

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

*Author: Brian Chu
Microchip Technology Inc.*

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 (LiFePO₄) batteries. The traditional LiFePO₄ 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 LiFePO₄ 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 LiFePO₄ battery manufacturers have different charge and discharge specifications for their batteries. However, all LiFePO₄ 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, LiFePO₄ 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 LiFePO₄ 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 LiFePO₄ batteries to reduce the product development cycle, cost and time to market.

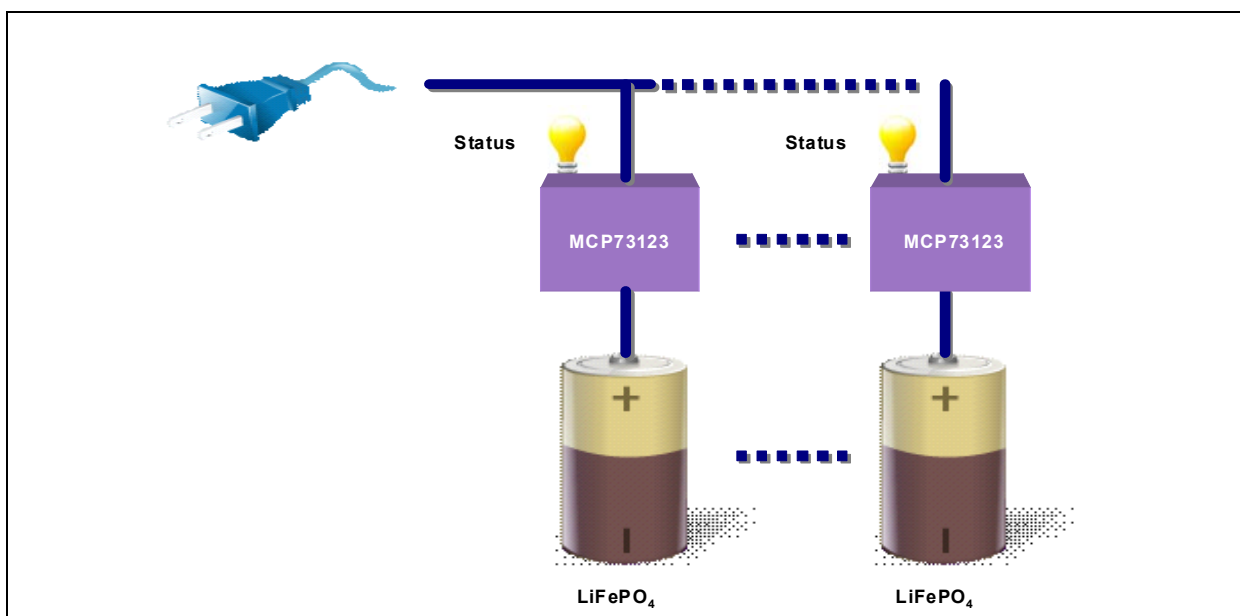


FIGURE 1: LiFePO₄ Charger Cradle Illustration of the MCP73123.

MCP73123 DEVICE DESCRIPTION

The MCP73123 is a highly integrated Lithium Iron Phosphate (LiFePO₄) battery charge management controller for use in space-limited and cost-sensitive applications. The MCP73123 provides specific charge algorithms for LiFePO₄ 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 LiFePO ₄ 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).

