Measuring Speed and Position with the QEI Module

Author: *Jorge Zambada*
Microchip Technology Inc.

INTRODUCTION

This document provides an overview of the Quadrature Encoder Interface (QEI) module present on the motor control family of dsPIC30F Digital Signal Controllers. Code examples are also provided for a typical motor control application, where speed and position measurements of the rotor are required.

QEI MODULE

Quadrature encoders (also known as incremental encoders or optical encoders) are used for position and speed detection of rotating motion systems. Quadrature encoders enable closed loop control of many motor control applications.

The QEI module provides a simple interface to incremental optical encoders, which allows you to obtain signed velocity and relative rotor position information from the motor or mechanical system. The QEI module accepts the A, B and index connections from the incremental encoder and stores the accumulated count pulses in a dedicated 16-bit time base. Velocity and position information can be measured at X2 or X4 resolution.

The two channels, Phase A (QEA) and Phase B (QEB), have a unique relationship. If Phase A leads Phase B, then the direction of the motor is deemed positive or forward. If Phase A lags Phase B then the direction of the motor is deemed negative or reverse. A third channel, termed Index pulse, occurs once per revolution and is used as a reference to establish an absolute position. The index signal may not be present on all encoders and is not required for proper operation of the QEI. See Figure 1 for a relative timing diagram of these three signals.

The QEI consists of quadrature decoder logic to interpret the Phase A, Phase B and Index signals and an up/down counter to accumulate the count. Digital glitch filters on the inputs condition the input signal. Figure 2 depicts a simplified block diagram of the QEI Module.

The QEI module includes these features:

- Three input pins for two phase signals and index pulse
- Programmable digital noise filters on inputs
- Quadrature decoder (provides counter pulses and count direction)
- 16-bit up/down position counter
- Count direction status
- X2 and X4 count resolution
- Two modes of position counter reset
- General purpose16-bit Timer/Counter mode
- Interrupts generated by QEI or counter events

