AN1276

Design A Low-Cost Lithium Iron Phosphate (LiFePO4) Battery Charger With MCP73123

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INTRODUCTION

Demand of fast-discharge rated energy storage sources for Electrical Vehicle (EV), Hybrid Electrical Vehicle HEV) or portable power tools have driven the commercial development of Lithium Iron Phosphate ($LiFePO_4$) batteries. The traditional $LiFePO_4$ battery systems usually require high voltages or large capacities. However, the nature of its characters, such as longer cycle life than typical Li-Ion (Lithium Iron) batteries, better resistance to thermal runaway and higher output and peak current rating make them ideal candidates to RC (remote control) toys and backup power applications.

The typical capacity of $LiFePO_4$ battery cells are available in the ranged from 500 mAh to 2300 mAh. They are usually rated at 3.2V. There are systems or applications that do not require large capacity (multiple cells in parallel) or high voltage (multiple cells in series) battery packs. Figure 1 illustrates a charge cradle that can range from one cell to 'n' cells batteries. Each power path has one IC (Integrated Circuit) to manage the charge profile and display the state of charge.

Most $LiFePO_4$ battery manufacturers have different charge and discharge specifications for their batteries. However, all $LiFePO_4$ share Constant Current-Constant Voltage (CC-CV) algorithm with Li-Ion batteries. The preferred charge voltage is typically 3.6V. The termination current can be either fixed value or ratio of fast charge current. Unlike Li-Ion chemistry, $LiFePO_4$ can be charged with higher C rate.

Note:	Please consult the battery manufacturer for the desired maximum charge rated.

Microchip's MCP73123 family is developed to simplify the design for mid to low range capacity $LiFePO_4$ batteries or if the total charge time is not critical for larger capacity applications.

This application note is intended to provide design guidance for designers who are interested in taking advantage of using Microchip's MCP73123 to charge $LiFePO_4$ batteries to reduce the product development cycle, cost and time to market.

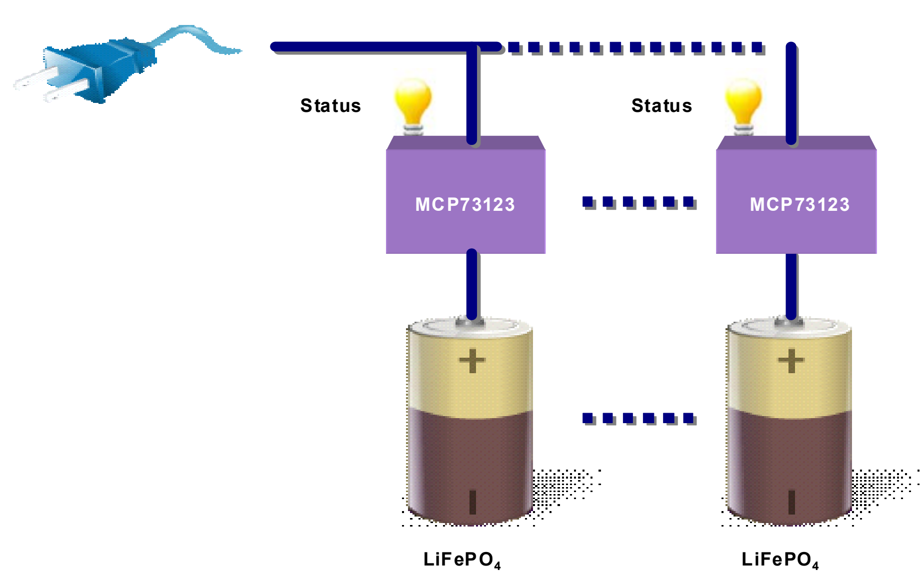

FIGURE 1: *$LiFePO_4$ Charger Cradle Illustration of the MCP73123.*

MCP73123 DEVICE DESCRIPTION

The MCP73123 is a highly integrated Lithium Iron Phosphate ($LiFePO_4$) battery charge management controller for use in space-limited and cost-sensitive applications. The MCP73123 provides specific charge algorithms for $LiFePO_4$ batteries to achieve optimal capacity and safety in the shortest charging time possible. Along with its small physical size, the low number of external components make the MCP73123 ideally suitable for various applications. The absolute maximum voltage, up to 18V, allows the use of MCP73123 in harsh environments, such as low cost wall wart or voltage spikes from plug/unplug.