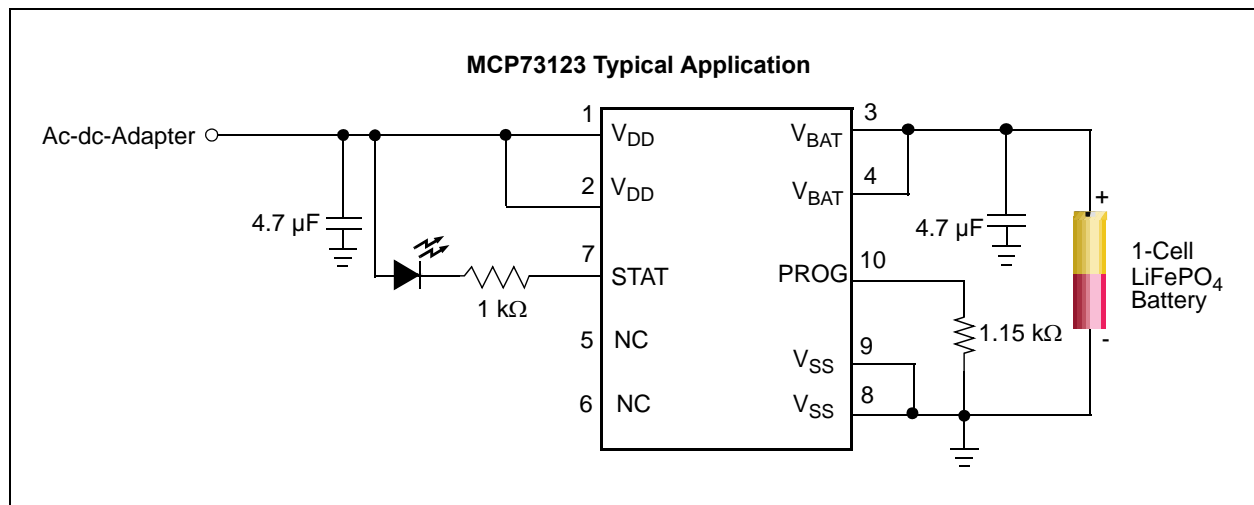


FIGURE 2: Typical MCP73123 Applications.

LIFEPO₄ 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.

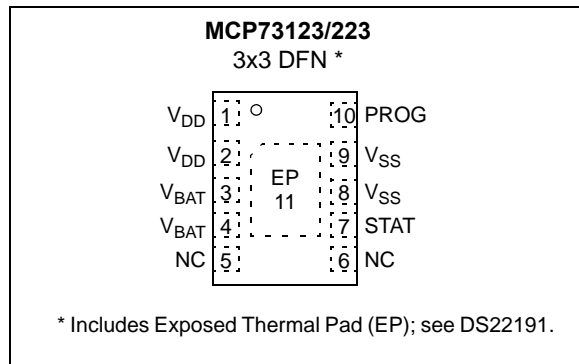


FIGURE 3: MCP73123/223 Package

For non-standard combinations of options, contact your local Microchip representatives or distributors. This section will offer detailed design guide to develop a LiFePO₄ 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 unstable or when the end user accidentally 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} = milliamperes (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} = milliamperes (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 k Ω 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)

AN1276

SUMMARY

The MCP73123 helps designers to reduce design complexities and minimize external components for LiFePO₄ 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 LiFePO₄ 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, LiFePO₄ 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.

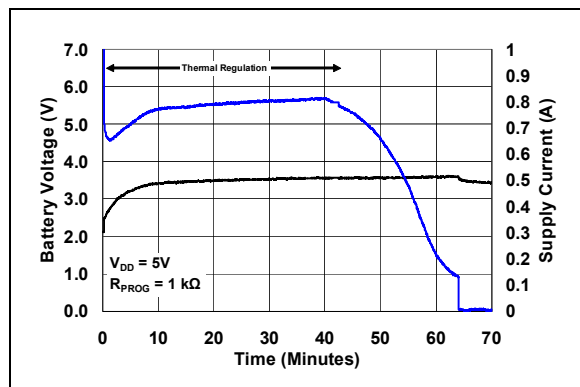


FIGURE 4: Typical MCP73123 Charge Profile (1100 mAh LiFePO₄ Battery Cell).

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.

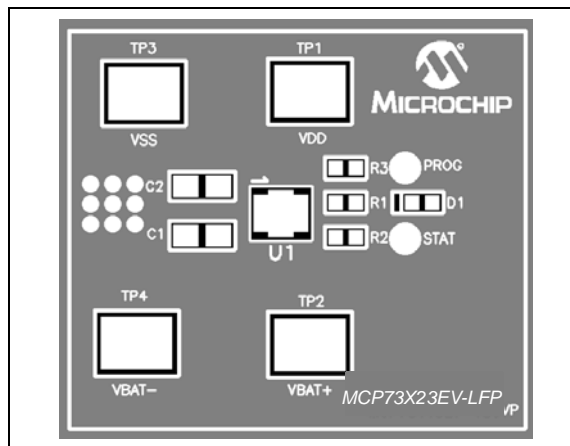


FIGURE 5: MCP73X23 Evaluation Board.

