AN1260

Li-Ion/Li-Poly Battery Charge and System Load Sharing Management Design Guide With MCP73871

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INTRODUCTION

The rechargeable Li-Ion/Li-Poly batteries are widely used in today's portable CE (consumer electronics). Commonly seen Li-Poly batteries are Li-Ion Polymer batteries that use solid polymer separator and share the same charge algorithm with Li-Ion batteries. Thus, Li-Ion batteries will represent both Li-Ion and Li-Poly batteries in this application note. Because of the growing features and the increasing size of the display in a portable electronic product, the battery usage is also modifying. The daily battery charging frequency increases, and it becomes important to operate a device while charging its battery.

The traditional method to design a battery-powered system is to connect system load directly on the battery. The system load continuously discharges the Li-Ion battery and costs a battery's life cycle. In order to maximize the life cycle of Li-Ion batteries, it is recommended to terminate the charge properly and power the system from the input power supply when it is available. To prevent overcharging Li-Ion batteries, an elapse timer is usually required as a secondary method to turn off the battery charge activities before a proper termination condition is met. Minimum current detection during CV (constant voltage) stage is the typical termination method for Li-Ion batteries. If a system is constantly drawing current out of a Li-Ion battery, the charge management system will never be terminated properly by minimum current. It can turn on and off periodically or result in an error by timer-fault condition.

Microchip's MCP73871 was developed to overcome these design challenges of Li-Ion battery-powered applications. The MCP73871 is a monolithic solution that offers compact size and rich features. It is an ideal candidate to design in a small form-factor systems while extending the system runtimes and battery life.

This application note is intended to offer detailed design guidance for portable electronics designers who are interested in taking advantage of using Microchip's MCP73871 in their projects. The MCP73871 demonstrates strategies to deliver Li-Ion charge management solutions in short time that satisfies various needs for space and cost concerned applications.

