TB3277

MCP16311/2 High Efficiency Buck-Boost Converter

Author: Andrei Radulescu
Microchip Technology Inc.

INTRODUCTION

This Technical Brief proposes a high-efficiency buck-boost converter design which is implemented using the simple 30V input MCP16311/2 synchronous step-down switching regulator with a typical application depicted in Figure 1. There are many buck-boost converter designs available in the literature, but most of them suffer from low-efficiency, which is mainly caused by the utilization of four switches that operate alternately. This application not only demonstrates that the MCP16311/2 can be used in a step-down/step-up converter, but also comprises a method of improving the converter's efficiency while enhancing the output current capabilities in some conditions.

The proposed method consists in providing a buck-only operation as shown in Figure 2. This is described in detail in the **Mode of Operation** section.

The MCP16311/2 is a compact, high-efficiency, fixed frequency, synchronous step-down DC-DC converter in an 8-pin MSOP and 2 mm x 3 mm TDFN package that operates from input voltage sources up to 30V. Integrated features include a high-side and a low-side switch, fixed frequency peak current mode control, internal compensation, peak current limit and overtemperature protection. The MCP16311/2 provides all of the active functions for local DC-DC conversion with fast transient response and accurate regulation.

MCP16311/2 switching regulator's high-efficiency is achieved by integrating the current-limited, low-resistance, high-speed, high-side and low-side switches and associated drive circuitry. The MCP16311 is capable of running in Pulse Frequency Modulation/Pulse Width Modulation (PFM/PWM) mode. It switches in PFM mode for light load conditions and for large Buck conversion ratios. This results in a higher efficiency over all load ranges. The MCP16312 runs in PWM-only mode and is recommended for noise-sensitive applications.

The MCP16311/2 device family can supply up to 1A of continuous current while regulating the output voltage from 2V to 12V. An integrated high-performance peak current mode architecture keeps the output voltage tightly regulated, even during input voltage steps and output current transient conditions which are common in power systems.

The EN input is used to turn the device on and off. While off, only a few micro amps of current are drawn from the input.

Output voltage is set with an external resistive divider. The MCP16311/2 is offered in small MSOP-8 and 2 mm x 3 mm TDFN surface mount packages.

DEVICE FEATURES

- Up to 95% Efficiency
- Input Voltage Range: 4.4V to 30V
- 1A Output Current Capability
- Qualification: AEC-Q100 Rev. G, Grade 1 (-40°C to +125°C)
- Integrated N-Channel High-Side and Low-Side Switches:
  - 170 mΩ Low Side
  - 300 mΩ High Side
- Stable Reference Voltage: 0.8V
- Automatic PFM/PWM Operation (MCP16311):
  - PFM Operation Disabled (MCP16312)
  - PWM Operation: 500 kHz
- Low Device Shutdown Current: 3 µA typical
- Low Device Quiescent Current: 44 µA (Non-switching, PFM Mode)
- Internal Compensation
- Internal Soft-Start: 300 µs (EN Low-to-High)
- Peak Current Mode Control
- Cycle-by-Cycle Peak Current Limit
- Undervoltage Lockout (UVLO)
  - 4.1V typical to start
  - 3.6V typical to stop
- Thermal Shutdown:
  - +150°C
  - +25°C Hysteresis

