



PolarFire® SoC FPGA: Interrupt Latency and Data Transfer Throughput Measurements

Introduction

Microchip's PolarFire® SoC FPGAs include the industry's RISC-V based Microprocessor Subsystem (MSS) and FPGA fabric that inherits all the features of the PolarFire family. The PolarFire SoC MSS includes 5x 64-bit RISC-V processor cores, AXI switch, DDR controller, Fabric Interface Controllers (FIC), and a rich set of peripherals. It also offers an unparalleled combination of low power consumption, thermal efficiency, and defense-grade security for smart, connected systems. It is the first SoC FPGA with a deterministic L2 memory subsystem enabling real-time applications. Built on the award-winning, mid-range, low-power PolarFire FPGA architecture, PolarFire SoC devices deliver up to 50% lower power than alternative FPGAs, span from 25k to 460k logic elements, and feature 12.7G transceivers.

Microchip's PolarFire SoC Icicle kit features an MPFS250T PolarFire SoC device and on-board memories such as LPDDR4, SPI, and eMMC flash for running Linux. For more information, see the [PolarFire® SoC FPGA ICICLE Kit User Guide](#).

The following measurements are performed on PolarFire SoC FPGA:

- Interrupt latency difference between Global and Local interrupts.
- Data transfer throughput is measured from LIM to Fabric LSRAM and Fabric LSRAM to LIM.

Interrupt latency refers to the delay between the start of an Interrupt and the detection of the interrupt by the processor in the application. The interrupt latency is expressed in processor clock cycles. Latency measurement is carried out and compared between Local interrupt and Global interrupt using the Bare metal application. Local interrupts are signaled directly to an individual hart with a dedicated interrupt value. This allows for reduced interrupt latency. Global interrupts by contrast, are routed through a Platform-Level Interrupt Controller (PLIC), which can direct interrupts to any hart in the system through the external interrupt.

For more information, see the [PolarFire SoC FPGA MSS Technical Reference Manual](#).

The interrupt latency and the data transfer throughput are measured using the PolarFire SoC FPGA Icycle kit. The following table lists the configuration used for the measurements.

Table 1. System Configuration

System Configuration	Description
Device	PolarFire SoC FPGA, RISC-V 64-bit
Application	Bare Metal
CPU Core Frequency	625 MHz
Compiler	RISC-V GCC
Target Processor	riscv64
Tool Chain	SoftConsole v2021.1
SoftConsole Tool Optimization Level	None is used for interrupt latency measurement. Optimize fast (-Ofast) is used for data transfer throughput measurement between LIM and Fabric LSRAM.
MPFS-HAL	Version 1.8.117
Linker Script Settings	Instruction Tightly Integrated Memory (ITIM) used for the code section. Scratchpad is used for the stack.
FIC and Fabric Frequency	200 MHz
Interrupt Lines Used	MSS_INT_F2M0 (Local) and MSS_INT_F2M1 (Global)

Table of Contents

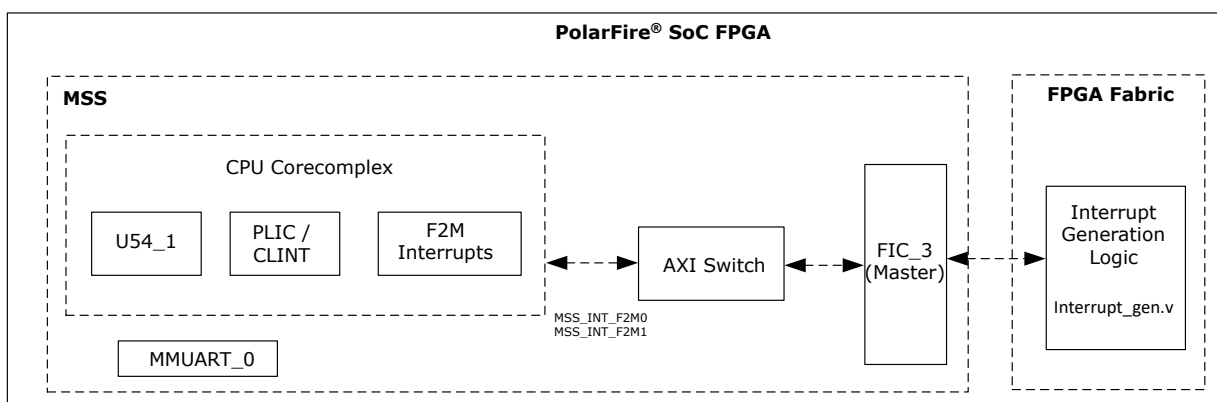
Introduction.....	1
1. Interrupt Latency Measurement	4
2. Data Transfers Throughput between LIM and FPGA Fabric LSRAM.....	6
3. Results.....	7
4. Conclusion.....	8
The Microchip Website.....	9
Product Change Notification Service.....	9
Customer Support.....	9
Microchip Devices Code Protection Feature.....	9
Legal Notice.....	10
Trademarks.....	10
Quality Management System.....	11
Worldwide Sales and Service.....	12

