

USB-BASED LINEAR LI-ION BATTERY CHARGERS

In addition to linking peripherals and computers, the USB protocol also delivers high speed at an economic cost. Connecting devices and peripherals through USB ports to a computer has become the most popular method. With a voltage range of 4.75 to 5.25 V, USB is an excellent candidate for restoring energy back to single-cell Li-ion battery cells or packs as previously discussed. There are many methods for charging single-cell Li-ion batteries.

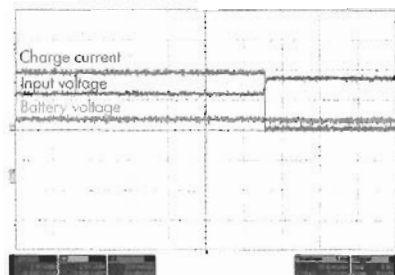
Table 3 lists a few basic methods for designing a single-cell Li-ion battery charger from USB ports. The first method utilizes a low-power USB port for a fixed charging current. This method usually ends up below the absolute maximum current of a low-speed USB port, which is 100 mA. Due to the resistor's tolerance, charge current, and supply current, this charge current is typically under 90 mA. This simply treats a USB port as a 5-V, 100-mA-rated power supply.

To take advantage of high-speed USB ports, an external MOSFET can be used to set two different charging currents when driving the gate low or high. A high-speed USB port allows an absolute maximum current of 500 mA, but a port should always start at low speed until verification is complete.

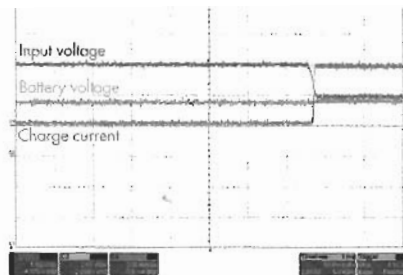
An integrated MOSFET for setting two different charging currents simplifies this design and offers either a preset or resistor-programmable charge current. Figure 2 shows an example that offers three different charge-current settings and can seamlessly switch between a wall wart (ac-dc adapter) and a USB port.

When a wall wart is present, the maximum charging current can easily be higher than 500 mA from a high-speed USB port. When just a USB cable is applied, the charge current will be based on the logic level high or low. Some designs require only one input-power rail, but a different input type can be set by communication between interfaces.

Typically, the preset USB charging current is below 450 mA for a high-speed USB port for the same reason as it is in a low-speed USB port. Proper design methods should also limit the amount of input current drawn from the USB port for safety, as well as to meet USB specifications.



4. Charge current terminates when input overvoltage protection is activated.



5. Charge current resumes once the input voltage falls back to the designed range.

Table 2: Typical Li-ion Battery Applications

Number of Li-ion cells in series	Typical applications
1	Mobile phones, digital still cameras, media players, toys, Bluetooth headsets, global positioning systems, digital picture frames, home entertainment remotes with touchscreen
2	Netbooks, digital camcorders, communication devices, power tools, medical devices
3	Netbooks, ultra-mobile computing devices, laptop computers, power tools
4 and above	Laptop computers, power tools, electric bikes, electric wheelchairs, hybrid electrical vehicles, military equipment, medical devices

Table 3: Methods For Charging From USB Ports*

Method	Description
1	Fixed charge current (typically < 90 mA)
2	External MOSFET charge-current control
3	Integrated MOSFET for multiple charge-current controls
4	Logic dual-input charge control (typically 450 mA/90 mA)
5	Input current-limit control with maximum charge-current setting

*system load-sharing and power-path management-type Li-ion battery charger

As today's portable devices become more feature-rich, requirements for proper battery management increase. In space-constrained applications, highly integrated power-rail controls advance a designer's experience. Each power rail must be well managed for seamless switching among the input power path, system load, and battery cell.

Figure 3 demonstrates a typical application circuit of a Li-ion battery charger with system load-sharing and power-path management features that can switch between power sources. One advantage to using this design instead of a traditional method is that each power rail is managed and the battery is in support mode when the input voltage is insufficient to keep the output voltage steady. Sometimes, additional features such as low-power indicators or controls, as well as power-source selection, offer functionality beyond just restoring energy back to batteries.

ADDITIONAL BATTERY-CHARGER FEATURES

Increased use of Li-ion batteries leads to a broader range of safety and functionality requirements. These requirements may come from internal organizations that promote hazard-free design guidance; local governmental regulations or policies; regional product-manufacturer preference; battery-manufacturer specifications; a designer's level of experience; or an end-user's habits. Common functions include timers for each charging stage, input overvoltage protection, communication protocols, multiple channels of regulated outputs, and battery authentication.