REFERENCES

- [1] MCP73123/223 Data Sheet, "Lithium Iron Phosphate (LiFePO₄) 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.

Note the following details of the code protection feature on Microchip devices:

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip's Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
- Microchip is willing to work with the customer who is concerned about the integrity of their code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of their code. Code protection does not mean that we are guaranteeing the product as “unbreakable.”

Code protection is constantly evolving. We at Microchip are committed to continuously improving the code protection features of our products. Attempts to break Microchip's code protection feature may be a violation of the Digital Millennium Copyright Act. If such acts allow unauthorized access to your software or other copyrighted work, you may have a right to sue for relief under that Act.

Information contained in this publication regarding device applications and the like is provided only for your convenience and may be superseded by updates. It is your responsibility to ensure that your application meets with your specifications. MICROCHIP MAKES NO REPRESENTATIONS OR WARRANTIES OF ANY KIND WHETHER EXPRESS OR IMPLIED, WRITTEN OR ORAL, STATUTORY OR OTHERWISE, RELATED TO THE INFORMATION, INCLUDING BUT NOT LIMITED TO ITS CONDITION, QUALITY, PERFORMANCE, MERCHANTABILITY OR FITNESS FOR PURPOSE. Microchip disclaims all liability arising from this information and its use. Use of Microchip devices in life support and/or safety applications is entirely at the buyer's risk, and the buyer agrees to defend, indemnify and hold harmless Microchip from any and all damages, claims, suits, or expenses resulting from such use. No licenses are conveyed, implicitly or otherwise, under any Microchip intellectual property rights.

Trademarks

The Microchip name and logo, the Microchip logo, dsPIC, KEELOQ, KEELOQ logo, MPLAB, PIC, PICmicro, PICSTART, rfPIC and UNI/O are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

FilterLab, Hampshire, HI-TECH C, Linear Active Thermistor, MXDEV, MXLAB, SEEVAL and The Embedded Control Solutions Company are registered trademarks of Microchip Technology Incorporated in the U.S.A.

Analog-for-the-Digital Age, Application Maestro, CodeGuard, dsPICDEM, dsPICDEM.net, dsPICworks, dsSPEAK, ECAN, ECONOMONITOR, FanSense, HI-TIDE, In-Circuit Serial Programming, ICSP, ICEPIC, Mindi, MiWi, MPASM, MPLAB Certified logo, MPLIB, MPLINK, mTouch, Omniscent Code Generation, PICC, PICC-18, PICkit, PICDEM, PICDEM.net, PICtail, PIC³² logo, REAL ICE, rLAB, Select Mode, Total Endurance, TSHARC, WiperLock and ZENA are trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

SQTP is a service mark of Microchip Technology Incorporated in the U.S.A.

All other trademarks mentioned herein are property of their respective companies.

© 2009, Microchip Technology Incorporated, Printed in the U.S.A., All Rights Reserved.

 Printed on recycled paper.

QUALITY MANAGEMENT SYSTEM
CERTIFIED BY DNV
== ISO/TS 16949:2002 ==

Microchip received ISO/TS-16949:2002 certification for its worldwide headquarters, design and wafer fabrication facilities in Chandler and Tempe, Arizona; Gresham, Oregon and design centers in California and India. The Company's quality system processes and procedures are for its PIC® MCUs and dsPIC® DSCs, KEELOQ® code hopping devices, Serial EEPROMs, microperipherals, nonvolatile memory and analog products. In addition, Microchip's quality system for the design and manufacture of development systems is ISO 9001:2000 certified.



