AN3506

Low I_Q Powering Solutions for One Alkaline Battery

Author: Valentin Constantin
Microchip Technology Inc.

INTRODUCTION

Designing single cell battery-powered applications requires good knowledge and understanding of the battery's capabilities and its chemistry as well as choosing the optimum converter to power the target application.

This application note focuses on the efficient utilization of alkaline cells, considering safety precautions provided by battery manufacturers and recommending the appropriate circuitry and converter topology for low-voltage applications that are powered from a single cell.

ALKALINE BATTERY CONSIDERATIONS WHILE POWERING BOOST CONVERTERS

Battery manufacturers (OEMs) do not recommend the utilization of a battery below its specified Functional End Point (FEP) or cut-off voltage. This is a battery voltage value where there is not enough energy to deliver power as "all usable capacity" is used up. For an alkaline cell, the FEP is 0.9V or 0.8V. Discharging below the FEP even with a very small current will increase the risk of the battery to leak.

Leaking may produce serious damage (mostly irreversible) to the applications or the battery casing. Figure 1 shows a battery some time after it leaked. Corrosion can be noticed.

***FIGURE 1:** Discharged Alkaline Battery after Leakage, Showing Corrosion (Left Side).*

As the battery discharges, its energy capacity decreases while its internal electrical resistance increases. A notable difference (hundreds of millivolts) can be observed between the open load and the loaded battery's voltage due to the internal resistance. As expected, this voltage drop is dependent upon the load's current flow.

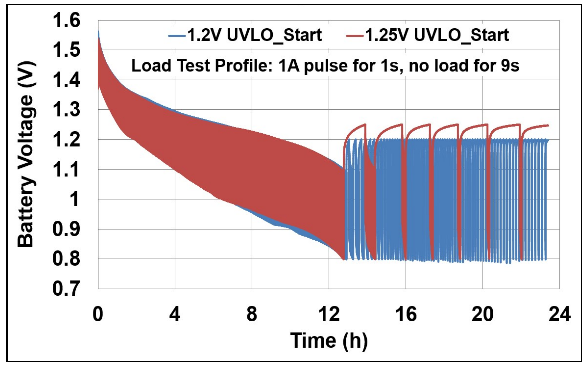

***FIGURE 2:** AA Alkaline Cell Discharged with Two Simulated UVLO Start Thresholds at 1.2V and 1.25V Using a Pulsed Load Profile. FEP is Set to 0.8V.*

When the load is removed, the battery voltage starts to recover slowly, in a matter of minutes. This process may bring the battery voltage close to its nominal value. However, a nearly depleted battery will not be capable of maintaining its voltage once the load is applied again because of its increased internal resistance. This will result in a bigger voltage drop which will impact the proper start-up of the DC-DC converter. This malfunction can affect time-variable load applications such as personal care products, wireless transmitters/receivers, data loggers, etc. The experiments illustrated in Figure 2 and Figure 3 demonstrate this issue. Fresh AA alkaline batteries are discharged down to 0.8V with the following profile: cycles of 1A load for 1 second followed by cycles of no load for 9 seconds. As shown in Figure 2, the battery voltage drop is the result of the increase of the battery's internal resistance from approximately 100 mΩ to approximately 300 mΩ (battery's voltage drop divided by load current). Usually, when an alkaline battery reaches its FEP (0.8V), its internal resistance increases up to 800 mΩ. For the purpose of this demonstration, two virtual UVLO Start thresholds were generated to simulate two real DC-DC start-up scenarios: 1.2V and 1.25V. Figure 2 illustrates that, after being discharged to the approximate 0.8V limit, the battery recovers slowly and

cannot ensure proper start-up or functioning under the 1A load. As the load applied to the battery through the DC-DC converter increases, the higher the UVLO Start threshold and the better the protection for the system.

Therefore, the UVLO Start threshold must be well correlated with the load current. In the case of step-up (boost) converters, their peak inductor current limit, I_{Lpeak} (see Table 1) or the current consumed from the battery (equal with the average of the inductor's current) is a few times higher than what the application's load consumes.