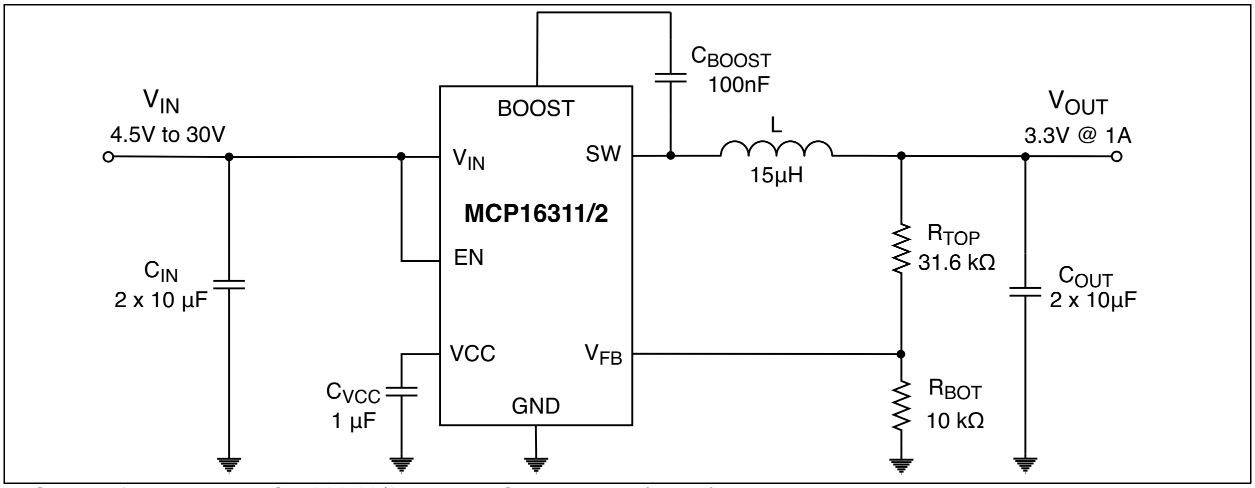

FIGURE 1: *MCP16311/2 Typical Step-Down (Buck) Application.*

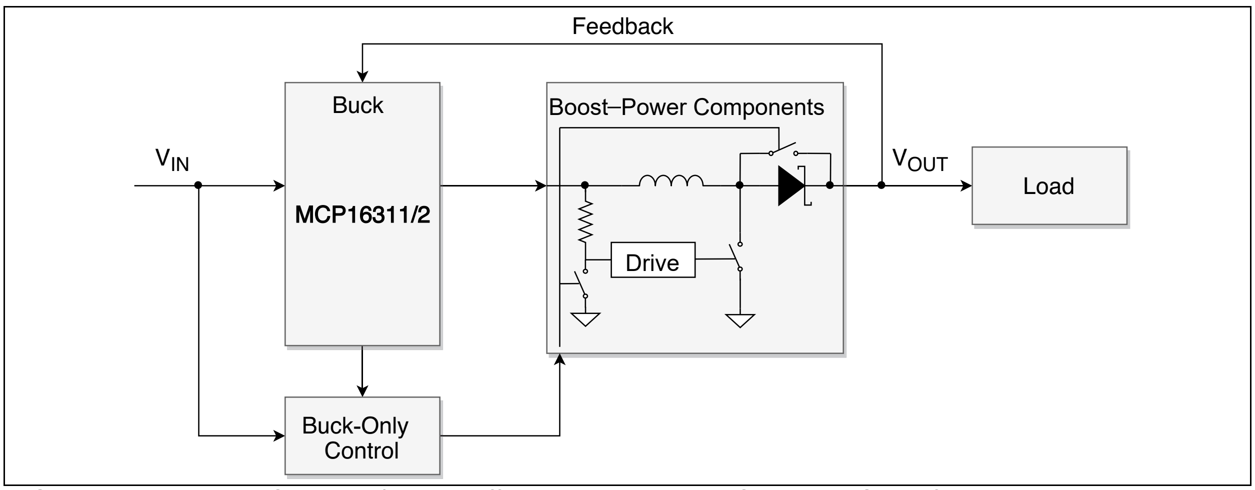

FIGURE 2: *MCP16311/2 High Efficiency Buck-Boost Converter Simplified Block Diagram.*