1. Interrupt Latency Measurement

Figure 1-1 shows the top-level block diagram for Interrupt latency measurement. The **Expose Interrupt ports to Fabric** option in the **PolarFire SoC MSS configurator > Misc** tab and the **Use Master interface** option in the **PolarFire SoC MSS configurator > Fabric Interface Controllers** tab are enabled. The Global or Local interrupt that is generated from the fabric interrupt_gen.v is connected to MSS F2M interrupt lines. The application running on the U54_1 processor clears the interrupt by writing to the fabric register using the FIC3 interface.

Interrupt lines used are MSS_INT_F2M0 and MSS_INT_F2M1. The common interrupt vector is used for global and local interrupts. The source of the interrupt is verified in the handle_trap function of mpfs_hal by reading mcause Control and Status Register (CSR).

Figure 1-1. For Interrupt Latency Measurement



The following table lists the fabric logic address map for generating Local and Global interrupts.

Table 1-1. MSS Memory Map for Interrupt Generation

FIC3 Address	Data	Operation
0x40000000	0x1	Generates the local interrupt
0x40000000	0x0	Clears the interrupt
0x40000000	0x2	Generates the global interrupt
0x40000000	0x0	Clears the interrupt

Implementation

The MSS_INT_F2M0 port is used for the local interrupt and MSS_INT_F2M1 port is used for the Global interrupt. Both these interrupts are mapped to the U54_1 application core. The FIC3 is used for interfacing with the fabric interrupt generation logic. The MMUART port is enabled for serial communication.

See [Table 1-1](#) for generating Local and Global interrupts.

For measuring the interrupt latency, the hardware performance monitoring CSR “mcycle” is read before asserting an interrupt. The mcycle CSR is again read as soon as the interrupts enter the trap vector function, as shown in [Figure 1-2](#). The time difference between mcycle read values are used to measure the interrupt latency.

Figure 1-2. Stop mcycle CSR in entry.S

SC softconsole_project_latency - Latency_measure_app/src/platform/mpfs_hal/entry.S - SoftConsole v6.6.0.463

File Edit Source Refactor Navigate Search Project Run Window UltraDevelop Help

Project Explorer

- Latency_measure_app
 - Binaries
 - Includes
 - Debug
 - Release
 - src
 - application
 - boards
 - platform
 - drivers
 - hal
 - mpfs_hal
 - nwc
 - atomic.h
 - bits.h
 - encoding.h
 - entry.S**
 - mcall.h
 - mss_assert.h
 - mss_axiswitch.c
 - mss_axiswitch.h
 - mss_clint.h
 - mss_coreplex.h

```
226 li a1, HLS_DATA_PASSED_WFI
227 STORE a1, 0(tp)
228 j main_other_hart
229 .LoopForeverOther:
230 #in case of return, loop forever. nop's added so can be seen in debugger
231 nop
232 nop
233 j .LoopForeverOther
234
235 /*****
236 /*****interrupt handling below here*****/
237 /*****/
238 trap_vector:
239 # The mscratch register is an XLEN-bit read/write register dedicated for us
240 # Typically, it is used to hold a pointer to a machine-mode hart-local cont
241 # with a user register upon entry to an M-mode trap handler.
242 # In this implementation, we are not using HLS
243 # csrcw sp, mscratch, sp #copy sp to mscratch, and msdra
244 csrcw a1, mcycle
245 addi sp, sp, -INTEGER_CONTEXT_SIZE # moves sp down stack to make I
246 # INTEGER_CONTEXT_SIZE area
247 # Preserve the registers.
248 STORE sp, 2*REGBYTES(sp) # sp
249 STORE a0, 10*REGBYTES(sp) # save a0,a1 in the created CONTEXT
250 # STORE a1, 11*REGBYTES(sp)
251 STORE ra, 1*REGBYTES(sp)
252 STORE gp, 3*REGBYTES(sp)
253 STORE tp, 4*REGBYTES(sp)
254 STORE t0, 5*REGBYTES(sp)
```

2. Data Transfers Throughput between LIM and FPGA Fabric LSRAM

Figure 2-1 shows the block diagram for measuring the throughput for data transfers between LIM and fabric LSRAM. LSRAM block is connected to the MSS using the FIC0 interface. The core complex Direct Memory Access (DMA) is used for data transfers between LIM and LSRAM, and throughput is measured. To achieve this, the PDMA driver is added to the Bare Metal application and configured with required registers. See Table 2-1 for fabric LSRAM and LIM address map.

