AN1070

Driving Liquid Crystal Displays with the PIC16F913/914/916/917/946

Author: *Brian Claveria*
Microchip Technology Inc.

INTRODUCTION

The PIC16F913/914/916/917/946 microcontroller family provides an integrated LCD Driver module that directly drives LCD displays. In large scale applications, directly driving a custom LCD display can provide significant cost savings. In addition, low-power applications can benefit from the low operating current of a PIC® microcontroller compared to stand-alone LCD controllers.

This application note will describe all of the steps necessary in configuring and operating LCD displays with the LCD Driver module. The theory of LCD operation will not be discussed here as these details have been thoroughly explained in *AN658, LCD Fundamentals Using PIC16C92X Microcontrollers* (DS00658) available at www.microchip.com.

WHAT DOES THE LCD DRIVER MODULE DO?

The integrated LCD Driver module generates all of the waveforms needed to drive many different LCD configurations. The bias levels, frequency, and drive scheme are all configurable in software on the PIC microcontroller. The only external inputs required by the LCD module are the bias levels provided at the VLCD1, VLCD2 and VLCD3 pins.

The LCD Driver module directly connects to the segment and common lines of an LCD display. Internally within the LCD Driver module, the bias levels are switched onto the segment and common lines to generate the appropriate output on the LCD. By properly mapping each LCD segment in software based on the common and segment pins it is associated with, the LCD can be manipulated very easily for its particular application.

INITIAL SETUP

There are 3 steps that need to be completed before writing software that can manipulate the LCD:

1. Hardware connections: Inputs and outputs of the LCD Driver module must be physically connected to the LCD.
2. LCD Driver module Initialization: Special Function Registers must be configured to operate with the connected LCD display.
3. LCD Segment Mapping: Each segment of the LCD needs to be mapped in software. The mapping of LCD segments allows for very easy manipulation of the display.

Each of these will be discussed in detail.

1. Hardware Connections

The hardware connections consist of the following inputs:

- LCD Bias Voltage Levels (required)
- External clock (optional)

The LCD bias voltage pins are labeled **VLCD3, VLCD2** and **VLCD1**. These are analog voltage inputs to the LCD Driver module which provide the voltage levels that are switched on to the common and segment lines to generate the appropriate drive levels for the LCD display.

There are three bias modes supported by the LCD Driver module: Static, 1/2, or 1/3 Bias. The data sheet for an LCD display will specify the voltage biasing that is required to drive it. Based on this specification, the proper bias voltages need to be provided to the VLCD inputs.

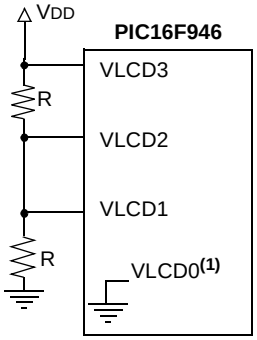
For static operation, an input voltage only needs to be provided at VLCD3. This input voltage is specified in the data sheet for the LCD display. Keep in mind however, that the voltage input providing any of the VLCD inputs cannot be greater than the V_{DD} of the microcontroller because of the clamping diodes on these inputs.

For 1/2 and 1/3 biasing, a voltage divider can be used to provide +V and +1/2V for 1/2 biasing and the +V, +2/3V, and +1/3V for 1/3 biasing (where V is the drive voltage specified in the LCD data sheet).

Shown below in Figure 1 and Figure 2 are example resistor dividers schematics. The selection of the resistor size, R, is dependent upon many factors beyond the scope of this application note. In short, if R is too large, not enough current will be provided to sufficiently drive the display. The result will be an LCD with poor contrast. If R is too small, excessive current may be drawn by the resistor ladder. Empirical testing (bench testing)

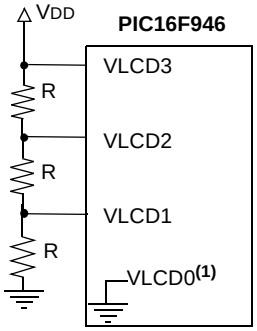
various resistor values is the best way of determining an optimum resistor value that meets the design requirements. Typical resistor values range from 10 KΩ to 1 MΩ.

FIGURE 1: RESISTOR LADDER FOR 1/2 BIASING



Note: Internal connection

FIGURE 2: RESISTOR LADDER FOR 1/3 BIASING



Note: Internal connection

The LCD Driver module can generate waveform timing from one of three clock sources. The clock inputs to the LCD Drive module are one of the following:

- FOSC/8192
- T1OSC/32
- LFINTOSC/32

An external clock/crystal (32 kHz) can be connected to clock the T1OSC. The choice of which clock source to use depends on the application. One feature of the LCD Driver module is the ability to generate LCD waveforms for the LCD display while in low-power (**Sleep**) mode. To assist in selecting the proper clock source for an LCD application a table is shown below (Table 1) illustrating which clock configurations can utilize this feature.