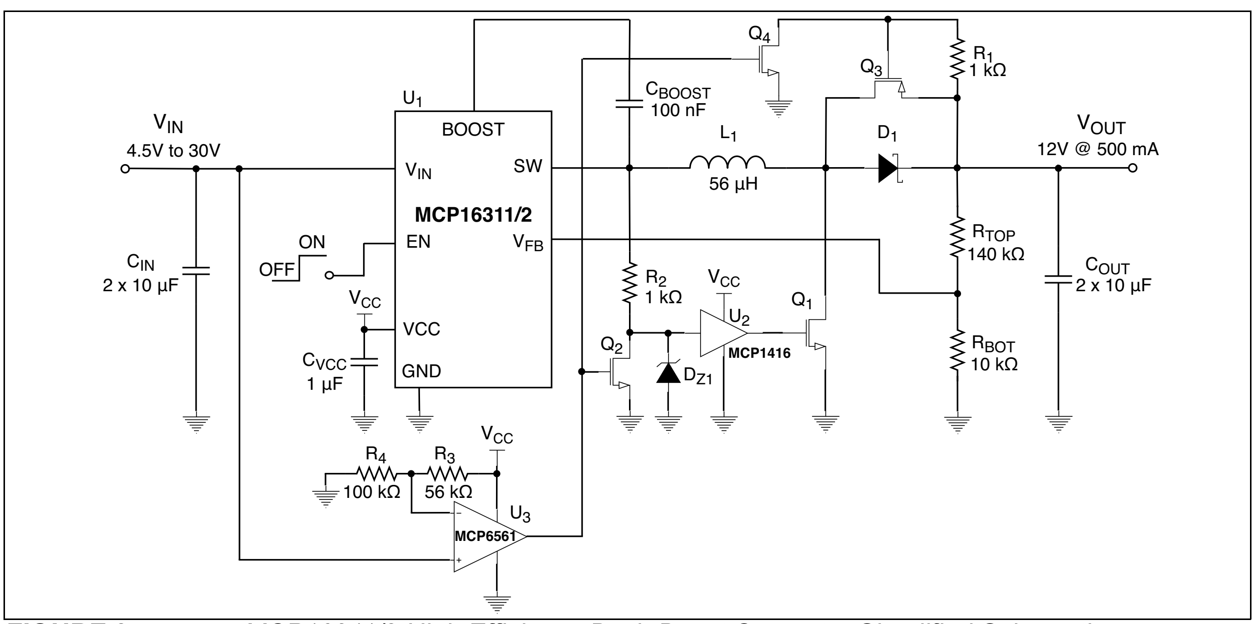

FIGURE 3: *MCP16311/2 High Efficiency Buck-Boost Converter Simplified Schematic.*

MODE OF OPERATION

The proposed solution is a conventional noninverting buck-boost converter which uses a single inductor (Figure 3), and has an additional MOSFET (Q_1) and an additional diode (D_1), compared to a classic inverting buck-boost or a step-down converter. By turning the internal high-side switch together with Q_1 on and off simultaneously, the converter operates in buck-boost mode. The ideal waveforms of a noninverting buck-boost converter operating in buck-boost mode and Continuous Conduction Mode (CCM) are shown in Figure 4.

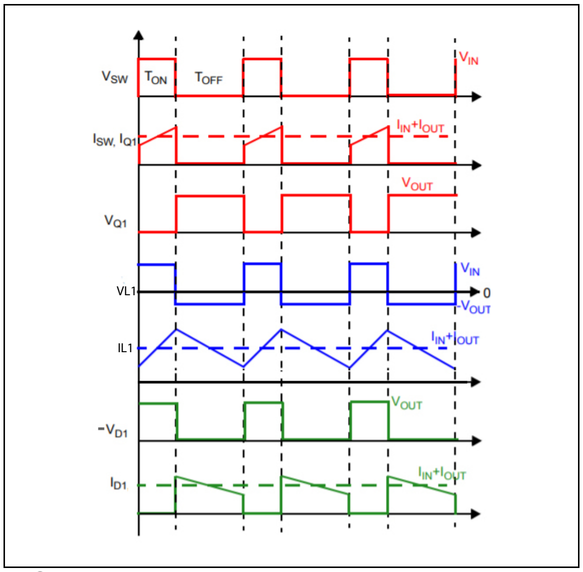

FIGURE 4: Noninverting Buck-Boost Converter Waveforms in CCM.