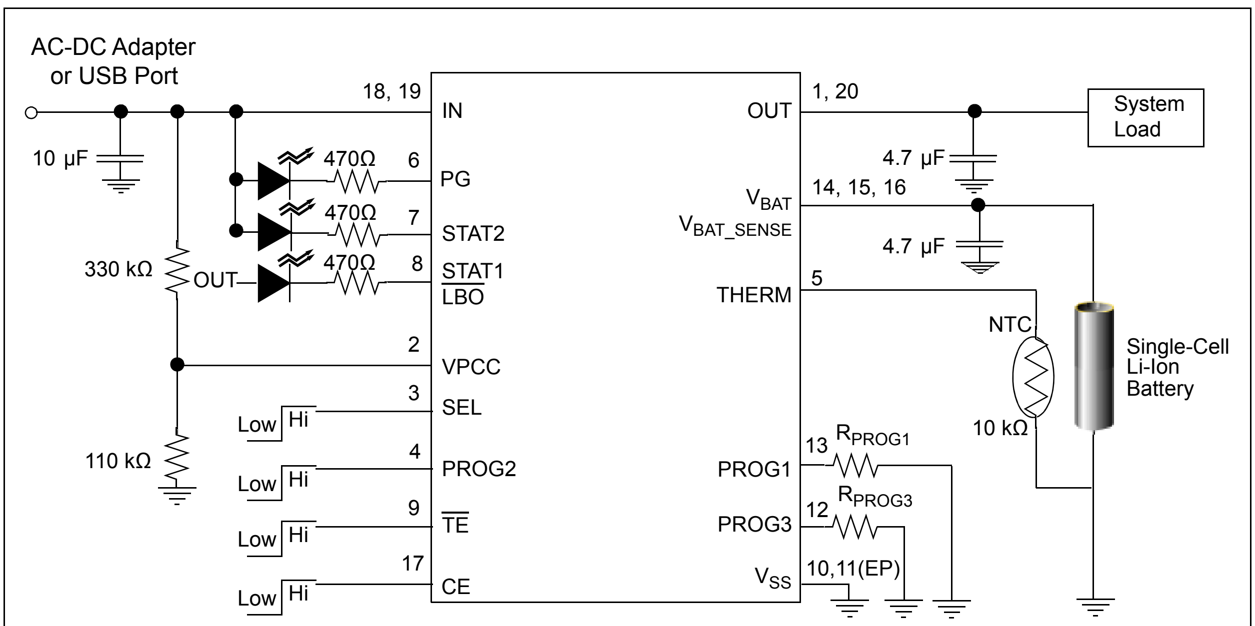

FIGURE 1: *Typical MCP73871 Application.*

MCP73871 DEVICE DESCRIPTION

The MCP73871 device is a fully integrated linear solution for system load sharing and Li-Ion / Li-Polymer battery charge management with ac-dc wall adapter and USB port power sources selection. It is also capable of autonomous power source selection between input or battery. Along with its small physical size, the low number of required external components makes the device ideally suited for portable applications. The MCP73871 device automatically obtains power for the system load from a single-cell Li-Ion battery or an input power source (ac-dc wall adapter or USB port). The MCP73871 device specifically adheres to the current drawn limits governed by the USB specification. With an ac-dc wall adapter providing power to the system, an external resistor sets the magnitude of 1A maximum charge current while supporting up to 1.8A total current for the system load and battery charge current.

The MCP73871 device employs a constant current / constant voltage (CC/CV) charge algorithm with selectable charge termination point. The constant voltage regulation is fixed with four available options: 4.10V, 4.20V, 4.35V, or 4.40V to accommodate the new, emerging battery charging requirements. The MCP73871 device also limits the charge current based on die temperature during high power or high ambient conditions. This thermal regulation optimizes the charge cycle time while maintaining the device reliability.

The MCP73871 device includes a low battery indicator, a power-good indicator and two charge status indicators that allows for outputs with LEDs or communication with host microcontrollers. The MCP73871 device is fully specified over the ambient temperature range of -40°C to +85°C.

This Applications Note shows how to design a simple system load sharing and battery management system with Microchip's popular MCP73871 for cost-sensitive applications.

References to documents that treat these subjects in more depth and breadth have been included in **Section "References"**.

Note:	The above information is available in the MCP73871 data sheet (DS22090).

EXAMPLE OF BATTERY CHARGER AND SYSTEM LOAD SHARING DESIGN SPECIFICATIONS

The example system that will be applied in this application note requires an average of 100 mA load current and consumes a maximum of 500 mA peak current for a short duration of time. A 950 mAh rated Li-Ion battery is used to operate the example system.

The system continuously operates while charging the Li-Ion battery. The input power supply supplies the system load and charges battery when a battery is present in the system. When input power source is removed, the system is supported by the battery. When the system load and the battery charge current requires more energy that the supply current can afford, the system load has higher priority than the battery charger.

Note:	Customers should contact their distributor, representative or field application engineer (FAE) for support. Local sales offices are also available to help customers. A listing of sales offices and locations is included at the back of this document.Technical support is available through the web site at: http://support.microchip.com. The information in this application note is for reference only. Product design and production are customer's responsibilities.

LI-ION / LI-POLYMER BATTERIES

Important attributes when selecting a battery are:

- Internal Resistance
- Operational Load Current
- Energy Density (Size & Weight)
- Charge/Discharge Cycles (Life Cycle)
- Capacity (dominates the operational duration without external power source present)

Like with the most engineering work, these key attributes do not exist at the same time with a reasonable cost. There is always a trade-off between them when selecting the battery chemistry for a portable application. Please refer to Microchip's AN1088 - *"Selecting the Right Battery System for Cost-Sensitive Portable Applications While Maintaining Excellent Quality"* for the details of battery chemistry comparisons. [5]

Li-Polymer batteries are also recognized as Li-Ion Polymer batteries. Li-Polymer can be charged with the same algorithm like Li-Ion batteries. The flexible form-factors, such as high energy density in weight (about 200 Wh/kg) and volume (about 400 Wh/kg), and a relatively low profile to fit inside the compact applications make them ideal candidates for portable products.

Note:	A Protection circuit is required for Li-Ion batteries to prevent over voltage during charge cycle and under voltage during discharge cycle; overcurrent as well in both directions.