FIGURE 1: QUADRATURE ENCODER INTERFACE SIGNALS

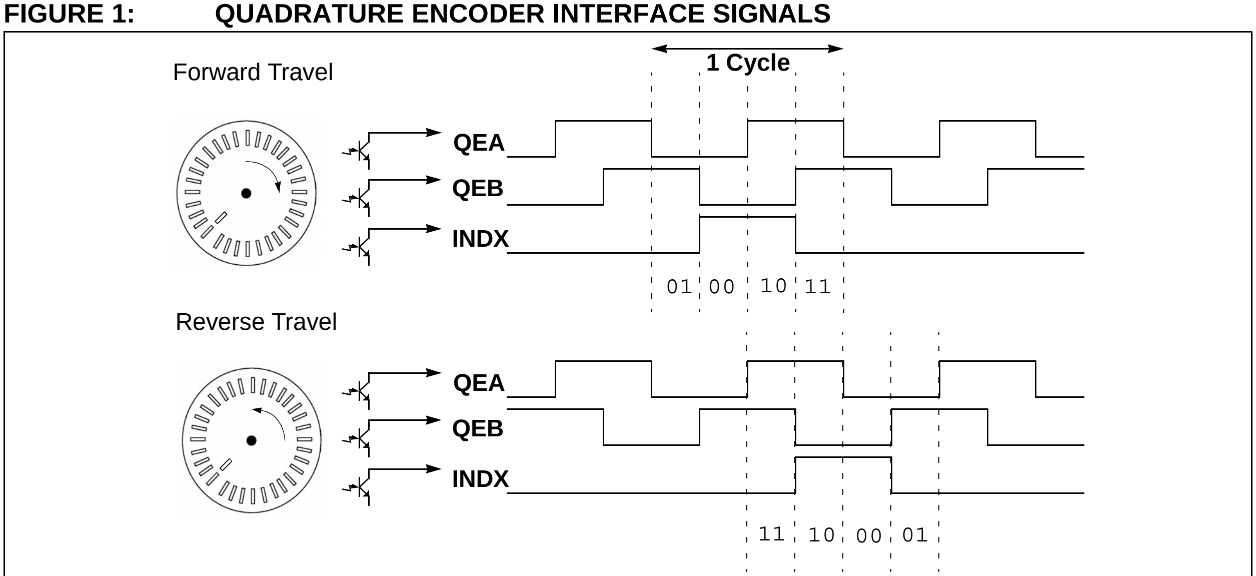
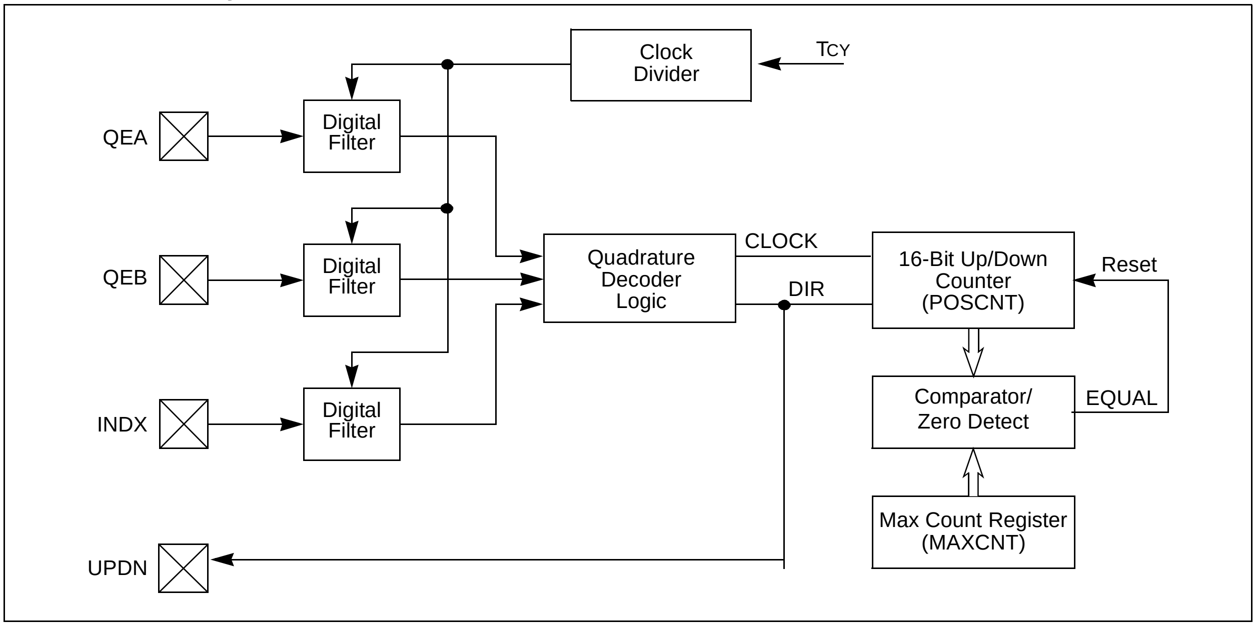