Figure 4 shows an input overvoltage protection feature of a single-cell Li-ion battery charger. The output-charge current terminates when the input voltage passes the protection threshold, and it resumes once the input voltage falls back to the designed range (Fig. 5). Since December 2006, this technique has been recommended for mobile devices as a technical requirement and test method of charger interfaces for mobile telecommunication terminal equipment.

Limiting the input voltage for a linear battery charger keeps end users from incorrectly using wall-wart or ac-dc adapters. It also prevents voltage spikes. Recall Equation 4:

$$P_{\text{DISSIPATION}} = I_{\text{CHARGE}} \times (V_{\text{IN}} - V_{\text{OUT}})$$

$$\begin{aligned} P_{\text{DISSIPATION}} &= 1 \text{ A} \times (7 \text{ V} - 3 \text{ V}) \\ &= 4 \text{ Watts} \end{aligned}$$

Assuming the charge current is 1 A, if the input and output voltages (battery voltage) increase, power dissipation grows. Therefore, when the differences between input and battery voltages jump to 4 V, the power dissipation is 4 W.


CONCLUSION

Green technology is always a hot topic. Engineers and scientists constantly work to improve existing designs and offer better solutions for society. Li-ion batteries can be designed with fuel cells, photovoltaic solar cells, hydro power, and wind power as storage, backup, or supportive power.

Highly integrated linear solutions may overcome hurdles in low-power designs, such as compactness and simplicity.

When intelligence, efficiency, or power dissipation are concerns, designers should survey their solutions thoroughly and understand the tradeoffs between

platforms that are available. When designing with batteries or any power systems, safety is always the first priority.

For more information, visit www.microchip.com/battery. Also, visit www.analog-talk.com to view Microchip's analog technology blog. 

APPLICATION NOTE 4189

Characterizing a Lithium-Ion (Li+) Cell for Use with an Open-Circuit-Voltage (OCV) Based Fuel Gauge

Abstract: The DS2786 is an open-circuit-voltage (OCV) based fuel gauge that reports the total energy that is stored in a lithium-ion (Li+) cell. The device leaves the factory with a best-fit OCV profile that can be used to accurately predict the remaining capacity of a Li+ cell. The accuracy of the DS2786 OCV fuel gauge can be improved by characterizing the Li+ cell under the conditions of the application in which it will be used.

Introduction

The [DS2786](#) stand-alone, open-circuit-voltage (OCV) based fuel gauge estimates the available capacity of rechargeable lithium-ion (Li+) batteries based on the cell voltage in an open-circuit state following a relaxation period. The open-circuit voltage is used to determine relative cell capacity based on a lookup table stored in the IC. The DS2786 leaves the factory with a best-fit OCV profile loaded into the EEPROM of the device. The accuracy of the DS2786 can be improved by customizing the OCV profile of the Li+ cell with the charge and discharge parameters that are used in the application.

This application note outlines a method for characterizing a Li+ cell for use with an OCV-based fuel gauge, collecting and interpreting the data, and then loading the data into the [DS2786K](#) evaluation software.

Procedure for Characterizing a Li+ Cell

1. Determine the full and empty point

The best way to characterize a Li+ cell is to create an environment as close as possible to the actual application in which it will be used. This includes the protection circuitry, a discharge profile consisting of the typical active and standby currents of the application, and a charging profile. This requires a method to simulate the charging and discharging of the cell and a method to monitor and record the current and voltage.

The full point (100% capacity) is defined as the capacity where the Li+ cell is considered fully charged by the charging circuitry. The empty point (0% capacity) can be defined to be the active empty point, the standby empty point, or the absolute energy remaining in the cell.

2. Characterize the cell

The procedure to characterize a Li+ cell for use with an OCV-based fuel gauge can be performed at room temperature. It is best to perform the following steps on at least three cells to obtain an average OCV profile.

1. Charge the cell to the full point.
2. Discharge the cell to the 0% point to learn the capacity of the cell, which should be recorded in mAh.
3. Charge the cell to the full point.
4. Allow the cell to relax for 60 minutes.
5. Record the open-circuit voltage for the 100% point.
6. Discharge the cell 5% (based on the capacity of the cell from Step 2) at a rate of approximately 0.2C.
7. Allow the cell to relax for 60 minutes.
8. Record the open-circuit voltage for the 95% point.
9. Repeat Steps 6–8 19 times until the capacity reaches 0%.

3. Analyze the data

Table 1 contains sample data of a typical cell that was characterized by Maxim Integrated Products. The twenty Capacity/OCV pairs must be summarized into nine pairs that are stored in the EEPROM of the DS2786. The 100% and 0% pairs must be stored in the device. The other seven points should be selected to approximate the full set of data. **Table 2** shows the nine data pairs that were chosen to approximate the data in Table 1. **Figure 1** compares the data in Table 1 and Table 2.