Batteries usually take a considerable amount of space and weight in today's portable devices. The energy density for each chemistry dominates the size and weight for the battery pack. Li-Ion has advantages in both energy density weight and energy density volume among other available battery technologies.

MCP73871 DESIGN GUIDE

The integrated system load sharing and the power path management features of the MCP73871 simplify the design and reduce the circuit board space. Unlike low-cost Li-Ion battery charge management solutions, the MCP73871 requires additional plan ahead when design a system around it. This section will offer a detailed design guidance to develop a Li-Ion battery powered system.

System Output Terminal (OUT)

The MCP73871 powers a device from system output terminals, pin 1 and pin 20. There is no fixed voltage regulation to the system from the device. Therefore, proper dc-dc converters might be required for system design. A designer has to carefully review his specifications when developing a new product. The OUT is supported by either input power supply or a single cell Li-Ion battery. The available typical system load is 1.65A while the minimum is 1.5A from wall wart power supply. A system designer should always consider the worst condition. Please refer to page 5 of the MCP73871 Data Sheet (DS22090) for details.

Typical voltage converters are included, but not limited to buck, boost, buck/boost and LDO.

- Buck Converter - Step down to proper voltage level
- Boost Converter - Step up to proper voltage level
- Buck/Boost Converter - Step down and up depends on the input source and output requirement
- LDO - Low dropout voltage regulator for step down only

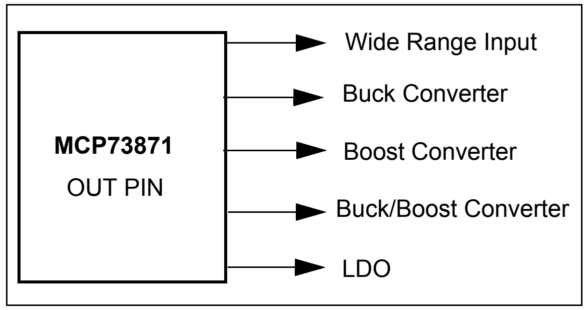

FIGURE 2: *Typical DC-DC Voltage Converter Examples.*

Note:	When operating with single cell Li-Ion batteries, output voltage range can be from 3.0V - 4.2V. It is recommended not to operate at minimum battery voltage to prolong a Li-Ion battery's life. Please refer to battery manufacturer's datasheet or design guide for details.

Power Supply Input (IN)

The MCP73871 can use a regular wall wart or a USB port from computers as its primary power supply. When using a regulated wall wart, the proper input voltage range must be between V_{BAT}+300 mV and 6V. The rated supply current of the wall wart has to meet the system requirement. Keep in mind that the MCP73871 device only supports up to 1.8A combined current for the system load and the charge current of a Li-Ion battery. When supplying from a USB port, the MCP73871 submits to the current limits governed by the USB specification.

INPUT CURRENT LIMIT CONTROL (ICLC)

Input Current Limit Control prevents the system and charger over drawing the available current from power sources. When the system demands more current than the input power supply can provide or the input ICLC is reached, the switch will become forward biased and the battery is able to supplement the input current to the system load.

The ICLC sustains the system load as its highest priority. This is done by reducing the non-critical charge current while adhering to the current limits governed by the USB specification or the maximum ac-dc adapter current supported. Further demand from the system is supported by the battery, if possible.

Selectable USB-Port Input Current:

- Low: 1 Unit Load / High: 5 Unit Loads

Note:	Each unit load is of 100 mA. A device should not draw more than specified unit of loads.

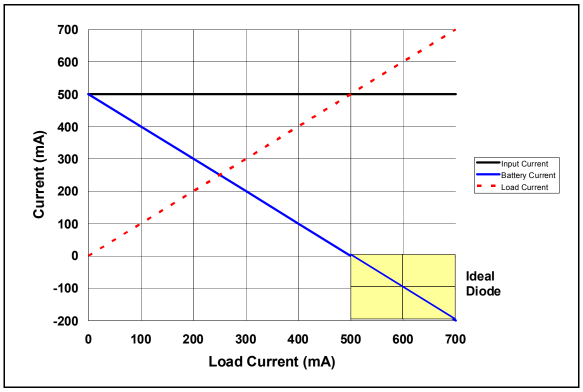

FIGURE 3: *USB_{High} -Input Current Limit Control.*

Figure 3 illustrates the function of ICLC when USB_{HIGH} is selected.