The MCP73123 employs a constant current-constant voltage charge algorithm. The 3.6V per cell factory preset reference voltage simplifies design with 2V preconditioning threshold. The fast charge, constant current value is set with one external resistor from 130 mA to 1100 mA. The MCP73123 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 device reliability.

The PROG pin of the MCP73123 also serves as enable pin. When a high impedance is applied, the MCP73123 will be in standby mode.

The MCP73123 is fully specified over the ambient temperature range of -40°C to +85°C. The MCP73123 is available in a 10 lead, DFN package.

This Applications Note shows how to design a simple Lithium Iron Phosphate battery charge management system with Microchip's MCP73123 for cost-sensitive applications.

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

Note:	MCP73223 is also available for dual cell charger to charge two LiFePO4 in series.

MCP73123 DEVICE FEATURES

- Constant Current / Constant Voltage Operation with Thermal Regulation
- 4.15V Undervoltage Lockout (UVLO)
- 18V Absolute Maximum Input with OVP:
  - 6.5V - MCP73123
- High Accuracy Preset Voltage Regulation Through Full Temperature Range (-5°C to +55°C):
  - $\pm$ 0.5%
- Battery Charge Voltage Options:
  - 3.6V - MCP73123
- Resistor Programmable Fast Charge Current:
  - 130 mA - 1100 mA
- Preconditioning of Deeply Depleted Cells:
  - Available Options: 10% or Disable
- Integrated Precondition Timer:
  - 32 Minutes or Disable
- Automatic End-of-Charge Control:
  - Selectable Minimum Current Ratio: 5%, 7.5%, 10% or 20%
  - Elapse Safety Timer: 4 HR, 6 HR, 8 HR or Disable
- Automatic Recharge:
  - Available Options: 95% or Disable
- Two Charge Status Output Available - On or Flash
- Soft Start
- Temperature Range: -40°C to +85°C
- Packaging:
  - DFN-10 (3 mm x 3 mm)

TABLE 1: AVAILABLE FACTORY PRESET OPTIONS

Charge Voltage	OVP	Pre-conditioning Charge Current	Pre-conditioning Threshold	Precondition Timer	Elapse Timer	End-of-Charge Control	Automatic Recharge	Output Status
3.6V	6.5V	Disable / 10%	2V	Disable / 32 Minimum	Disable / 4 HR / 6 HR / 8 HR	5% / 7.5% / 10% / 20%	No / Yes	Type 1 / Type 2
7.2V	13V	Disable / 10%	4V	Disable / 32 Minimum	Disable / 4 HR / 6 HR / 8 HR	5% / 7.5% / 10% / 20%	No / Yes	Type 1 / Type 2

TABLE 2: STANDARD SAMPLE OPTIONS

Part Number	V_{REG}	OVP	I_{PREG}/I_{REG}	Pre-charge Timer	Elapse Timer	I_{TERM}/I_{REG}	V_{RTH}/V_{REG}	V_{PTH}/V_{REG}	Output Status
MCP73123-22SI/MF	3.6V	6.5V	10%	32 Min.	6 HR	10%	95%	71.5%	Type 1
MCP73223-C2SI/MF	7.2V	6.5V	10%	32 Min.	6 HR	10%	95%	71.5%	Type 1

Note 1: I_{REG}: Regulated fast charge current.
2: V_{REG}: Regulated charge voltage.
3: I_{PREG}/I_{REG}: Preconditioning charge current; ratio of regulated fast charge current.
4: I_{TERM}/I_{REG}: End-of-Charge control; ratio of regulated fast charge current.
5: V_{RTH}/V_{REG}: Recharge threshold; ratio of regulated battery voltage.
6: V_{PTH}/V_{REG}: Preconditioning threshold voltage.
7: Type 1 Output Status - Open-drain.
8: Type 2 Output Status - Open-drain with 50% duty cycle on/off.
9: Customers should contact their distributor, representatives or field application engineer (FAE) for support and sample. Local sales offices are also available to help customers. A listing of sales offices and locations is included in the back of this document. Technical support is available through the web site at: http//support.microchip.com.