Figure 2-1. Data Transfers between LIM and FPGA Fabric LSRAM

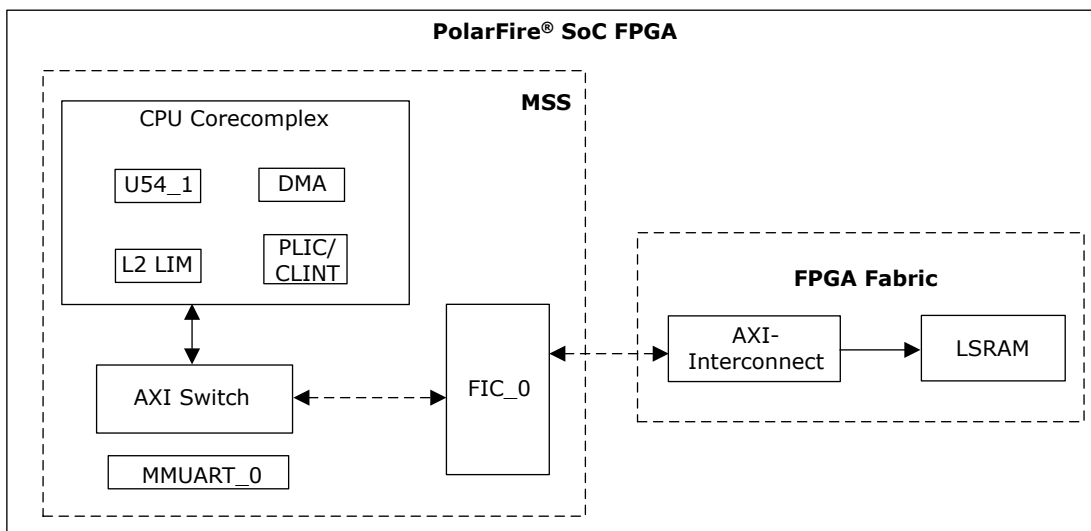


Table 2-1. Memory Map for Data Transfer Between LIM and Fabric LSRAM

Address Range Used	Memory
0x61000000 to 0x61ffffff	Fabric LSRAM
0x08000000 to 0x08100000	LIM

Implementation

To perform LSRAM to LIM data transfer, the fabric LSRAM is initialized by the application core (U54_1), with an incremental data pattern. Core complex DMA is initialized by declaring DMA channel and configured by writing to the channel registers —source address (LSRAM), destination address (LIM), and number of bytes to transfer. The DMA transfer is initiated using setup transfer and start DMA transfer functions. DMA transfer complete status is checked, then the LIM data is read and verified.

To perform LIM to LSRAM data transfer, the source address is replaced with the destination address and vice-versa. The same process as described in preceding paragraph is repeated.

For measuring the data transfer throughput, CSR mcycle is read before DMA transfer and after the DMA transfer completion. The time difference between mcycle read values are used to convert into bits/seconds.

3. Results

The following table lists the interrupt latency measurement results.

Table 3-1. Interrupt Latency Measurement Results

Interrupt Type	Interrupt Latency
Global	37 core clock cycles
Local	30 core clock cycles
CLINT Software Interrupt	16 core clock cycles

Note: Software CLINT latency is generated in u54_1 core and handled in mtrap function.

Table 3-2. Data Transfer Throughput Between LIM and Fabric LSRAM using MSS PDMA

Transfer Size in Bytes	LSRAM to LIM		LIM to LSRAM	
	Core Clock Cycles	Mbits/Seconds	Core Clock Cycles	Mbits/Seconds
1 Kbyte	965	5350.052	1061	4862.298
4 Kbytes	3439	5969.105	3683	5572.789
8 Kbytes	6743	6081.663	7169	5719.872
16 Kbytes	13363	6134.032	14165	5786.537
32 Kbytes	26521	6179.61	28129	5826.251
64 Kbytes	52933	6191.403	56033	5848.817
128 Kbytes	105719	6199.544	112009	5851.376
256 Kbytes	211439	6199.28	223789	5857.155

4. Conclusion

This white paper provides the latency measurements for the Global and Local interrupts, and the throughput measurements for data transfers between LIM and Fabric LSRAM. The Local interrupt detection time is seven core clock cycles faster than the Global interrupt detection. For a DMA transfer of size 64 Kbytes, a throughput of 6191 Mbps for LSRAM to LIM and 5848 Mbps for LIM and LSRAM can be achieved.

The Microchip Website

Microchip provides online support via our website at www.microchip.com/. This website is used to make files and information easily available to customers. Some of the content available includes:

- **Product Support** – Data sheets and errata, application notes and sample programs, design resources, user's guides and hardware support documents, latest software releases and archived software
- **General Technical Support** – Frequently Asked Questions (FAQs), technical support requests, online discussion groups, Microchip design partner program member listing
- **Business of Microchip** – Product selector and ordering guides, latest Microchip press releases, listing of seminars and events, listings of Microchip sales offices, distributors and factory representatives

Product Change Notification Service

Microchip's product change notification service helps keep customers current on Microchip products. Subscribers will receive email notification whenever there are changes, updates, revisions or errata related to a specified product family or development tool of interest.