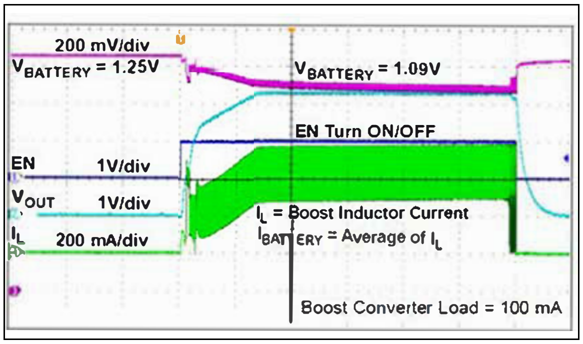

FIGURE 3: *A Start-Up Example with an In-Use Battery Showing an Approximate 0.38Ω Internal Resistance. (*Notice the Voltage Drop from 1.25V to 1.09V while Load Is Powered.*)*

For step-down (buck) converters, the battery current is lower than the load current. However, there are rare cases or applications for which a single battery voltage needs to be lowered. Therefore, the focus is on boost converters as they are more critical when choosing the input power. All boost converters require a larger amount of energy during their start-up sequence, a high peak current for a short period, usually hundreds of milliamps for tens of microseconds. A typical start-up sequence for a boost converter is shown in Figure 4.

A low voltage synchronous boost DC-DC start-up sequence begins with a linear, constant charge of the output capacitor using a controlled current. The synchronous rectifier works in the linear (or ohmic) region and the amount of load current is gate controlled. This part is called the "Pre-Charge" phase of the output capacitor and tracks the output to reach the battery's value (minus a small drop of hundreds of millivolts on the rectifier switch). Then, the device starts switching in "Open Loop" mode with limited inductor peak current. This current is usually a percentage of the maximum peak inductor current. When the output voltage reaches more than 60%-75% of its target, the converter's logic switches in "Closed Loop" PWM mode and starts regulating. Therefore, the "Pre-Charge" and "Open Loop" phases require a large amount of energy for very small periods to ensure proper start-up and to reach the nominal output voltage set.

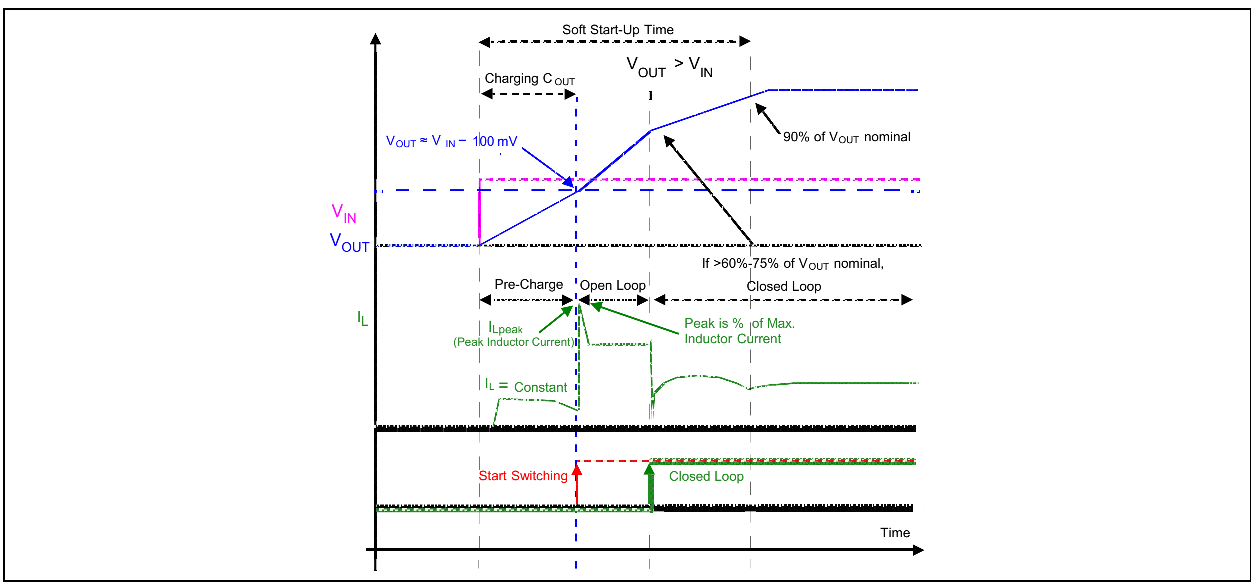

FIGURE 4: *Microchip Boost Converters Typical Start-Up Sequence.*

As the discharged battery is not able to provide the necessary energy, a converter without any start-up protection circuit such as "UVLO Start" or "UVLO Stop" may end up in a loop in which it attempts to start unsuccessfully. At each attempt, it drains a large amount of current, draining the battery even more.

