

PID Control on PIC16F161X by using a PID Peripheral

Author: Daniel Hou
Microchip Technology Inc.

INTRODUCTION

Several products in the PIC[®] device family have many features that can be applied to motor control or power supplies, including the Proportional Integral Derivative (PID) control module. A PID control mode is implemented in this module to do a discrete-time PID or PI, PD, etc. control. This technical brief describes briefly how the module works, how to use this module in users' applications, and what should be observed.

BASIC PRINCIPLE

In control theory, a PID controller is an algorithm that uses the present error (proportional), the sum of the present and all previous errors (integral), and the difference between the present and previous change (derivative) to correct errors and provide stability in a system. It provides feedback to a system through a series of iterations, using the present error as well as previous errors to calculate a new input to the controller.

In a continuous-time system, the PID controller can be transferred from time domain to s-domain by using a Laplace Transform. The PID output equation is shown below.

$$\frac{C(s)}{E(s)} = K_p + \frac{K_i}{s} + K_d s$$

Next, a Finite Difference Method Z-transform is implemented on the continuous-time output equation.

The method is simply replacing 's' with $(1-z)^{-1}/T$, and T is the sampling period of the discrete-time system. The discrete-time PID output equation is shown below.

$$\frac{C_o(z)}{E(z)} = \frac{\left(K_p + K_i T + \frac{K_d}{T}\right) + \left(-K_p - \frac{2K_d}{T}\right)z^{-1} + \left(\frac{K_d}{T}\right)z^{-2}}{1 - z^{-1}}$$

Where:

$$K1 = K_p + K_i T + \frac{K_d}{T}$$

$$K2 = -K_p - \frac{2K_d}{T}$$

$$K3 = \frac{K_d}{T}$$

Then the output equation can be written as:

$$\frac{C_o(z)}{E(z)} = \frac{K1 + K2 \cdot z^{-1} + K3 \cdot z^{-2}}{1 - z^{-1}}$$

At last, as z^{-1} represents one delay in time, the output equation is transferred into a difference equation in time domain by replacing z^0 with [k], z^{-1} with [k-1], and z^{-2} with [k-2]:

$$C_o[k] = C_o[k-1] + {}^0K_1 e[k] + {}^0K_2 e[k-1] + {}^0K_3 e[k-2]$$

Where $c_0[k]$ is the current PID output, $c_0[k-1]$ is the previous PID output, and $K1$, $K2$ and $K3$ are the parameters of the current error, the previous error and the one before the previous error.

Based on the difference equation, the module is designed as shown in [Figure 1](#).

IMPLEMENTATION

Inputs

To implement this module, three major inputs need to be calculated or determined, which are the set point value, the PID input value (feedback value), and the $K1$, $K2$ and $K3$ values.

The set point value is designed by users based on their own application, and it should be a 15-bit signed or a 16-bit unsigned integer. Users are free to design their set point, such as a CCP value of a PWM waveform, or an ADC value of the desired voltage. The set point value is written into the PIDxSET register.

The PID input value, also known as the feedback, should be measured by users on the process they want to control (motor, power supply, heater, etc.). The measured value is stored in the PIDxIN register and should be the exact same type as the set point value. For instance, if the set point value is a 16-bit ADC value, the PID input should also be a 16-bit ADC value that users measure from their application.

To calculate K1, K2 and K3, two things need to be designed by the user. One is the K_p , K_i and K_d in the users control systems. Another is the sampling period T of the system. Once these are designed, the K1, K2 and K3 can be calculated. Since the sampling period is taken into account, the calculated results of K1, K2 and K3 are usually not integers. The user needs to scale them up to three 15-bit signed integers, and then store them in the PIDxK1, PIDxK2 and PIDxK3 registers, respectively. Please note that the scale factors for K1, K2 and K3 should be the same, and the PID output value should be scaled back down by the same factor in order to be used as the real output of the PID controller. All the scaling is done in software by the user.