Input Source Type Selection (SEL)

The Input Source Type Selection pin is used to select the input power source for input current limit control feature. With logic level high, the MCP73871 allows maximum current of 1800 mA from a typical wall wart. With logic level low the MCP73871 assumes that a USB-port input power source is selected.

USB-Port Current Set (PROG2)

The USB-Port Current Regulation Set input (PROG2) is a digital input selection. A logic Low limits a 1-unit load input current from low-power port (100 mA); a logic High limits a 5-unit loads input current from the high-power port (500 mA).

Unlike many monolithic battery charge management controllers that set the charge current for USB-port operations, the PROG2 of MCP73871 sets input current limits for both system load and battery charge current, which ensures that no over-current is drawn from the USB ports.

Note:	The Overcurrent protection circuit that ensures proper operations and the safety of USB ports should be implemented at the host and self-powered hubs. The MCP73871 serves as secondary overcurrent protection from USB-port only.

Fast Charge Current Set (PROG1)

Fast Charge Current Set (PROG1) determines maximum constant current with a resistor tie from pin 13 to the ground (V_{SS}). PROG1 also sets the maximum allowed charge current and the termination current set point (10% of fast charge current). The programming resistance for desired charge current can be calculated using the following equation:

EQUATION 1: RESISTOR VS. CURRENT

$$I_{CHAREG} = \frac{1000V}{R_{PROG1}}$$

Where:

R_{PROG1} = kilo-ohms (kΩ)

I_{REG} = milli-ampere (mA)

For example, a fast charge current that equals 760 mA is calculated to meet the design specification for a 950 mAh rated battery at 0.8C. A 750 mA fast charge current is selected to simplify the design process. A 1.3 kΩ resistor is choose to allows a 750 mA fast charge current. A 750 mA precondition current, 10% of fast charge current, is applied to the Li-Ion battery when V_{BAT} is below preconditioning cut-off voltage.

EQUATION 2: CHARGE CURRENT

$$950mA \times 0.8 = 760mA$$

Note:	Select I_{REG} = 750 mA

EQUATION 3: SELECT RESISTOR

$$R_{PROG1} = \frac{1000V}{750mA} = 1.3k\Omega$$

EQUATION 4: FAST CHARGE

When: $SEL = High$

$$I_{FastCharge} = I_{Supply} - I_{SystemLoad}$$

When: $SEL = Low; PROG2 = High$

$$I_{FastCharge} = 500mA - I_{SystemLoad}$$

When: $SEL = Low; PROG2 = Low$

$$I_{FastCharge} = 100mA - I_{SystemLoad}$$

The supply current has to be sufficient for the system load current and fast charge current. Otherwise, system load current has priority over fast charge current.

Termination Current Set (PROG3)

The charge cycle is terminated when, during the constant voltage mode, the average charge current diminishes below a threshold established with the value of a resistor connected from PROG3 to V_{SS} or the internal timer has expired. The charge current is latched off and the MCP73871 enters a charge complete mode.

EQUATION 5: RESISTOR VS. CURRENT

$$I_{TERMINATION} = \frac{1000V}{R_{PROG3}}$$

Where:

R_{PROG3} = kilo-ohms (kΩ)

$I_{TERMINATION}$ = milli-ampere (mA)

Termination current is the same for inputs from either USB port or ac-dc adapter and needs to be less than charge current set to ensure system function properly.

Voltage Proportional Charge Control (VPCC)

Voltage Proportional Charge Control is a key feature of MCP73871 that allows output to maintain proper voltage level even when the input varies. Equation 6 demonstrates how to calculate the proper value for VPCC. When VPCC voltage drops below 1.23V, it will trigger the dynamic function of MCP73871 to maintain proper output voltage level with support from Li-Ion battery. Equation 6 assumes the required input voltage of 5V. The resistor selection is flexible. Figure 4 depicted the connection of voltage divider that supplies proper voltage for VPCC pin. The divider is based on the calculation of Equation 6. However, if the input drops below UVLO, the Li-Ion battery will become the primary power source.