There are a number of step-up converters designed with very low cut-off voltage, down to 0.35V-0.5V. Even though a battery boost circuit might be able to operate down to a very low input voltage, discharging alkaline cells below 0.8V is not advisable. Below 0.8V, parasitic drains should be kept as low as possible and preferably removed entirely. N.B.: *There are exceptions to this: some OEMs recommend that alkaline cells be discharged down to 0.5V if the cell's voltage is strictly monitored.*

Operating temperature may also impact device performance. Cold environments, in particular, may reduce runtime. Extremely high temperatures can also cause serious damage. Engineers should consider this aspect and always correlate battery temperature operating ratings and the environment in which their application will be used.

MICROCHIP ONE CELL-POWERED DEVICES SOLUTIONS OVERVIEW

The Microchip one-cell converters enable designers to use a wide variety of battery types to power applications that generally require higher operating voltages. Table 1 summarizes Microchip low-voltage, single cell-powered management devices. One of these devices, the MIC23099, is a power management IC (PMIC) that offers both boost and buck capabilities.

The MCP1640 is the best known and first designed step-up (boost) solution in the family, a high-performance low-voltage boost converter with only 19 µA quiescent current and 800 mA peak input current limit. The MCP1623/4 are low-cost versions of the MCP1640 that provide half peak current limit, less output current and a ±7% output voltage accuracy. With 650 mA I_L peak limit, the MCP16251/2 is the best in the family, offering the lowest quiescent current (I_Q) for energy saving, with only 4–5 µA typical. The I_Q bias for internal circuits comes from the output of the converter (after start-up), increasing the efficiency of the conversion. The MCP1642 offers 1.8A high inductor peak current. Its LED driver version, the MCP1643, provides an efficient solution for driving a power LED in constant current from one single alkaline cell.

It is to be noted that many of these power management solutions run on battery at very low voltage (e.g. 0.35V), after start-up (see Table 1).

TABLE 1: LOW I_Q, ONE CELL-POWERED DEVICES OVERVIEW

Device	I_Q[3] [µA]	V_{IN} [V]	V_{OUT} [V]	$V_{Start\text{-}Up}$ [V]	I_{Lpeak} [A]	$I_{Pre\text{-}Charge}$[4] [mA]	$I_{L\ Open\ Loop}$[4] [mA]	Features
MIC23099[1]	—	0.5-1.6	1.0-3.3	0.75	1.5	80	120	Boost and Buck Mode, Power Good and Low Battery Monitoring
MCP16251/2	4	0.35-5.5	1.8-5.5	0.82	0.65	130	550	PFM/PWM, True Disconnect Output or Input-to-Output Bypass
MCP1640/B/C/D	19	0.35-5.5	2.0-5.5	0.65	0.8	130	—	PFM/PWM or PWM Only, True Disconnect Output or Input-to-Output Bypass
MCP1623/4	—	0.35-5.0	2.0-5.5	0.65	0.425	130	—	PWM/PFM Mode or PWM Mode Only
MCP1642B/D	400	0.35-5.5	1.8-5.5	0.65	1.8	200	1100	Power Good, PWM, True Disconnect Output or Input-to-Output Bypass
MCP1643[2]	—	0.5-5.0	max. 5.0	0.65	1.6	—	—	Open Load Protection (output overvoltage)

Note 1: MIC23099 is a dual output Boost and Buck converter. I_Q_PFM is 200 µA typical in the following conditions: no load on both outputs, device is running (switching) and the LED pin is not connected.

2: MCP1643 is an LED Constant Current Regulator. If no LED is connected, V_{OUT} will be clamped at 5V maximum. Minimum LED current to achieve regulation is approximatively 15 mA for one alkaline cell. While in shutdown, the device consumes 1.2 µA typical.

3: I_Q is in sleep mode — device is not switching. This is the current necessary to bias the device's internal blocks and is measured at V_{OUT}.

4: Values are from bench testing on a limited number of samples, not characterized values. The Pre-Charge and I_L Open Loop currents were measured for V_{OUT} = 3.3V and V_{IN} = 1.25V with 1 mA load at room temperature.