TABLE 1: CLOCK CONFIGURATIONS

Clock Source	Operate During Sleep?
Timer 1 Oscillator	Yes
Internal RC Oscillator	Yes
Main Oscillator (FOSC)	No

After providing all the inputs to the LCD Driver module, the outputs must be connected. The outputs of the LCD Driver module are the common (COM0, COM1…COM3) and segment (SEG0, SEG1…SEGn) pins. These pins should be connected to the corresponding segment and common pins specific to the LCD display being used.

The LCD display may have 1 to 4 commons depending on its multiplexing specification. The order in which segment pins of the microcontroller are connected to the LCD does not matter because the mapping of each segment on the LCD is made in software. More important is ensuring that the multiplexed functions (comparators, PWM, A/D) on the pins that are needed for other aspects of the application are available.

2. LCD Driver Module Initialization

The following are the 10 steps to initialize and configure the LCD Driver module:

1. Configure TRIS settings

The LCD Driver module, when enabled overrides TRIS settings, but it is important to ensure that the microcontroller TRIS settings are initialized in a known state.

2. Enable LCD Bias Voltage Pins

LCD bias voltage pins (VLCD3, VLCD2, VLCD1) are multipurpose pins. When the LCDCON, VLCDEN bit is set, all TRIS settings are overridden and the pins function as LCD bias voltage inputs.

3. Select Clock Source

Selecting a clock source depends on many factors. One factor discussed earlier is the use of Sleep mode to minimize current. The following bit settings in the LCDCON register select a specific clock source setting:

- CS<1:0> = 00 = FOSC/8192
- CS<1:0> = 01 = T1OSC/32
- CS<1:0> = 1x = LFINTOSC/32

4. Select Multiplex Mode

Multiplexing minimizes the number of pins necessary to drive an LCD display. In the data sheet of the LCD display being used, the multiplexing specification should be indicated as 1/2, 1/3 or 1/4 multiplexing.

The following bit settings in the LCDCON register select the Multiplex mode:

- LMUX<1:0> = 00 = Static
- LMUX<1:0> = 01 = 1/2 Mux
- LMUX<1:0> = 10 = 1/3 Mux
- LMUX<1:0> = 11 = 1/4 Mux

5. Select Waveform Type

The LCD Driver module is capable of generating Type-A or Type-B waveforms. Details on the operation of both waveforms are beyond the scope of the application note. More information can be found in AN658, *LCD Fundamentals Using PIC16C92X Microcontrollers* (DS00658) at www.microchip.com. In short, the main difference between the two is Type-B waveforms contain fewer transitions than Type-A. This is particularly important in dealing with high capacitance LCD glass which are typically physically larger. Fewer transitions allow the display to have better contrast when driving with Type-B waveforms. The trade-off in using Type-B waveforms however is that LCD interrupts must be used to write LCD data registers only when frame transitions have completed.

The LCDPS,WFT bit is set to enable Type-B waveforms and cleared to enable Type-A.

6. Select Bias Mode

The Bias mode should have been selected during the hardware setup. This mode is specified in the data sheet for the LCD display being used. This mode is selected by LCDPS, BIASMD bit.

The configurations are shown below:

- When LMUX<1:0> = `00`

  `0` = Static Bias mode, do not set the bit to `1`

- When LMUX<1:0> = `01`

  `0` = 1/2 Bias mode

  `1` = 1/3 Bias mode

- When LMUX<1:0> = `10`

  `0` = 1/2 Bias mode

  `1` = 1/3 Bias mode

- When LMUX<1:0> = `11`

  `0` = 1/3 Bias mode, do not set the bit to `0`

7. Select Refresh Rate

The refresh rate or frequency of LCD waveforms affects the quality of display. If a frequency less than 30 Hz is selected, there will be visible flicker. Choosing too high of a frequency will not allow the LCD to transition to its full on state, causing contrast problems. Bench testing various refresh rates is a good way of determining the ideal refresh rate.

The refresh rate is selected by writing a 4-bit value to the LP3:LP0 bits of the LCDPS register. This prescaler takes the incoming clock source, scales it, and divides it down to generate the timing of the LCD waveforms. Shown below in Table 2 are the frame frequency calculations, which are dependent upon the multiplexing of the LCD.