With regard to the ratings, both the internal high-side and low-side switches see a voltage stress of V_{IN}, while Q_1 and D_1 see a voltage stress of V_{OUT}. The internal high-side and low-side switches, together with Q_1, D_1 and L_1, all see a current stress of $I_{IN} + I_{OUT}$, with inductor ripple current neglected. The relatively large number of power devices and high-current stress in buck-boost mode prevent the converter from being efficient.

The proposed noninverting buck-boost converter is a cascaded combination of a Buck converter followed by a Boost converter, both sharing the same inductor. The internal high-side switch and Q_1 have identical gate-control signals. In order to increase the converter efficiency (Figure 5) and maximum output current capabilities (Figure 6), a few additional components are needed (Q_2, Q_3 and U_3) and represent a slight increase in complexity. The mode of operation for the proposed circuit is described in the following paragraphs.

When the input voltage is greater than the output voltage ($V_{IN} > V_{OUT}$), the output of the U_3 comparator goes from low to high and turns on Q_2 and Q_3 switches, in order to disable the Pulse-Width Modulation (PWM) signal for the main switch of the Boost leg and to bypass its rectifier (Schottky diode). As a result, Q_1 and D_1 are off and the circuit operates as a Buck converter. The comparator (U_3) has a hysteresis adjusted to about 400 mV to avoid instability when the input voltage is very close to the threshold value.

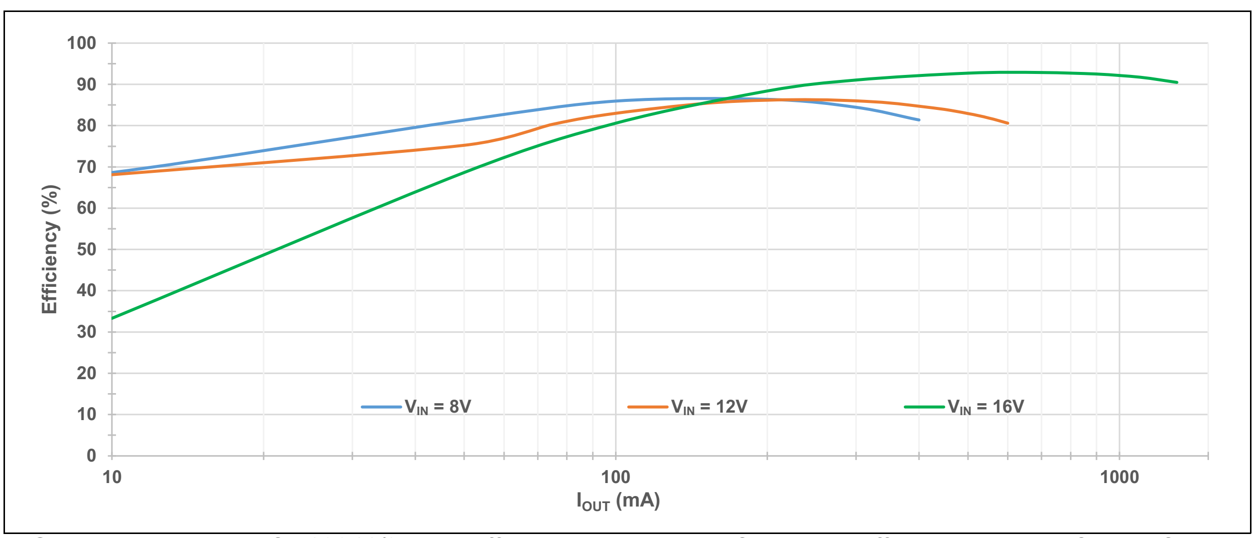

FIGURE 5: MCP16311/2 High Efficiency Buck-Boost Converter Efficiency Plot vs. Output Current for 12V V_{OUT}.