These devices have been designed to operate with a wide input voltage range, starting from 0.65V-0.82V and running down to 0.35V, with the purpose of accommodating a large variety of input sources (battery types). For alkaline batteries in particular, if the application has no other control circuits for monitoring the battery's voltage (a system microcontroller), there might be a need for a simple and inexpensive analog discrete UVLO Start/Stop circuit with ultra-low additional power consumption, as shown in Figure 5. This circuit is powered from the same input source or battery and consumes only 0.5 µA-2 µA (Figure 6). Also, it can easily drive the Enable (EN) pin of the boost converter and both "Start" and "Stop" thresholds are user programmable using Equation 1 and Equation 2.

The circuit in Figure 5 offers approx. 1.1V trip point to start and 0.8V to shut down.

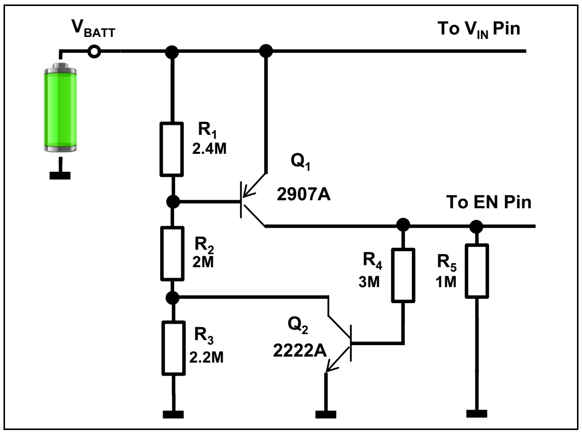

FIGURE 5: *Ultra-Low I_Q UVLO Circuit Example, with 1.1V Start-Up and 0.8V Shutdown Thresholds.*

EQUATION 1:

$$UVLO\ V_{IN\_START} \approx 0.4 \times \frac{R_1 + R_2 + R_3}{R_1}$$

EQUATION 2:

$$UVLO\ V_{IN\_STOP} \approx 0.4 \times \frac{R_1 + R_2}{R_1}$$

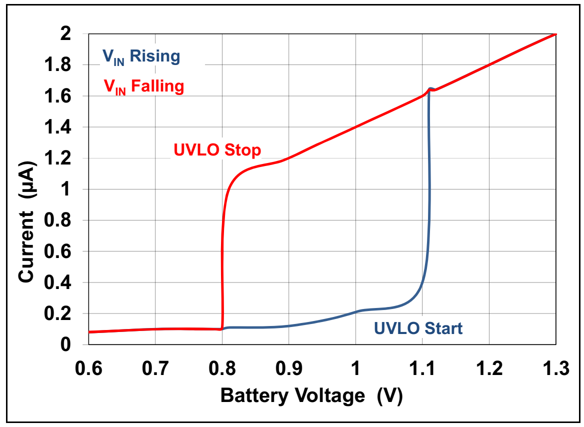

FIGURE 6: *Current Consumed by the Additional UVLO Circuit in Figure 5.*

Note: For the evaluation of the UVLO circuit in Figure 5, the following reference design is available on the Microchip website:

- - MCP16251 Reference Design – ARD00797

MIC23099 — BOOST AND BUCK PMIC WITH BATTERY MONITORING

The MIC23099 is a One-Cell Power Management Controller (PMIC) which integrates one boost and one low current buck converter. The buck section is powered internally directly from the boost's output and can supply up to maximum 30 mA to the load, being one of the very few low-power, under 2V input step-down solutions on the market. It can convert the 1.8V input or the battery's voltage down to 0.9V.

The MIC23099 features a battery monitoring circuit. An open drain output can provide information on the battery status to any system's MCU. The LED output pin shows the battery level is low. While the battery gets discharged and reaches the device's internal 1.2V threshold, the LED will start blinking at low intervals (0.25 Hz and 25% duty cycle), until the user replaces the battery.