FIGURE 2: QUADRATURE ENCODER INTERFACE MODULE SIMPLIFIED BLOCK DIAGRAM

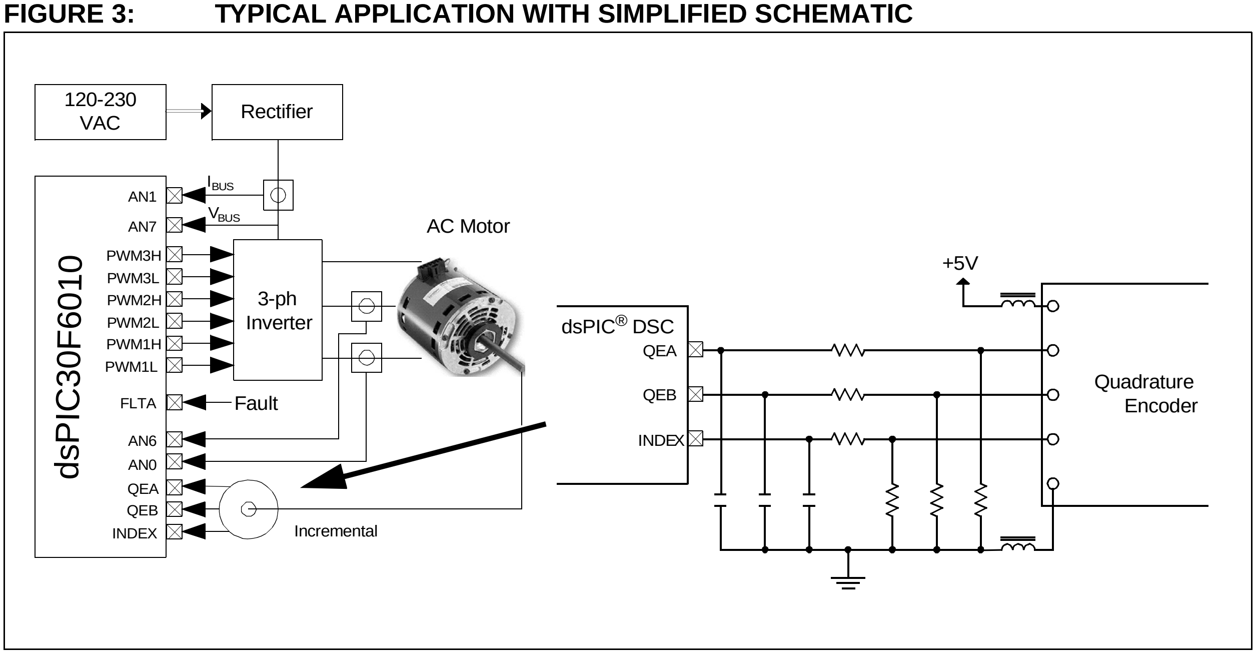


For more information on the CPU, peripherals, register descriptions and general device functionality, refer to the "*dsPIC30F Family Reference Manual"* (DS70046).

APPLICATION EXAMPLE

Figure 3 illustrates a typical application using the QEI module, where an AC Induction Motor (ACIM) is controlled by using a quadrature encoder for feedback information.

FIGURE 3: TYPICAL APPLICATION WITH SIMPLIFIED SCHEMATIC



 Advance Information

The requirements of the application example are:

1. **Measure rotor angular position from 0° to 360°.** The number of lines of the incremental encoder must be known in order to set the proper scaling factors. A 16-bit unsigned variable is used for this requirement.
2. **Measure signed angular speed.** Motor maximum speed is to be known for proper conversion. A signed 16-bit variable is used, where the sign represents forward (+) or reverse (-) direction of rotation.

For these requirements, you need information about the incremental encoder that is used and the speed ranges of the motor.

The following motor and encoder combination was used to develop this application example:

Motor	Leeson Cat# 102684 Rated speed 3450 RPM.
Encoder	U.S. Digital model E3-500-500-IHT. 500 lines of resolution

Note: The Leeson motor can be obtained from an electric motor distributor, or you can order it from Microchip. The encoder can be ordered from the U.S. Digital web site, www.usdigital.com. Any other similar encoder with 500 lines of resolution may be used instead of the U.S. Digital device, if desired.

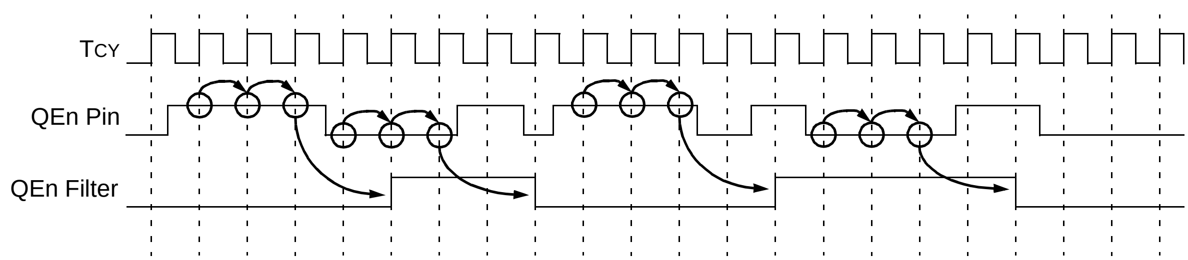
INITIALIZING THE QEI MODULE

Based on the incremental encoder used in this example, the module is configured as follows:

Enable Digital Filters

Enabling the digital filters is desirable to filter any possible glitches on the incremental encoder signals. For the configuration used in this example, the timing diagram of Figure 4 shows how the input signals are filtered.