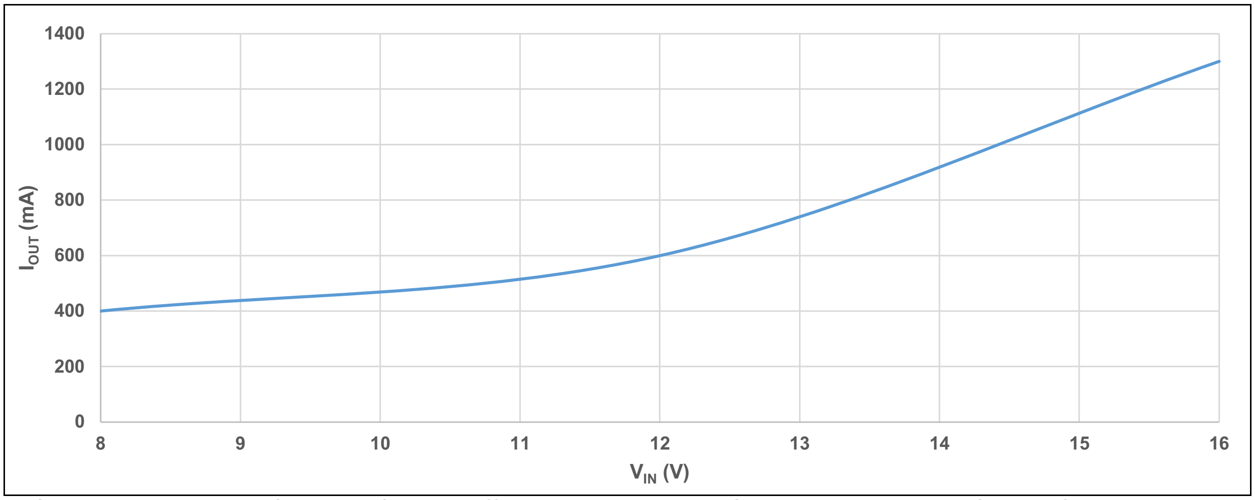

FIGURE 6: *MCP16311/2 High Efficiency Buck-Boost Converter Maximum Output Current vs. Input Voltage for 12V V_{OUT}.*

NONINVERTING BUCK-BOOST CONVERTER DESIGN STAGE

In order to calculate the noninverting buck-boost converter application parameters and inductor's value for Continuous Conduction Mode operation, Equations 1 to 5 can be used.

EQUATION 1: DUTY CYCLE

$$D = \frac{V_{OUT} + V_D}{V_{IN} + V_{OUT} + V_D}$$

EQUATION 2: MAXIMUM DUTY CYCLE

$$D_{max} = \frac{V_{OUT} + V_D}{V_{INmin} + V_{OUT} + V_D}$$

Note 1: V_D represents the voltage drop on D_1 diode

The duty cycle of the noninverting buck-boost converter can be calculated using the equations above; at minimum input voltage (V_{INmin}), the duty cycle has the maximum value, while at maximum input voltage (V_{INmax}), the duty cycle has the minimum value. For the noninverting buck-boost converter, the DC current flowing through L_1 is the sum of the input current and output current.

EQUATION 3: INDUCTOR RIPPLE CURRENT

$$I_{Lp-p} = (I_{IN} + I_{OUT}) \times k$$

Note 1: k takes values between 0.2 to 0.4

2: k represents a percentage of the inductor current

The inductor ripple current represents a percentage of the DC current; depending on the application, this percentage is usually chosen between 20% and 40%. The higher the ripple (coefficient k is higher), the lower the inductor value. Therefore, output current capabilities will be lower, as the current ripple will reach the peak current limitation sooner.