Overall, in order to set up the module, the user needs to set the PIDxK1, PIDxK2, PIDxK3 and PIDxSET registers as inputs. The module is able to do the PID calculation by itself.

Operating

After setting up the set point value and the K1, K2 and K3 values, the PID module is ready to operate. Please note that the calculation is started when PIDxINL (the lower byte of PIDxIN) is written, so any changes to any register has to be made before the low value of the PIDxIN register is updated.

A BUSY flag of the PIDxCON register is set to '1' when the module is busy calculating, and the flag will return to '0' when the module is done calculating. A PIDxDIF interrupt flag is also triggered after one successful calculation. The user can read the value in PIDxOUT after the BUSY flag returns to '0' or the PIDxDIF interrupt is triggered, and scale the value down by the same factor used when scaling up the K values to get the real PID output of this iteration.

Sampling Period

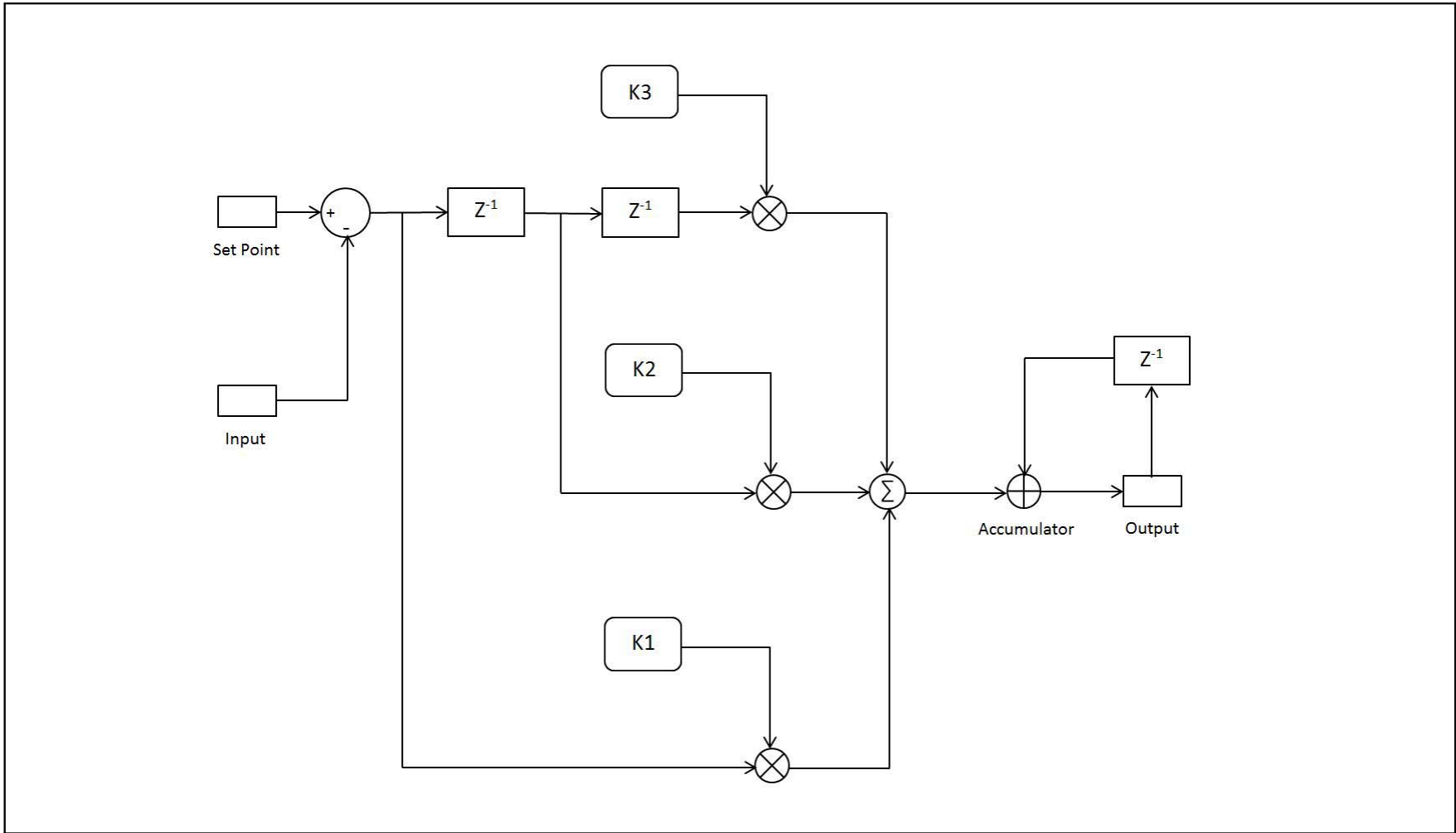
Since it's a discrete-time system, a sampling rate should be determined. The sampling period of the system should be the time from when one PID input is loaded until the next PID input is loaded. Please note that the sampling period is not the time of one PID calculation, since users can implement their own algorithms or programs in one iteration and the PID module calculation could only take up a small amount of time. Users can choose the sampling period according to their needs, but within the limitation of the module and the system (accumulator size, K1, K2, K3 registers' size, etc.).