Table 1. OCV Characterization Data for a Typical Li+ Cell

Capacity (%)	OCV (V)
100	4.177454
95	4.129486
90	4.085934
85	4.045427
80	4.008118
75	3.974769
70	3.945074
65	3.917968
60	3.884009
55	3.841219
50	3.820965
45	3.805737
40	3.79325
35	3.783504
30	3.775129
25	3.762185
20	3.741018
15	3.7098
10	3.686654
5	3.674776
0	3.305545

Table 2. OCV Characterization Data Stored in the DS2786

Breakpoint	Capacity (%)	OCV (V)
8	100.0	4.177454
7	82.5	4.026773
6	60.0	3.884009
5	55.0	3.841219
4	40.0	3.79325
3	25.0	3.762185
2	10.0	3.686654
1	5.0	3.674776
0	0.0	3.305545

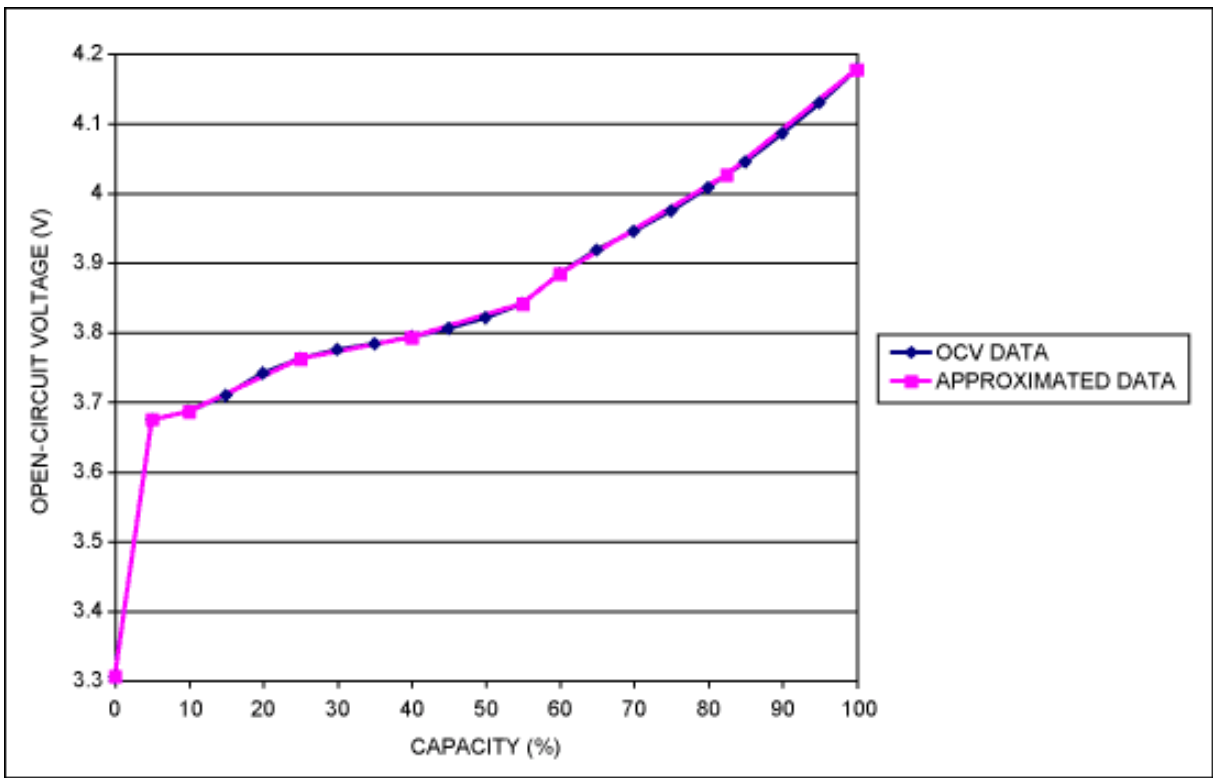


Figure 1. OCV characterization data and the nine approximated breakpoints.

4. **Store the data**

The last step is to program the data into the EEPROM of the DS2786. The DS2786K evaluation software can be used to easily convert the data into the appropriate format that will be stored in EEPROM. Simply load the values from Table 2 into the Parameters tab of the DS2786K as shown in **Figure 2**. Additionally, the capacity of the cell (learned in Step 2) should be entered into the Initial Cell Capacity text box. Then click the Write & Copy button. Make sure a programming voltage is applied to the V_{PROG} pin of the DS2786 in order for the EEPROM to be properly programmed.