For lower k coefficient values, the inductance will be higher; the output current will increase as the ripple will decrease, requiring more load to hit the current limit. As a result of higher output current, the power dissipation of the device needs to be taken into consideration; the converter may enter thermal shutdown before reaching the peak current limit. Eventually, requirements of the application will determine the acceptable inductor current ripple range. However, because MCP16311/2 is a peak current mode control converter, it requires a significant inductor current ripple, in order to provide the best transient response. Usually, a k = 30% is a good trade-off between output current capabilities and dynamic response.

The inductor's peak current is dependent on the following parameters, as shown in Equation 4:

- Converter's input current
- Converter's output current
- The inductor current ripple which is designed to meet the application requirements

EQUATION 4: INDUCTOR PEAK CURRENT

$$I_{Lpeak} = I_{IN} + I_{OUT} + \frac{I_{Lp-p}}{2}$$

During the design phase, the efficiency of the converter is estimated, in order to simplify all the calculations. The real application results may differ to a small extent, because they are influenced by the component/system tolerances and accuracy of the estimated parameters.

The value of the inductor can be calculated using Equation 5.

EQUATION 5: INDUCTOR VALUE

$$L = \frac{V_{IN} \times D}{I_{Lp-p} \times f_{SW}}$$

Note 1: f_{SW} represents the switching frequency

High Inductor Current Ripple

- Advantages:
  - Lower inductor value required, lowering application's necessary board space, thus reducing overall costs
  - Better dynamic response
- Drawbacks:
  - Lower output current capabilities
  - Increased EMI (electromagnetic interference), therefore requiring additional output filtering

Low Inductor Current Ripple

- Advantages:
  - Higher output current capabilities
  - Decreased EMI
- Drawbacks:
  - Bigger inductor value/package (size)

One possible implementation of the proposed buck-boost converter Printed Circuit Board (PCB) assembly is shown in Figure 7.

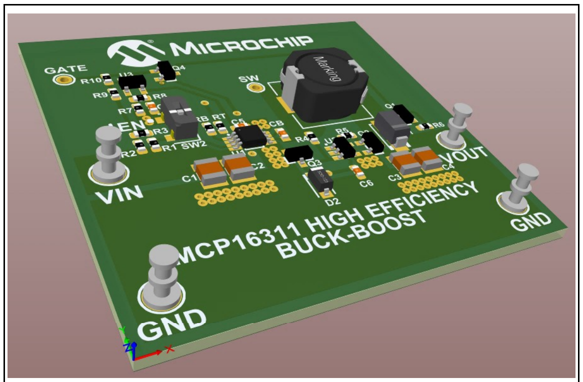

FIGURE 7: MCP16311/2 High Efficiency Buck-Boost Assembly.

CONCLUSIONS

When a step-down/step-up DC/DC converter solution is needed for an application, some engineers might be reluctant to choose the buck-boost topology, knowing that it might have limited output current capabilities and low efficiency. This technical brief proposes a solution to overcome these problems, which is represented by a noninverting buck-boost converter designed using the MCP16311/2 synchronous step-down switching regulator. With just a few additional components, (compared to a typical noninverting buck-boost converter) the overall efficiency, as well as the output current capabilities are improved.

REFERENCES

- MCP16311/2 Data Sheet – *"30V Input, 1A Output, High-Efficiency, Integrated Synchronous Switch Step-Down Regulator"* (DS20005255)
- AN2102 – *"Designing Applications with MCP16331 High-Input Voltage Buck Converter"* (DS00002102)

NOTES:

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

- Microchip products meet the specifications contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is secure when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods being used in attempts to breach the code protection features of the Microchip devices. We believe that these methods require using the Microchip products in a manner outside the operating specifications contained in Microchip's Data Sheets. Attempts to breach these code protection features, most likely, cannot be accomplished without violating Microchip's intellectual property rights.
- Microchip is willing to work with any customer who is concerned about the integrity of its code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of its code. Code protection does not mean that we are guaranteeing the product is "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: 978-1-5224-6710-6

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

02/28/20