FIGURE 4: SIGNAL PROPAGATION THROUGH FILTER, 1:1 FILTER CLOCK DIVIDE



A rule of thumb to calculate the filter is based on the minimum pulse width of the encoder, which is determined by the maximum motor speed. In this example, the minimum pulse width is determined by Equation 1:

EQUATION 1: MINIMUM PULSE WIDTH

$$\text{MIN\_PULSE} = \frac{30}{\text{MAX\_RPM x ENCODER\_PULSES}} = \frac{30}{4000 \text{ x } 500} = 15\ \mu\text{sec}$$

So configuring the filter to reject any signal lower than 15 µs will be fine for the application. In this example, we are running at 14.75 MIPS, so the closest filter configuration to achieve our requirement is calculated as shown in Equation 2:

EQUATION 2: FILTER DIVIDER

$$\text{FILTER\_DIV} = \frac{\text{MIPS x FILTERED\_PULSE}}{3} = \frac{14.75 \text{ MIPS x } 15\ \mu\text{sec}}{3} = 73.7 \Rightarrow 64$$

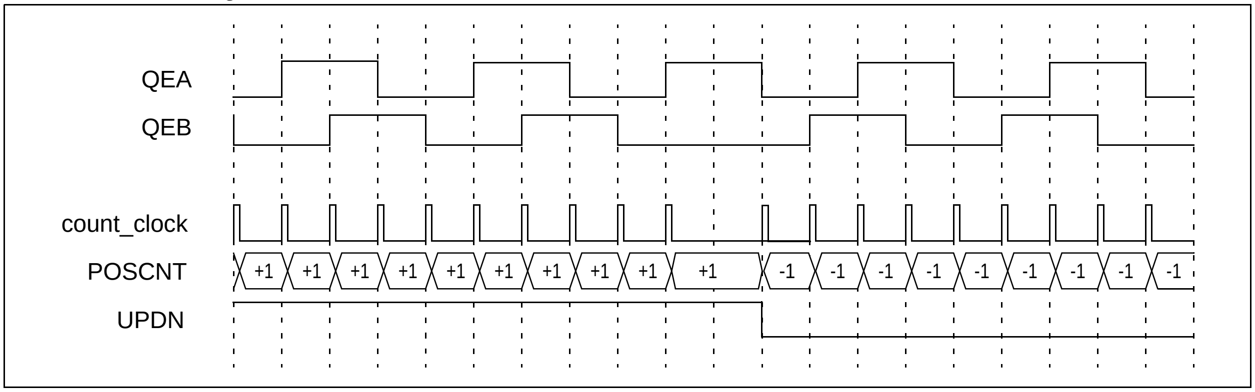
With the available options on the QEI module, a divider of 64 is selected, so pulses below 13 µsec will be filtered.

 Advance Information

Increment Pulse Counter

Increment pulse counter on each QEn pins transition. In order to get as much resolution as possible, the QEI is configured for X4. The X4 Counting mode increments or decrements the POSCNT register on every QEA and QEB signal edge. Figure 5 shows a timing diagram for the X4 configuration.