TABLE 2: LCD FRAME FREQUENCY CALCULATIONS

Multiplex	Frame Frequency
Static	Clock source/(4 x 1 x (LP3:LP0 +1))
1/2	Clock source/(2 x 2 x (LP3:LP0 +1))
1/3	Clock source/(1 x 3 x (LP3:LP0 +1))
1/4	Clock source/(1 x 4 x (LP3:LP0 +1))

8. Enable LCD Segment Lines

There are several LCDSE Special Function Registers, depending on the number of segment lines available. Each bit of a LCDSE register is associated with a corresponding segment pin (See PIC16F91X Data Sheet (DS41250) for details). By setting the LCDSE bit high, the corresponding microcontroller pin is configured for use as an LCD segment line. Setting the bit low disables LCD functionality on the pin. These settings override and TRIS settings that have previously been configured. Only enable segment lines for those pins that have been connected to the LCD display.

9. Clear LCDDATA registers

There are several LCDDATA Special Function Registers, depending on the number of segment lines available. Each bit of an LCDDATA register corresponds to a segment AND common line combination as indicated in the PIC16F91X Data Sheet (DS41250). Therefore these bits of the LCDDATA register are mapped to specific pixels/segments of the LCD display. Setting or clearing of these bits turns on or off the specific pixel/segment. Clear all of the LCDDATA registers to initialize the LCD in an off state.

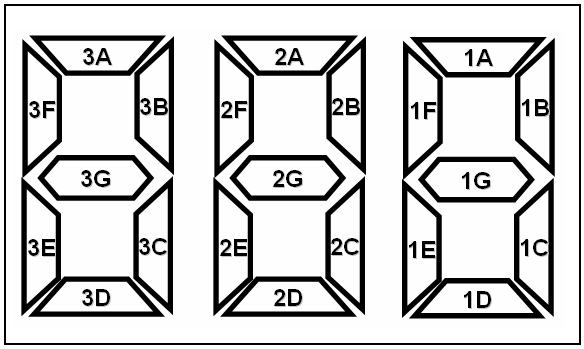
10. Turn on the LCD Driver module

Setting the LCDEN bit of the LCDCON register turns the LCD Driver module on.

3. LCD Segment Mapping

The next step to effectively use the LCD Driver module is to map each LCD segment. An LCD data sheet provides a page that names each segment on the LCD display, an example is shown in Figure 3. The ability to refer to each segment with this naming convention in software makes the use of the LCD Driver module very easy.

FIGURE 3: LCD DATA SHEET SEGMENT NAMES



Using “define” statements in C or Assembly to define each LCDDATA bit (recall: these bits map to one pixel/segment of the LCD), makes the setting and clearing of the bit to enable or disable segments very intuitive. In addition, this can assist in making code that displays a specific digit value less complex and more readable.

Each segment on the LCD is connected to a specific common (COM) and segment (SEG) line. A pinout diagram is typically included in an LCD data sheet that shows the pin and common line associated with each LCD pixel/segment. Shown in Table 3 is an example pinout.

TABLE 3: LCD DATA SHEET PINOUT

PIN	COM1	COM2	COM3	COM4
1	1A	1B	1C	1D
2	1E	1F	1G	2A
3	2B	2C	2D	2E
4	2F	2G	3A	3B
5	3C	3D	3E	3F
6	3G	---	---	---

The data sheet of a PIC16F91X microcontroller provides worksheet called the “LCD Mapping Worksheet.” This worksheet looks very similar to the LCD data sheet pinout shown in Table 3. An example LCD Mapping Worksheet is shown in the Appendix A of this document.

Using the LCD mapping worksheet, determine which LCD pin each microcontroller SEG pin is attached to. Next, fill in the symbol name of each LCD segment/pixel (from the LCD data sheet pinout) in the empty box corresponding to the SEG pin and COM pin of the microcontroller.

You will notice that in the LCD mapping worksheet, next to each LCD segment is an LCDDATAx Address. This is the LCDDATA bit that corresponds to the LCD segment next to it. When the LCD mapping worksheet has been completed, it is much easier to write code that maps the symbol name to the LCDDATA bit.

The final step is to write #define statements that map each LCDDATA register and bit to the corresponding LCD segment name. Once the worksheet is completed, the task of writing an LCD output routine will be much easier. Each LCD segment name is shown next to the LCDDATA register and bit that it is associated with. Shown below in Example 1 is code that maps example LCD segments to LCDDATA bits and registers.