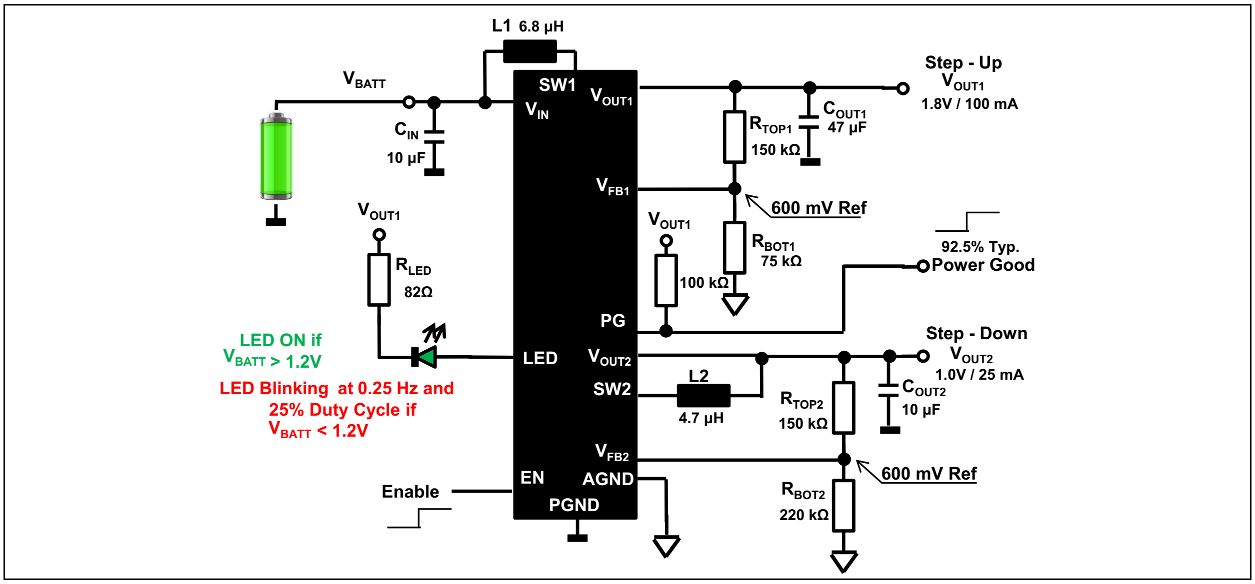

FIGURE 7: *MIC23099 Typical Application.*

Another key feature of the MIC23099 is the output latch-off in case the battery's voltage drops below 0.85V. The MIC23099 monitors both converter's outputs and the value of the battery's voltage. An internal circuit counts the output cut-offs and recovering cycles. If the counter reaches 15 cycles (Figure 8), the internal logic will shut down the device permanently to avoid the so-called "motorboating". The MIC23099 will resume operation after toggling the EN pin or replacing the battery. During sleep (or cooling off) cycles of 1.3s, both outputs are individually discharged by a 500Ω resistor.

Note: For evaluation and demo purposes, there are two options on the market:

- - MIC23099YFT-EV Evaluation Board
- - MIKROE-2765, MIC23099 Click Board.

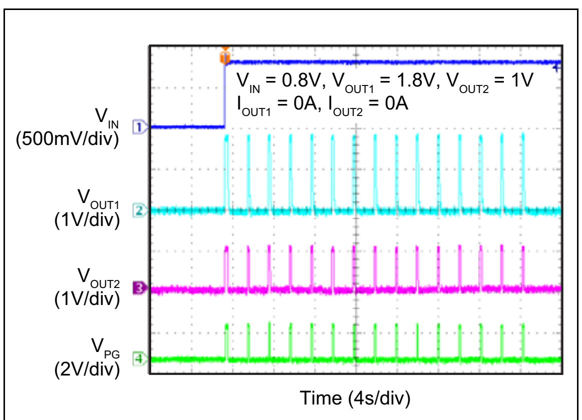

FIGURE 8: *MIC23099 Low Battery Outputs Latch-Off after 15 Cycles.*

CONCLUSION

Engineers should avoid deeply discharging alkaline batteries because it will increase the possibility of leakage. Even though a boost DC-DC converter might be able to operate down to a very low input voltage, discharging alkaline batteries below 0.8V is not advisable. Below 0.8V on the battery, parasitic drains should be kept as low as possible and preferably removed entirely. Alkaline batteries can be discharged down to 0.5V if the cell voltage is well monitored using dedicated circuits.