EQUATION 6: VPCC DIVIDER

$$V_{VPCC} = \left(\frac{R_2}{R_1 + R_2}\right) \times V_{IN} = 1.23V$$

Assume: $R_2 = 110k\Omega$

$$1.23V = \left(\frac{110k\Omega}{110k\Omega + R_1}\right) \times 5V$$

$$R_1 = 337.2k\Omega$$

R_1 = 330 kΩ is selected

Note: If VPCC function is not required in a system. VPCC pin can simply connect to V_{IN}. The resistors are selected at a hundred k ohm range to minimize the supply current from the voltage divider.

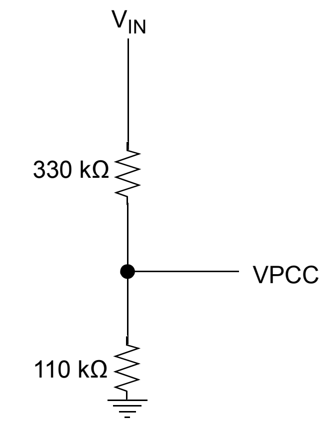

FIGURE 4: *VPCC Divider*

Battery Temperature Monitor (THERM)

The MCP73871 continuously monitors the battery temperature during a charge cycle by measuring the voltage between the THERM and V_{SS} pins. An internal 50 µA current source provides the bias for a typical 10 kΩ negative-temperature coefficient thermistors (NTC). The MCP73871 compares the voltage at the THERM pin to the factory set thresholds of 1.23V and 0.25V, typically. Once a voltage outside the thresholds is detected during a charge cycle, the MCP73871 immediately suspends the charge cycle. The charge cycle resumes when the voltage at the THERM pin returns to the normal range.

The charge temperature window can be set by placing fixed value resistors in series-parallel with a thermistor. The resistance values of R_{T1} and R_{T2} can be calculated with the following equations in order to set the temperature window of interest.

EQUATION 7: NTC

$$24k\Omega = R_{T1} + \frac{R_{T2} \times R_{COLD}}{R_{T2} + R_{COLD}}$$

$$5k\Omega = R_{T1} + \frac{R_{T2} \times R_{HOT}}{R_{T2} + R_{HOT}}$$

Where:

R_{T1} is the fixed series resistance

R_{T2} is the fixed parallel resistance

R_{COLD} is the thermistor resistance at the lower temperature of interest

R_{HOT} is the thermistor resistance at the upper temperature of interest

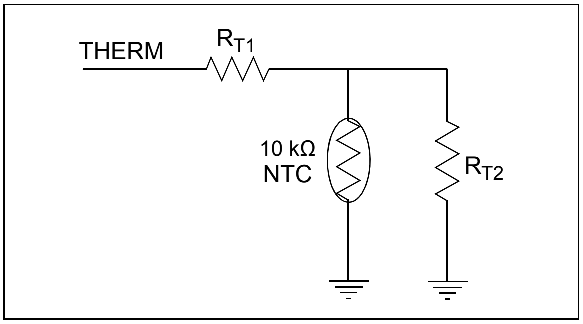

FIGURE 5: *Resistor Connection.*

Battery Charge Control Output (V_{BAT}) And Battery Voltage Sense (V_{BAT_SENSE})

Connect to the positive terminal of Li-Ion batteries for energy restoring back to the batteries. It is recommended to apply a ceramic capacitor with low ESR (equivalent series resistance) and ESL (equivalent series inductance) to ensure loop stability when the battery is disconnected. A precision internal voltage sense regulates the final voltage on this $V_{BATTERY\_VOLTAGE\_SENSE}$ to positive terminal of a Li-Ion battery.