EXAMPLE 1: #DEFINE LCD MAPPING

```
#define   1A   LCDDATA0, 1
#define   1B   LCDDATA3, 1
#define   1C   LCDDATA6, 1
#define   1D   LCDDATA9, 1
.
.
```

OPERATION

After connecting the hardware, configuring the LCD Driver module, and mapping the LCD segments, the LCD is ready to operate.

LCD segments can be turned on by setting and clearing LCDDATA register bits. If each LCD segment has been mapped then each segment can be turned on by setting the LCD segment name and turned off by clearing the segment name. Example 2 shown below shows code that turns segment a segment named 1A on and off.

EXAMPLE 2: TURNING LCD SEGMENTS OFF AND ON

```
#include <lcdmap.h> ; LCD Map


BSF    1A     ; turns on segment
              ; 1A
BCF    1A     ; turns off
              ; segment 1A
```

CONCLUSIONS

The LCD Driver module allows PIC microcontrollers to directly drive LCDs. The following steps to configuring the module have been discussed:

- Hardware Connections
- LCD Driver Module Initialization
- LCD Segment Mapping

Once these configuration steps have been completed, driving and controlling the LCD is easy. Microcontroller software is very flexible and programming constructs can be used to create efficient display routines (i.e., number, alphanumeric and graph display routines).

REFERENCES

LCD PICmicro MCU Tips 'n Tricks, DS41261

AN658*, "LCD Fundamentals using PIC16C92X Microcontroller",* DS00658

TB084, *"Contrast Control Circuits for the PIC16F91X",* DS91084

DS41250, "*PIC16F946/917/916/914/913 Data Sheet*",

APPENDIX A:

FIGURE A-1: LCD SEGMENT MAPPING WORKSHEET (PART 1 OF 2)

LCD Function	COM0 LCDDATAx Address	COM0 LCD Segment	COM1 LCDDATAx Address	COM1 LCD Segment	COM2 LCDDATAx Address	COM2 LCD Segment	COM3 LCDDATAx Address	COM3 LCD Segment	Pin No. 28/40-pin	PORT	Alternate Functions
SEG0	LCDDATA0, 0		LCDDATA3, 0		LCDDATA6, 0		LCDDATA9, 0		21/33	RB0	INT
SEG1	LCDDATA0, 1		LCDDATA3, 1		LCDDATA6, 1		LCDDATA9, 1		22/34	RB1	
SEG2	LCDDATA0, 2		LCDDATA3, 2		LCDDATA6, 2		LCDDATA9, 2		23/35	RB2	
SEG3	LCDDATA0, 3		LCDDATA3, 3		LCDDATA6, 3		LCDDATA9, 3		24/36	RB3	
SEG4	LCDDATA0, 4		LCDDATA3, 4		LCDDATA6, 4		LCDDATA9, 4		6/6	RA4	C1OUT/T0CKI
SEG5	LCDDATA0, 5		LCDDATA3, 5		LCDDATA6, 5		LCDDATA9, 5		7/7	RA5	C2OUT/AN4/$\overline{SS}$
SEG6	LCDDATA0, 6		LCDDATA3, 6		LCDDATA6, 6		LCDDATA9, 6		14/18	RC3	
SEG7	LCDDATA0, 7		LCDDATA3, 7		LCDDATA6, 7		LCDDATA9, 7		3/3	RA1	AN1
SEG8	LCDDATA1, 0		LCDDATA4, 0		LCDDATA7, 0		LCDDATA10, 0		18/26	RC7	RX/DT/SDI/SDA
SEG9	LCDDATA1, 1		LCDDATA4, 1		LCDDATA7, 1		LCDDATA10, 1		17/25	RC6	TX/CK/SCK/SCL
SEG10	LCDDATA1, 2		LCDDATA4, 2		LCDDATA7, 2		LCDDATA10, 2		16/24	RC5	T1CKI/CCP1
SEG11	LCDDATA1, 3		LCDDATA4, 3		LCDDATA7, 3		LCDDATA10, 3		15/23	RC4	$\overline{T1G}$/SDO
SEG12	LCDDATA1, 4		LCDDATA4, 4		LCDDATA7, 4		LCDDATA10, 4		2/2	RA0	AN0
SEG13	LCDDATA1, 5		LCDDATA4, 5		LCDDATA7, 5		LCDDATA10, 5		28/40	RB7	ICSPDAT/ICDDAT
SEG14	LCDDATA1, 6		LCDDATA4, 6		LCDDATA7, 6		LCDDATA10, 6		27/39	RB6	ICSPCK/ICDCK
SEG15	LCDDATA1, 7		LCDDATA4, 7		LCDDATA7, 7		LCDDATA10, 7		5/5	RA3	AN3/V_{REF}+
SEG16	LCDDATA2, 0		LCDDATA5, 0		LCDDATA8, 0		LCDDATA11, 0		-/26	RD3	
SEG17	LCDDATA2, 1		LCDDATA5, 1		LCDDATA8, 1		LCDDATA11, 1		-/27	RD4	
SEG18	LCDDATA2, 2		LCDDATA5, 2		LCDDATA8, 2		LCDDATA11, 2		-/28	RD5	
SEG19	LCDDATA2, 3		LCDDATA5, 3		LCDDATA8, 3		LCDDATA11, 3		-/29	RD6	
SEG20	LCDDATA2, 4		LCDDATA5, 4		LCDDATA8, 4		LCDDATA11, 4		-/30	RD7	
SEG21	LCDDATA2, 5		LCDDATA5, 5		LCDDATA8, 5		LCDDATA11, 5		-/8	RE0	AN5
SEG22	LCDDATA2, 6		LCDDATA5, 6		LCDDATA8, 6		LCDDATA11, 6		-/9	RE1	AN6
SEG23	LCDDATA2, 7		LCDDATA5, 7		LCDDATA8, 7		LCDDATA11, 7		-/10	RE2	AN7