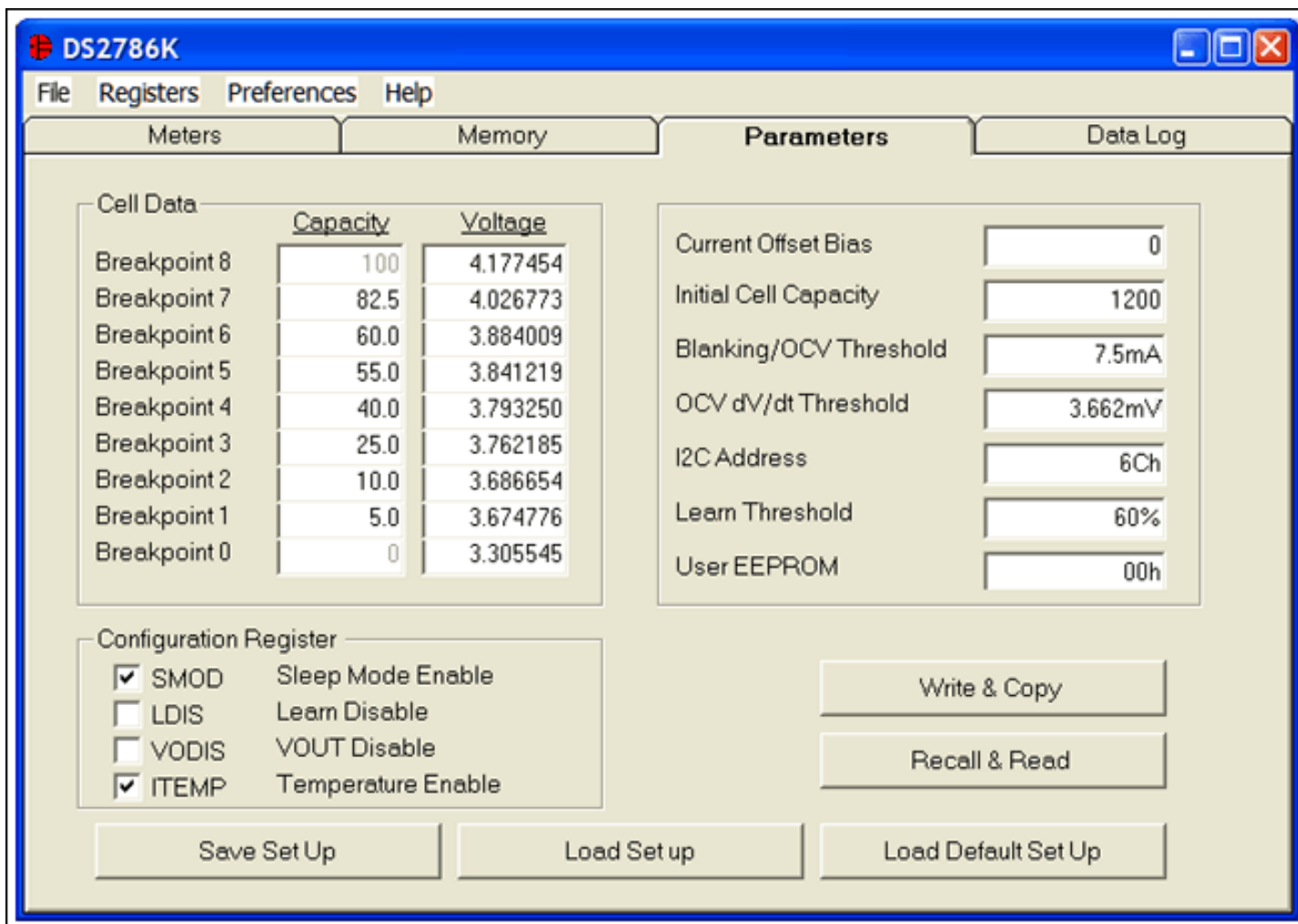


Figure 2. The Parameters tab of the DS2786K evaluation software.

Conclusion

Maxim's OCV-based 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. 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.

Application Note 4189: www.maxim-ic.com/an4189

More Information

For technical support: www.maxim-ic.com/support

For samples: www.maxim-ic.com/samples

Other questions and comments: www.maxim-ic.com/contact

Keep Me Informed

Preview new application notes in your areas of interest as soon as they are published. Subscribe to [EE-Mail - Application Notes](#) for weekly updates.

Related Parts

DS2786: [QuickView](#) -- [Full \(PDF\) Data Sheet](#) -- [Free Samples](#)

AN4189, AN 4189, APP4189, Appnote4189, Appnote 4189

Copyright © by Maxim Integrated Products

Additional legal notices: www.maxim-ic.com/legal