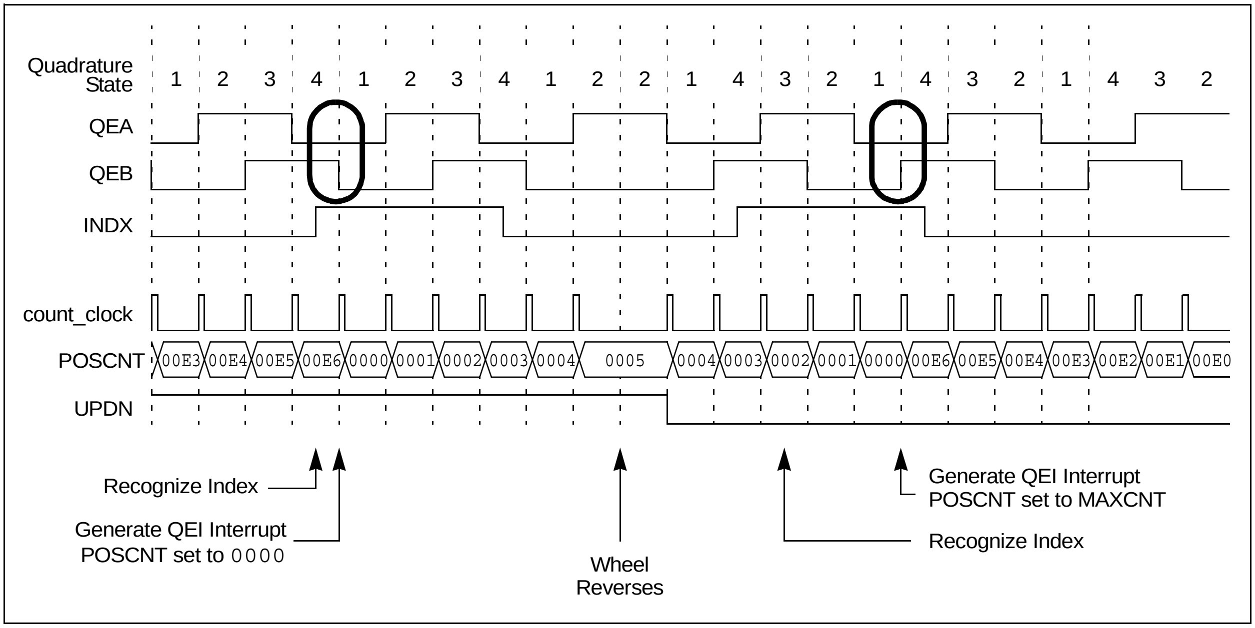
FIGURE 5: QUADRATURE ENCODER SIGNALS IN X4 MODES



Reset Pulse Counter

The pulse counter is reset by the index pin. Some incremental encoders don't have this output to generate an absolute reference position. However, the one used in this example has this output, and we will take advantage of it. See Figure 6 for a timing diagram when the index pulse resets the counter.

FIGURE 6: RESET BY INDEX MODE



Code Example

The following code example initializes the QEI module based on the requirements of this application example:

EXAMPLE 1: INITIALIZING THE QEI MODULE

```
void InitQEI(void)
{
    ADPCFG |= 0x0038;           // Configure QEI pins as digital inputs
    QEICONbits.QEIM = 0;        // Disable QEI Module
    QEICONbits.CNTERR = 0;      // Clear any count errors
    QEICONbits.QEISIDL = 0;     // Continue operation during sleep
    QEICONbits.SWPAB = 0;       // QEA and QEB not swapped
    QEICONbits.PCDOUT = 0;      // Normal I/O pin operation
    QEICONbits.POSRES = 1;      // Index pulse resets position counter
    DFLTCONbits.CEID = 1;       // Count error interrupts disabled
    DFLTCONbits.QEOUT = 1;      // Digital filters output enabled for QEn pins
    DFLTCONbits.QECK = 5;       // 1:64 clock divide for digital filter for QEn
    DFLTCONbits.INDOUT = 1;     // Digital filter output enabled for Index pin
    DFLTCONbits.INDCK = 5;      // 1:64 clock divide for digital filter for Index
    POSCNT = 0;                 // Reset position counter
    QEICONbits.QEIM = 6;        // X4 mode with position counter reset by Index
    return;
}
```

CALCULATING ANGULAR POSITION WITH QEI

To prepare the variable for fractional operations performed by control algorithms, you need to convert the position counter result into a signed fractional number. Equation 3 shows the calculation for maximum count per revolution, based on the information of the incremental encoder and the QEI module configuration.

EQUATION 3: MAXIMUM COUNT PER REVOLUTION

$$\text{MAX\_COUNT\_PER\_REV} = \text{PULSES\_PER\_REV x COUNT\_INC\_PER\_REV - 1} = 500 \times 4 - 1 = 1999$$

Where the resolution would be:

$$\text{RESOLUTION} = \frac{360°}{2000} = 0.18°$$

With this resolution, the position count variable needs to be converted from 0 to 1999 to a signed fractional 16-bit value of 0 to 32767. The following formula shows the scaling factor.

$$\text{AngPos[0]} = \frac{POSCNT \times 2048}{125}$$

Code Example

The following code example shows how to implement this simple subroutine in C:

EXAMPLE 2: CALCULATING ANGULAR POSITION WITH QEI

```
int AngPos[2] = {0,0};             // Two variables are used for Speed Calculation
int POSCNTcopy = 0;
void PositionCalculation(void)
{
    POSCNTcopy = (int)POSCNT;
    if (POSCNTcopy < 0)
        POSCNTcopy = -POSCNTcopy;
    AngPos[1] = AngPos[0];
    AngPos[0] = (unsigned int)(((unsigned long)POSCNTcopy * 2048)/125);
                                   // 0 <= POSCNT <= 1999 to 0 <= AngPos <= 32752
    return;
}
```

Note:	POSCNT is automatically reset by the Index pulse as configured.