Note: Above information is available in the MCP73123/223 data sheet (DS22191).

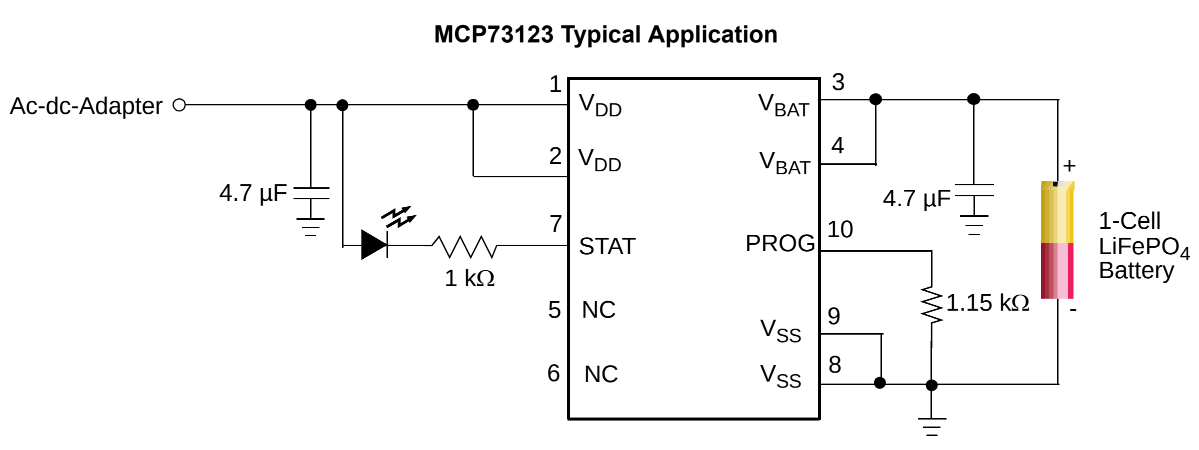

FIGURE 2: Typical MCP73123 Applications.

LIFEPO$_4$ CHARGER DESIGN GUIDE

Figure 2 depicts the typical application circuit. Designing with the MCP73123 is easy with minimum four external components. The output status pin connects to either MCU or LED for different display methods. Table 1 provides the available options of the MCP73123. The options in Table 2 are standard samples and can be obtained quickly. The MCP73123 is available in the 3 mm x 3 mm DFN package, as shown in Figure 3.

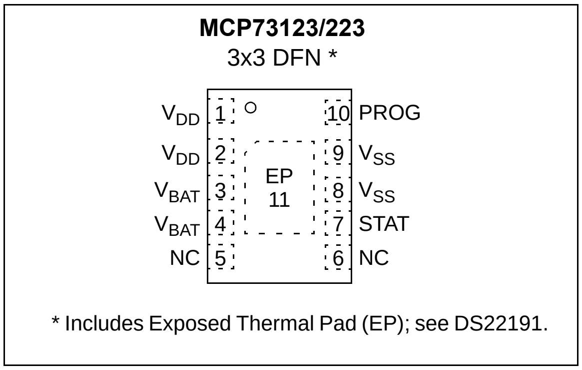

FIGURE 3: MCP73123/223 Package

For non-standard combinations of options, contact your local Microchip representatives or distributors. This section will offer detailed design guide to develop a LiFePO$_4$ battery charger system.