Accumulator

A 35-bit accumulator is used to accumulate the PID output. Please note that the accumulator may overflow when the error of the PID controller (set point, PID input) is too big or accumulates too much. There are certain circumstances that the accumulator may overflow easily. One is choosing a rather fast sampling rate, which makes the error add up quickly in a short time. One is integral windup, where there is a rapid big change of the set point, which results in a large error. A system with a long response time could also cause the accumulator to overflow since the error does not reduce fast with a long response time.

CONCLUSION

The PID module can be used in many control systems applications. Since the module does the multiplication and accumulation for the user, it saves users a lot of time and allows for implementation of more operations based on their own applications. It takes only nine instruction cycles for the module to do a PID calculation, while it takes around 1000 instruction cycles by using software to do the same calculation. Therefore, there is a huge efficiency improvement using the PID module.

FIGURE 1: PID MODULE BASIC DATA FLOW BLOCK DIAGRAM, PID MODULE

APPENDIX A: CODE FOR IMPLEMENTING THE MATH ACCELERATOR

Software License Agreement

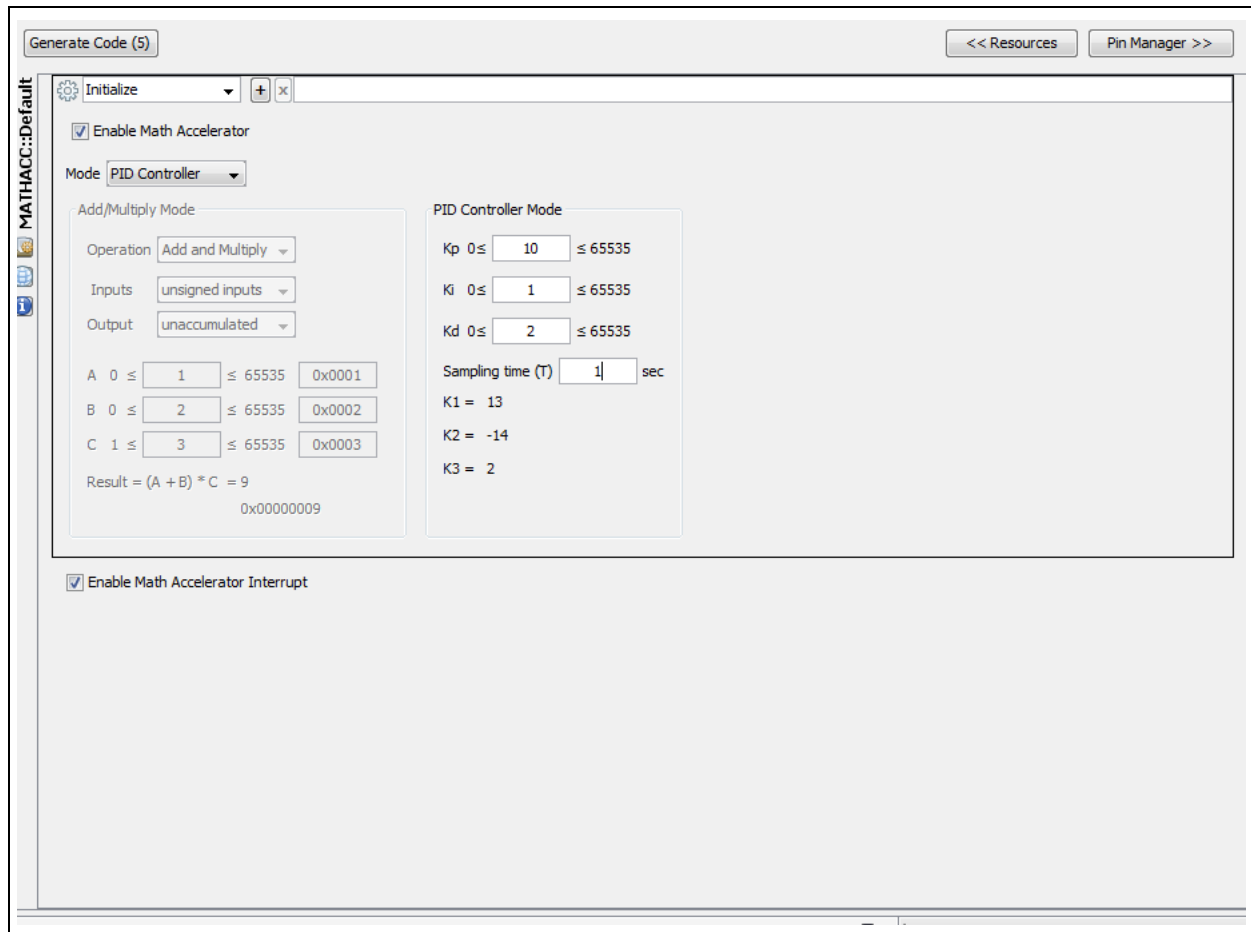
The software supplied herewith by Microchip Technology Incorporated (the "Company") is intended and supplied to you, the Company's customer, for use solely and exclusively with products manufactured by the Company.

The software is owned by the Company and/or its supplier, and is protected under applicable copyright laws. All rights are reserved. Any use in violation of the foregoing restrictions may subject the user to criminal sanctions under applicable laws, as well as to civil liability for the breach of the terms and conditions of this license.