CALCULATING ANGULAR VELOCITY WITH QEI

The velocity calculation is performed in a periodic interrupt, since the angular velocity is the number of increments in a fixed period of time. This interrupt interval must be less than the minimum time required for a ½ revolution at maximum speed. The motor's rated speed is 3450 RPM, so 4000 RPM is used in this example to avoid any velocity calculation overflow. The formula shown in Equation 4 is used to calculate time interval.

EQUATION 4: INTERRUPT PERIOD CALCULATION

$$\text{INTERRUPT\_PERIOD} = \frac{60}{2 \text{ x MAX\_SPEED\_RPM}} = \frac{60}{2 \times 4000} = 0.0075 \text{ seconds}$$

Example 3 shows the initialization of Timer1 used to generate this periodic interrupt with the dsPIC DSC running at 14.75 MIPS:

EXAMPLE 3: TIMER1 INITIALIZATION TO GENERATE 0.0075 SEC PERIODIC ISRS

```
void InitTMR1(void)
{
    TMR1 = 0;                   // Reset timer counter
    T1CONbits.TON = 0;          // Turn off timer 1
    T1CONbits.TSIDL = 0;        // Continue operation during sleep
    T1CONbits.TGATE = 0;        // Gated timer accumulation disabled
    T1CONbits.TCS = 0;          // use Tcy as source clock
    T1CONbits.TCKPS = 2;        // Tcy / 64 as input clock
    PR1 = 1728;                 // Interrupt period = 0.0075 sec with a 64 prescaler
    IFS0bits.T1IF = 0;          // Clear timer 1 interrupt flag
    IEC0bits.T1IE = 1;          // Enable timer 1 interrupts
    T1CONbits.TON = 1;          // Turn on timer 1
    return;
}
```

Example 4 shows how the Speed variable is calculated in the periodic ISR:

EXAMPLE 4: ANGULAR SPEED CALCULATION EXAMPLE

```
#define MAX_CNT_PER_REV (500 * 4 - 1)
#define MAXSPEED (unsigned int)(((unsigned long)MAX_CNT_PER_REV*2048)/125)
#define HALFMAXSPEED (MAXSPEED>>1)
int Speed;
void __attribute__((__interrupt__)) _T1Interrupt (void)
{
    IFS0bits.T1IF = 0;   // Clear timer 1 interrupt flag
    PositionCalculation();
    Speed = AngPos[0] - AngPos[1];
    if (Speed >= 0)
    {
        if (Speed >= (HALFMAXSPEED)
            Speed = Speed - MAXSPEED;
    }
    else
    {
        if (Speed < -(HALFMAXSPEED)
            Speed = Speed + MAXSPEED;
    }
    Speed *= 2;
    return;
}
```

 Advance Information

NOTES:

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
Alpharetta, GA
Tel: 770-640-0034
Fax: 770-640-0307

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
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

San Jose
Mountain View, CA
Tel: 650-215-1444
Fax: 650-961-0286

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

ASIA/PACIFIC

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: 86-28-8676-6200
Fax: 86-28-8676-6599

China - Fuzhou
Tel: 86-591-8750-3506
Fax: 86-591-8750-3521

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

China - Qingdao
Tel: 86-532-502-7355
Fax: 86-532-502-7205

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 - Shunde
Tel: 86-757-2839-5507
Fax: 86-757-2839-5571

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

China - Xian
Tel: 86-29-8833-7250
Fax: 86-29-8833-7256

ASIA/PACIFIC

India - Bangalore
Tel: 91-80-2229-0061
Fax: 91-80-2229-0062

India - New Delhi
Tel: 91-11-5160-8631
Fax: 91-11-5160-8632

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

Malaysia - Penang
Tel: 604-646-8870
Fax: 604-646-5086

Philippines - Manila
Tel: 011-632-634-9065
Fax: 011-632-634-9069

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

Taiwan - Hsinchu
Tel: 886-3-572-9526
Fax: 886-3-572-6459

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 - Weis
Tel: 43-7242-2244-399
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: 34-91-352-30-52
Fax: 34-91-352-11-47

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

07/01/05