Power Supply Input (V_{DD})

The MCP73123 operates from 4.15V to 5.8V or 6.5V, However, the MCP73123 can protect up to 18V absolute maximum voltage when the power supply is instable or when the end user accidently plug in the wrong ac-dc adapter. The selected input capacitor needs to meet the desired design specifications.

Battery Charger Output (V_{BAT})

The MCP73123 regulates V_{BAT} pin to 3.6V when charge begins. When 3.6V is detected, the algorithm moves to constant voltage range until minimum current is satisfied or elapse timer is up for automatic termination. The output capacitor will ensure the loop stability when the battery is disconnected.

EXTERNAL CAPACITORS

The MCP73123 is stable with or without a battery load. In order to maintain good AC stability in the Constant-voltage mode, a minimum capacitance of 1 µF is recommended to bypass the V_{BAT} pin to V_{SS}. This capacitance provides compensation when there is no battery load. In addition, the battery and interconnections appear inductive at high frequencies. These elements are in the control feedback loop during Constant-voltage mode. Therefore, the bypass capacitance may be necessary to compensate for the inductive nature of the battery pack. A minimum of 16V rated 1 µF, is recommended to apply for output capacitor and a minimum of 25V rated 1 µF, is recommended to apply for input capacitor for typical applications.

TABLE 3: MLCC CAPACITOR EXAMPLE

MLCC Capacitors	Temperature Range	Tolerance
X7R	-55°C to +125°C	±15%
X5R	-55°C to +85°C	±15%

Virtually any good quality output filter capacitor can be used, independent of the capacitor's minimum Effective Series Resistance (ESR) value. The actual value of the capacitor (and its associated ESR) depends on the output load current. A 1 µF ceramic, tantalum or aluminum electrolytic capacitor at the output is usually sufficient to ensure stability.

Fast Charge Current Set (PROG)

During the constant current mode, the programmed charge current is supplied to the battery or load.

The charge current is established using a single resistor from PROG to V_{SS}. The program resistor and the charge current are calculated using the following equation:

EQUATION 1: CHARGE CURRENT

$$I_{REG} = 1104 \times R^{-0.93}$$

Where:

R_{PROG} = kilo-ohms (kΩ)
I_{REG} = milliampere (mA)

EQUATION 2: SELECT RESISTOR

$$R_{PROG} = 10^{\left(\log\left(\frac{I_{REG}}{1104}\right)\right)/(-0.93)}$$

Where:

R_{PROG} = kilo-ohms (kΩ)
I_{REG} = milliampere (mA)

Table 4 provides commonly seen E96 (1%) and E24 (5%) resistors for various charge current to reduce design time.

TABLE 4: RESISTOR LOOKUP TABLE

Charge Current (mA)	Recommended E96 Resistor (Ω)	Recommended E24 Resistor (Ω)
130	10k	10k
150	8.45k	8.20k
200	6.20k	6.20k
250	4.99k	5.10k
300	4.02k	3.90k
350	3.40k	3.30k
400	3.00k	3.00k
450	2.61k	2.70k
500	2.32k	2.37k
550	2.10k	2.20k
600	1.91k	2.00k
650	1.78k	1.80k
700	1.62k	1.60k
750	1.50k	1.50k
800	1.40k	1.50k
850	1.33k	1.30k
900	1.24k	1.20k
950	1.18k	1.20k
1000	1.10k	1.10k
1100	1.00k	1.00k

Constant current mode is maintained until the voltage at the V_{BAT} pin reaches the regulation voltage, V_{REG}. When constant current mode is invoked, the internal timer is reset.

PROG pin also serves as charge control enable. When a typical 200 kΩ impedance is applied to PROG pin, the MCP73123 is disabled until the high impedance is removed.

Battery Charge Status Outputs (STAT)

The charge status outputs are open-drain outputs with two different states: Low (L), and High Impedance (Hi-Z). The charge status outputs can be used to illuminate LEDs. Optionally, the charge status outputs can be used as an interface to a host microcontroller. Table 5 summarize the state of the status outputs during a charge cycle.