WORLDWIDE SALES AND SERVICE

AMERICAS

Corporate Office
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7200
Fax: 480-792-7277
Technical Support:
<http://support.microchip.com>
Web Address:
www.microchip.com

Atlanta
Duluth, GA
Tel: 678-957-9614
Fax: 678-957-1455

Boston
Westborough, MA
Tel: 774-760-0087
Fax: 774-760-0088

Chicago
Itasca, IL
Tel: 630-285-0071
Fax: 630-285-0075

Cleveland
Independence, OH
Tel: 216-447-0464
Fax: 216-447-0643

Dallas
Addison, TX
Tel: 972-818-7423
Fax: 972-818-2924

Detroit
Farmington Hills, MI
Tel: 248-538-2250
Fax: 248-538-2260

Kokomo
Kokomo, IN
Tel: 765-864-8360
Fax: 765-864-8387

Los Angeles
Mission Viejo, CA
Tel: 949-462-9523
Fax: 949-462-9608

Santa Clara
Santa Clara, CA
Tel: 408-961-6444
Fax: 408-961-6445

Toronto
Mississauga, Ontario,
Canada
Tel: 905-673-0699
Fax: 905-673-6509

ASIA/PACIFIC

Asia Pacific Office
Suites 3707-14, 37th Floor
Tower 6, The Gateway
Harbour City, Kowloon
Hong Kong
Tel: 852-2401-1200
Fax: 852-2401-3431

Australia - Sydney
Tel: 61-2-9868-6733
Fax: 61-2-9868-6755

China - Beijing
Tel: 86-10-8528-2100
Fax: 86-10-8528-2104

China - Chengdu
Tel: 86-28-8665-5511
Fax: 86-28-8665-7889

China - Hong Kong SAR
Tel: 852-2401-1200
Fax: 852-2401-3431

China - Nanjing
Tel: 86-25-8473-2460
Fax: 86-25-8473-2470

China - Qingdao
Tel: 86-532-8502-7355
Fax: 86-532-8502-7205

China - Shanghai
Tel: 86-21-5407-5533
Fax: 86-21-5407-5066

China - Shenyang
Tel: 86-24-2334-2829
Fax: 86-24-2334-2393

China - Shenzhen
Tel: 86-755-8203-2660
Fax: 86-755-8203-1760

China - Wuhan
Tel: 86-27-5980-5300
Fax: 86-27-5980-5118

China - Xiamen
Tel: 86-592-2388138
Fax: 86-592-2388130

China - Xian
Tel: 86-29-8833-7252
Fax: 86-29-8833-7256

China - Zhuhai
Tel: 86-756-3210040
Fax: 86-756-3210049

ASIA/PACIFIC

India - Bangalore
Tel: 91-80-3090-4444
Fax: 91-80-3090-4080

India - New Delhi
Tel: 91-11-4160-8631
Fax: 91-11-4160-8632

India - Pune
Tel: 91-20-2566-1512
Fax: 91-20-2566-1513

Japan - Yokohama
Tel: 81-45-471- 6166
Fax: 81-45-471-6122

Korea - Daegu
Tel: 82-53-744-4301
Fax: 82-53-744-4302

Korea - Seoul
Tel: 82-2-554-7200
Fax: 82-2-558-5932 or
82-2-558-5934

Malaysia - Kuala Lumpur
Tel: 60-3-6201-9857
Fax: 60-3-6201-9859

Malaysia - Penang
Tel: 60-4-227-8870
Fax: 60-4-227-4068

Philippines - Manila
Tel: 63-2-634-9065
Fax: 63-2-634-9069

Singapore
Tel: 65-6334-8870
Fax: 65-6334-8850

Taiwan - Hsin Chu
Tel: 886-3-6578-300
Fax: 886-3-6578-370

Taiwan - Kaohsiung
Tel: 886-7-536-4818
Fax: 886-7-536-4803

Taiwan - Taipei
Tel: 886-2-2500-6610
Fax: 886-2-2508-0102

Thailand - Bangkok
Tel: 66-2-694-1351
Fax: 66-2-694-1350

EUROPE

Austria - Wels
Tel: 43-7242-2244-39
Fax: 43-7242-2244-393

Denmark - Copenhagen
Tel: 45-4450-2828
Fax: 45-4485-2829

France - Paris
Tel: 33-1-69-53-63-20
Fax: 33-1-69-30-90-79

Germany - Munich
Tel: 49-89-627-144-0
Fax: 49-89-627-144-44

Italy - Milan
Tel: 39-0331-742611
Fax: 39-0331-466781

Netherlands - Drunen
Tel: 31-416-690399
Fax: 31-416-690340

Spain - Madrid
Tel: 34-91-708-08-90
Fax: 34-91-708-08-91

UK - Wokingham
Tel: 44-118-921-5869
Fax: 44-118-921-5820

03/26/09