REFERENCES

1. MIC23099 Data Sheet – *"Single AA/AAA Cell Step-up/Step-Down Regulators with Battery Monitoring"* (DS20005684)
2. MCP16251/2 Data Sheet – *"Low Quiescent Current, PFM/PWM Synchronous Boost Regulator with True Output Disconnect or Input/ Output Bypass Option"* (DS20005173)
3. MCP16251 Reference Design – *"One-Cell Boost Converter with External UVLO Circuit" (DS50002561)*
4. MCP1640/B/C/D Data Sheet – *"0.65V Start-Up Synchronous Boost Regulator with True Output Disconnect or Input/Output Bypass Option"* (DS20002234)
5. MCP1623/4 Data Sheet – *"Low-Voltage Input Boost Regulator for PIC® Microcontrollers"* (DS40001420)
6. MCP1642B/D Data Sheet – *"1.8A Input Current Switch, 1 MHz Low-Voltage Start-Up Synchronous Boost Regulator"* (DS20005253)

7. MCP1643 Data Sheet – *“1 MHz Low Start-up Voltage Synchronous Boost LED Constant Current Regulator”* (DS20005208)
8. MIKROE-2765 – *“MIC23099 Click Board - visit* ***https://www.mikroe.com/mic23099-click***

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.

For information regarding Microchip's Quality Management Systems, please visit www.microchip.com/quality.

Trademarks

ISBN: 978-1-5224-6272-9

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://www.microchip.com/support
Web Address:
www.microchip.com

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

Austin, TX
Tel: 512-257-3370

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

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

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

Detroit
Novi, MI
Tel: 248-848-4000

Houston, TX
Tel: 281-894-5983

Indianapolis
Noblesville, IN
Tel: 317-773-8323
Fax: 317-773-5453
Tel: 317-536-2380

Los Angeles
Mission Viejo, CA
Tel: 949-462-9523
Fax: 949-462-9608
Tel: 951-273-7800

Raleigh, NC
Tel: 919-844-7510

New York, NY
Tel: 631-435-6000

San Jose, CA
Tel: 408-735-9110
Tel: 408-436-4270

Canada - Toronto
Tel: 905-695-1980
Fax: 905-695-2078

ASIA/PACIFIC

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

China - Beijing
Tel: 86-10-8569-7000

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

China - Chongqing
Tel: 86-23-8980-9588

China - Dongguan
Tel: 86-769-8702-9880

China - Guangzhou
Tel: 86-20-8755-8029

China - Hangzhou
Tel: 86-571-8792-8115

China - Hong Kong SAR
Tel: 852-2943-5100

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

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

China - Shanghai
Tel: 86-21-3326-8000

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

China - Shenzhen
Tel: 86-755-8864-2200

China - Suzhou
Tel: 86-186-6233-1526

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

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

China - Xiamen
Tel: 86-592-2388138

China - Zhuhai
Tel: 86-756-3210040

ASIA/PACIFIC

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

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

India - Pune
Tel: 91-20-4121-0141

Japan - Osaka
Tel: 81-6-6152-7160

Japan - Tokyo
Tel: 81-3-6880- 3770

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

Korea - Seoul
Tel: 82-2-554-7200

Malaysia - Kuala Lumpur
Tel: 60-3-7651-7906

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

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

Singapore
Tel: 65-6334-8870

Taiwan - Hsin Chu
Tel: 886-3-577-8366

Taiwan - Kaohsiung
Tel: 886-7-213-7830

Taiwan - Taipei
Tel: 886-2-2508-8600

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

Vietnam - Ho Chi Minh
Tel: 84-28-5448-2100

EUROPE

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

Denmark - Copenhagen
Tel: 45-4485-5910
Fax: 45-4485-2829

Finland - Espoo
Tel: 358-9-4520-820

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

Germany - Garching
Tel: 49-8931-9700

Germany - Haan
Tel: 49-2129-3766400

Germany - Heilbronn
Tel: 49-7131-72400

Germany - Karlsruhe
Tel: 49-721-625370

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

Germany - Rosenheim
Tel: 49-8031-354-560

Israel - Ra’anana
Tel: 972-9-744-7705

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

Italy - Padova
Tel: 39-049-7625286

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

Norway - Trondheim
Tel: 47-7288-4388

Poland - Warsaw
Tel: 48-22-3325737

Romania - Bucharest
Tel: 40-21-407-87-50

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

Sweden - Gothenberg
Tel: 46-31-704-60-40

Sweden - Stockholm
Tel: 46-8-5090-4654

UK - Wokingham
Tel: 44-118-921-5800
Fax: 44-118-921-5820