TABLE 5: STATUS OUTPUTS

CHARGE CYCLE STATE	STAT
Shutdown	Hi-Z
Standby	Hi-Z
Preconditioning	L
Constant Current Fast Charge	L
Constant Voltage	L
Charge Complete - Standby	Hi-Z
Temperature Fault	1.6 second 50% D.C. Flashing (Type 2) Hi-Z (Type 1)
Timer Fault	1.6 second 50% D.C. Flashing (Type 2) Hi-Z (Type 1)
Preconditioning Timer Fault	1.6 second 50% D.C. Flashing (Type 2) Hi-Z (Type 1)

SUMMARY

The MCP73123 helps designers to reduce design complexities and minimize external components for $LiFePO_4$ charger cradles or chargers. Integrated input overvoltage protection and battery short protection allow seamless switching between different input/output voltage conditions. The MCP73123 also offers built-in preconditioning timer and overall elapse timer to prevent overcharge of a bad battery.

Due to the power dissipations in the linear charger design, the thermal foldback provides better heat management that prevents the system temperature from increasing and prolong the life of the products. Figure 4 depicts the complete charge cycle of a 1100 mAh rated $LiFePO_4$ battery. The charge current is set at 1A. At the beginning of charge cycle, the battery voltage is 2V when input voltage is 5V. The 3 watts power dissipation triggers the thermal foldback to begin. Unlike Li-Ion batteries, $LiFePO_4$ batteries can restore energy back faster if battery capacity and fast charge current speed are equal. A typical Li-Ion battery may require 2-3 hours when charge with 1C rate.

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.

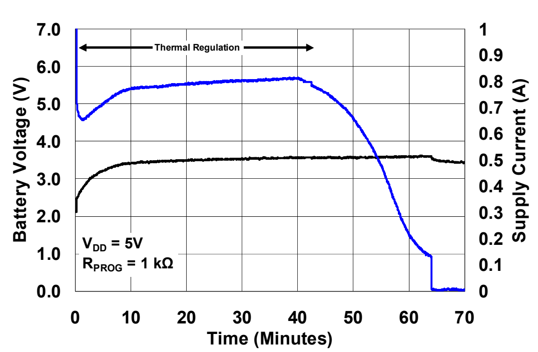

FIGURE 4: *Typical MCP73123 Charge Profile (1100 mAh $LiFePO_4$ Battery Cell).*

Figure 5 shows half of top layer of the MCP73X23EV-LFP evaluation board. There are two independent circuits on the MCP73X23EV-LFP for single-cell and dual-cell applications. The user's guide and Gerber file for the MCP73X23EV-LFP are available on Microchip's website.

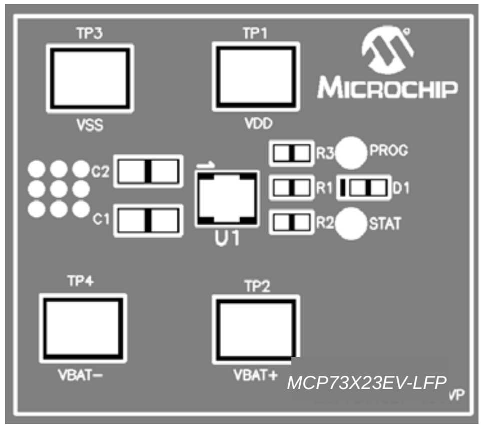

FIGURE 5: *MCP73X23 Evaluation Board.*

REFERENCES

[1] MCP73123/223 Data Sheet, *"Lithium Iron Phosphate ($LiFePO_4$) Battery Charge Management Controller with Input Overvoltage Protection"*, Microchip Technology Inc., DS22191, ©2009.

[2] *"Lithium Batteries"*, Gholam-Abbas Nazri and Gianfranco Pistoia Eds.; Kluwer Academic Publishers, ©2004.

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