FIGURE A-2: LCD SEGMENT MAPPING WORKSHEET (PART 2 OF 2)

LCD Function	COM0		COM1		COM2		COM3		Pin No.	PORT	Alternate Functions
	LCDDATAx Address	LCD Segment	LCDDATAx Address	LCD Segment	LCDDATAx Address	LCD Segment	LCDDATAx Address	LCD Segment	28/40-pin		
SEG24	LCDDATA12, 0		LCDDATA15, 0		LCDDATA18, 0		LCDDATA21, 0		37	RE4	
SEG25	LCDDATA12, 1		LCDDATA15, 1		LCDDATA18, 1		LCDDATA21, 1		42	RE5	
SEG26	LCDDATA12, 2		LCDDATA15, 2		LCDDATA18, 2		LCDDATA21, 2		43	RE6	
SEG27	LCDDATA12, 3		LCDDATA15, 3		LCDDATA18, 3		LCDDATA21, 3		44	RE7	
SEG28	LCDDATA12, 4		LCDDATA15, 4		LCDDATA18, 4		LCDDATA21, 4		45	RF4	
SEG29	LCDDATA12, 5		LCDDATA15, 5		LCDDATA18, 5		LCDDATA21, 5		46	RF5	
SEG30	LCDDATA12, 6		LCDDATA15, 6		LCDDATA18, 6		LCDDATA21, 6		47	RF6	
SEG31	LCDDATA12, 7		LCDDATA15, 7		LCDDATA18, 7		LCDDATA21, 7		48	RF7	
SEG32	LCDDATA13, 0		LCDDATA16, 0		LCDDATA19, 0		LCDDATA22, 0		11	RF0	
SEG33	LCDDATA13, 1		LCDDATA16, 1		LCDDATA19, 1		LCDDATA22, 1		12	RF1	
SEG34	LCDDATA13, 2		LCDDATA16, 2		LCDDATA19, 2		LCDDATA22, 2		13	RF2	
SEG35	LCDDATA13, 3		LCDDATA16, 3		LCDDATA19, 3		LCDDATA22, 3		14	RF3	
SEG36	LCDDATA13, 4		LCDDATA16, 4		LCDDATA19, 4		LCDDATA22, 4		3	RG0	
SEG37	LCDDATA13, 5		LCDDATA16, 5		LCDDATA19, 5		LCDDATA22, 5		4	RG1	
SEG38	LCDDATA13, 6		LCDDATA16, 6		LCDDATA19, 6		LCDDATA22, 6		5	RG2	
SEG39	LCDDATA13, 7		LCDDATA16, 7		LCDDATA19, 7		LCDDATA22, 7		6	RG3	
SEG40	LCDDATA14, 0		LCDDATA17, 0		LCDDATA20, 0		LCDDATA23, 0		7	RG4	
SEG41	LCDDATA14, 1		LCDDATA17, 1		LCDDATA20, 1		LCDDATA23, 1		8	RG5	

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.

Trademarks

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 Mountain View, California. 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

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 - 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: 86-532-8502-7355
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 - 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: 91-80-4182-8400
Fax: 91-80-4182-8422

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 - Gumi
Tel: 82-54-473-4301
Fax: 82-54-473-4302

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

Malaysia - Penang
Tel: 60-4-646-8870
Fax: 60-4-646-5086

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: 886-3-572-9526
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 - 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

12/08/06