THIS SOFTWARE IS PROVIDED IN AN "AS IS" CONDITION. NO WARRANTIES, WHETHER EXPRESS, IMPLIED OR STATUTORY, INCLUDING, BUT NOT LIMITED TO, IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE APPLY TO THIS SOFTWARE. THE COMPANY SHALL NOT, IN ANY CIRCUMSTANCES, BE LIABLE FOR SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGES, FOR ANY REASON WHATSOEVER.

```
/**
 * Setup the PID module to do a PID calculation.
 */
////////////////////////////////////
PID1ACCU = 0;           // Clear the Accumulator (PID1ACCU)
PID1ACCHH = 0;          // Clear the Accumulator (PID1ACCHH)
PID1ACCHL = 0;          // Clear the Accumulator (PID1ACCHL)
PID1ACCLH = 0;          // Clear the Accumulator (PID1ACCLH)
PID1ACCLL = 0;          // Clear the Accumulator (PID1ACCLL)
PID1CON1bits.MODE = 0b101; // PID mode
PID1CON1bits.EN = 1;      // PID module is enabled (PID1CON1)
////////////////////////////////////
/**
 * Calculate K1, K2, K3 based on Kp, Ki, Kd and the sampling rate
 */
////////////////////////////////////
kp = 912;
ki = 9000;
kd = 41;
// Sampled at 256 Hz. Sampling period is 3.9 ms
K1 = kp + (ki >> 8) + (kd << 8); // K1 = Kp + Ki*T + Kd/T
K2 = -kp - (2 * (kd << 8)); // K2 = -Kp - 2*Kd/T
K3 = (kd << 8); // K3 = Kd/T
////////////////////////////////////
/**
 * Load in the values
 */
////////////////////////////////////
PID1K1 = K1;
PID1K2 = K2;
PID1K3 = K3;

PID1SET = 100;
PID1INH = 0; //
PID1INL = 0; // This starts the math execution (PIDxINL)
////////////////////////////////////
while(PID1CONbits.BUSY); // Wait for the module to complete
result = PID1OUT; // Load the result
```