Timer Enable ($\overline{TE}$)

The timer enable input option is used to enable or disable the internal timer. A low signal on this pin enables the internal timer and a high signal disables the internal timer. The $\overline{TE}$ input can be used to disable the timer when the system load is substantially limiting the available supply current to charge the battery. The $\overline{TE}$ input is compatible with 1.8V logic.

Note:	The built-in safety timer is available for the following options: 4 HR, 6 HR and 8 HR.

Charge Enable (CE)

With the CE input Low, the Li-Ion battery charger feature of the MCP73871 will be disabled. The charger feature is enabled when CE active High. Allowing CE pin float during charge cycle may cause system instability. The CE input is compatible with 1.8V logic.

Charge Status Outputs (STAT1, STAT2)

STAT1 and STAT2 are open-drain logic outputs for connection to LED for charge status indication. Alternatively, a pull-up resistor can be applied for interfacing to a host microcontroller. The low battery output ($\overline{LBO}$) indicator shares the same output pin with STAT1. It reminds the system or the end user when the Li-Ion battery level is low. The $\overline{LBO}$ feature enables when the system is running from the Li-Ion batteries. The $\overline{LBO}$ indicator can be used as an indication to the user via lit up LED or to the system via a pull-up resistor for interfacing with a host microcontroller that an input source, other than the battery, is supplying power. When using a low battery output indicator, STAT1 pin needs to connect to a working voltage source other than V_{IN}.

Power Good ($\overline{PG}$)

The Power Good ($\overline{PG}$) is an open-drain logic output for the input power supply indication. The $\overline{PG}$ output is low whenever the input to the MCP73871 is above the UVLO threshold and greater than the battery voltage. The $\overline{PG}$ output can be used as an indication to the user via lit up LED or to the system via a pull-up resistor for interfacing to a host microcontroller that an input source, other than the battery, is supplying power.

Table 1 depicts the status outputs of MCP73871 in various conditions.

TABLE 1: STATUS OUTPUTS

STATE	STAT1	STAT2	$\overline{PG}$
Shutdown	Hi-Z	Hi-Z	Hi-Z
Preconditioning	L	Hi-Z	L
Constant Current	L	Hi-Z	L
Constant Voltage	L	Hi-Z	L
Charge Complete - Standby	Hi-Z	L	L
Temperature Fault	Hi-Z	Hi-Z	L
Timer Fault	Hi-Z	Hi-Z	L
Low Battery Output	L	Hi-Z	Hi-Z
No Battery Present	Hi-Z	Hi-Z	L
No Input Power Present	Hi-Z	Hi-Z	Hi-Z

Design Specifications/Requirement

- Input Voltage Range:
  - 2A rated 5V +/- 5% ac-dc adapter
  - 950 mAh Li-Ion battery (3.6V Nominal)
- Constant Charge Current:
  - 1C (Please refer to the recommended value from selected battery manufacturer)
- Constant Charge Voltage: 4.2V
- Precondition Current:
  - 0.1C or recommend value (Please refer to the recommended value from selected battery manufacturer)
- Termination Current
  - 0.07C (Please refer to the recommended value from selected battery manufacturer)
- Low battery warning
- Safety Timer: Turn charger off after 6 hours before termination.

Note:	**"C" Rate Definition**: The theoretical capacity of a battery is determined by the amount of active materials in the battery. It is expressed as the total quantity of electricity involved in the electrochemical reaction and is defined in terms of coulombs or ampere-hours.

EQUATION 8: SELECT RESISTOR

$$R_{PROG1} = \frac{1000V}{950mA} = 1.05k\Omega$$

TESTING CONDITIONS:

- Battery Open Voltage: 3.8V (Both Charge and Discharge)
- Battery Capacity: 950 mAh
- Battery Charge Voltage: 4.2V
- Battery Nominal Voltage: 3.6V
- Supply Voltage: 5.2V
- Constant Current (Fast Charge): 950 mA
- - Minimum System Load: 100 mA
- - Maximum System Load: 520 mA

SUMMARY

The MCP73871 helps system designers to simplify the design complexities and minimize the external component for portable devices. Integrated load-sharing and power-path management allow seamless switch between system load and charge current in different conditions. The MCP73871 also offers an independent charge current and termination current settings through resistors and preset logic inputs.