APPENDIX B: SCREEN SHOT OF HOW TO INITIALIZE THE PID MODULE BY USING MPLAB CODE CONFIGURATOR

TB3136

NOTES:

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 unless otherwise stated.

Trademarks

The Microchip name and logo, the Microchip logo, dsPIC, FlashFlex, flexPWR, JukeBlox, KEELOQ, KEELOQ logo, Klear, LANCheck, MediaLB, MOST, MOST logo, MPLAB, OptoLyzer, PIC, PICSTART, PIC³² logo, RightTouch, SpyNIC, SST, SST Logo, SuperFlash and UNI/O are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

The Embedded Control Solutions Company and mTouch are registered trademarks of Microchip Technology Incorporated in the U.S.A.

Analog-for-the-Digital Age, BodyCom, chipKIT, chipKIT logo, CodeGuard, dsPICDEM, dsPICDEM.net, ECAN, In-Circuit Serial Programming, ICSP, Inter-Chip Connectivity, KlearNet, KlearNet logo, MiWi, MPASM, MPF, MPLAB Certified logo, MPLIB, MPLINK, MultiTRAK, NetDetach, Omniscient Code Generation, PICDEM, PICDEM.net, PICkit, PICtail, RightTouch logo, REAL ICE, SQI, Serial Quad I/O, Total Endurance, TSHARC, USBCheck, VariSense, ViewSpan, WiperLock, Wireless DNA, 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.

Silicon Storage Technology is a registered trademark of Microchip Technology Inc. in other countries.

GestIC is a registered trademark of Microchip Technology Germany II GmbH & Co. KG, a subsidiary of Microchip Technology Inc., in other countries.

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

© 2015, Microchip Technology Incorporated, Printed in the U.S.A., All Rights Reserved.

ISBN: 978-1-63277-497-2

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

Microchip received ISO/TS-16949:2009 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://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

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

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

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

New York, NY
 Tel: 631-435-6000

San Jose, CA
 Tel: 408-735-9110

Canada - Toronto
 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: 852-2943-5100
 Fax: 852-2401-3431

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

China - Beijing
 Tel: 86-10-8569-7000
 Fax: 86-10-8528-2104

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

China - Chongqing
 Tel: 86-23-8980-9588
 Fax: 86-23-8980-9500

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

China - Hangzhou
 Tel: 86-571-8792-8115
 Fax: 86-571-8792-8116

China - Hong Kong SAR
 Tel: 852-2943-5100
 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: 86-755-8864-2200
 Fax: 86-755-8203-1760

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

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

ASIA/PACIFIC

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

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

India - Bangalore
 Tel: 91-80-3090-4444
 Fax: 91-80-3090-4123

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

India - Pune
 Tel: 91-20-3019-1500

Japan - Osaka
 Tel: 81-6-6152-7160
 Fax: 81-6-6152-9310

Japan - Tokyo
 Tel: 81-3-6880-3770
 Fax: 81-3-6880-3771

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: 886-3-5778-366
 Fax: 886-3-5770-955

Taiwan - Kaohsiung
 Tel: 886-7-213-7828

Taiwan - Taipei
 Tel: 886-2-2508-8600
 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 - Dusseldorf
 Tel: 49-2129-3766400

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

Germany - Pforzheim
 Tel: 49-7231-424750

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

Italy - Venice
 Tel: 39-049-7625286

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

Poland - Warsaw
 Tel: 48-22-3325737

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

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

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