For input power management, the ICLC (input current limit control) avoids the overcurrent drain from a restricted power source, such as USB-Port. VPCC (Voltage Proportional Current Control) enables system load in maintaining proper voltage level when input power supply is insufficient. Depending on the power path conditions, the battery will either be in help mode or primary power source.

The MCP73871 also offers three standard status outputs, two statuses for battery management and one for power good. In addition to the standard status outputs, the low battery indicator is also available from the MCP73871. In order to minimize external components, there are many factory preset options to choose from. Please refer to MCP73871 Data Sheet (DS22090) for additional information.

Figure 6 and Figure 7 depicted the example system with a typical 950 mAh rated Li-Ion battery. Figure 6 shows a typical charge profile with a continuous current at 100 mA from the system load and 950 mA fast charge current. Figure 7 shows a typical discharge profile of a continuous current at 520 mA.

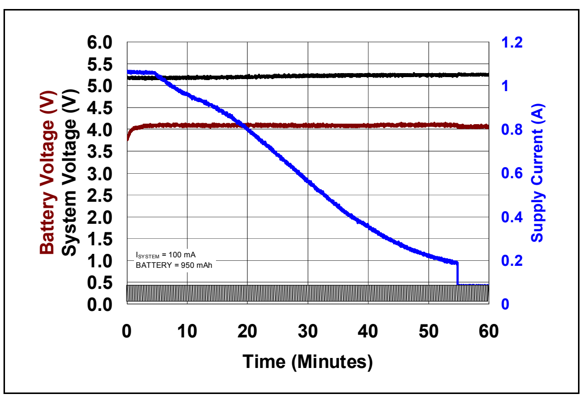

FIGURE 6: *Typical Charge Profile With 100 mA System Load.*

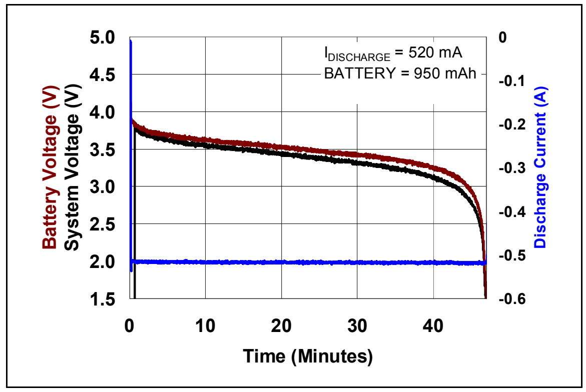

FIGURE 7: *Discharge Profile.*

The MCP73871 Evaluation Board, User's Guide and Gerber File are available through Microchip's web site: http://www.microchip.com.

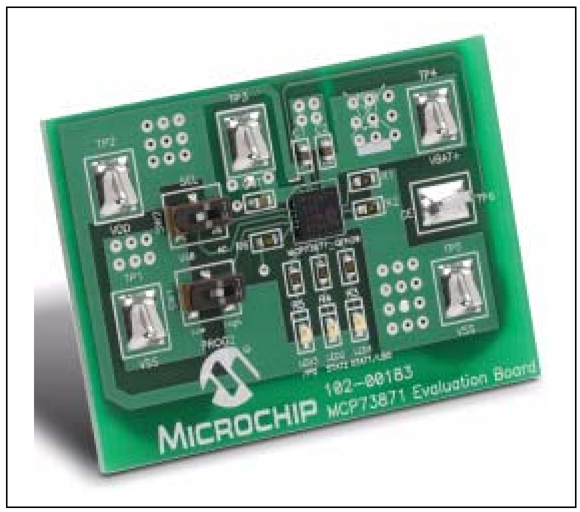

FIGURE 8: *MCP73871 Evaluation Board.*

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[5] AN1088, *"Selecting the Right Battery System for Cost-Sensitive Portable Applications. While Maintaining Excellent Quality"*, Brian Chu; Microchip Technology Inc., DS01088, ©2007.

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