To register, go to www.microchip.com/pcn and follow the registration instructions.

Customer Support

Users of Microchip products can receive assistance through several channels:

- Distributor or Representative
- Local Sales Office
- Embedded Solutions Engineer (ESE)
- Technical Support

Customers should contact their distributor, representative or ESE for support. Local sales offices are also available to help customers. A listing of sales offices and locations is included in this document.

Technical support is available through the website at: www.microchip.com/support

Microchip Devices Code Protection Feature

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.

Legal Notice

Information contained in this publication is provided for the sole purpose of designing with and using Microchip products. Information 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.

THIS INFORMATION IS PROVIDED BY MICROCHIP "AS IS". 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 ANY IMPLIED WARRANTIES OF NON-INFRINGEMENT, MERCHANTABILITY, AND FITNESS FOR A PARTICULAR PURPOSE OR WARRANTIES RELATED TO ITS CONDITION, QUALITY, OR PERFORMANCE.

IN NO EVENT WILL MICROCHIP BE LIABLE FOR ANY INDIRECT, SPECIAL, PUNITIVE, INCIDENTAL OR CONSEQUENTIAL LOSS, DAMAGE, COST OR EXPENSE OF ANY KIND WHATSOEVER RELATED TO THE INFORMATION OR ITS USE, HOWEVER CAUSED, EVEN IF MICROCHIP HAS BEEN ADVISED OF THE POSSIBILITY OR THE DAMAGES ARE FORESEEABLE. TO THE FULLEST EXTENT ALLOWED BY LAW, MICROCHIP'S TOTAL LIABILITY ON ALL CLAIMS IN ANY WAY RELATED TO THE INFORMATION OR ITS USE WILL NOT EXCEED THE AMOUNT OF FEES, IF ANY, THAT YOU HAVE PAID DIRECTLY TO MICROCHIP FOR THE INFORMATION. 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, Adaptec, AnyRate, AVR, AVR logo, AVR Freaks, BesTime, BitCloud, chipKIT, chipKIT logo, CryptoMemory, CryptoRF, dsPIC, FlashFlex, flexPWR, HELDO, IGLOO, JukeBlox, KeeLoq, Klear, LANCheck, LinkMD, maXStylus, maXTouch, MediaLB, megaAVR, Microsemi, Microsemi logo, MOST, MOST logo, MPLAB, OptoLyzer, PackeTime, PIC, picoPower, PICSTART, PIC32 logo, PolarFire, Prochip Designer, QTouch, SAM-BA, SenGenuity, SpyNIC, SST, SST Logo, SuperFlash, Symmetricom, SyncServer, Tachyon, TimeSource, tinyAVR, UNI/O, Vectron, and XMEGA are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

AgileSwitch, APT, ClockWorks, The Embedded Control Solutions Company, EtherSynch, FlashTec, Hyper Speed Control, HyperLight Load, IntelliMOS, Libero, motorBench, mTouch, Powermite 3, Precision Edge, ProASIC, ProASIC Plus, ProASIC Plus logo, Quiet-Wire, SmartFusion, SyncWorld, Temux, TimeCesium, TimeHub, TimePictra, TimeProvider, WinPath, and ZL are registered trademarks of Microchip Technology Incorporated in the U.S.A.

Adjacent Key Suppression, AKS, Analog-for-the-Digital Age, Any Capacitor, AnyIn, AnyOut, Augmented Switching, BlueSky, BodyCom, CodeGuard, CryptoAuthentication, CryptoAutomotive, CryptoCompanion, CryptoController, dsPICDEM, dsPICDEM.net, Dynamic Average Matching, DAM, ECAN, Espresso T1S, EtherGREEN, IdealBridge, In-Circuit Serial Programming, ICSP, INICnet, Intelligent Paralleling, Inter-Chip Connectivity, JitterBlocker, maxCrypto, maxView, memBrain, Mindi, MiWi, MPASM, MPF, MPLAB Certified logo, MPLIB, MPLINK, MultiTRAK, NetDetach, Omniscient Code Generation, PICDEM, PICDEM.net, PICKit, PICtail, PowerSmart, PureSilicon, QMatrix, REAL ICE, Ripple Blocker, RTAX, RTG4, SAM-ICE, Serial Quad I/O, simpleMAP, SimpliPHY, SmartBuffer, SMART-I.S., storClad, SQL, SuperSwitcher, SuperSwitcher II, Switchtec, SynchroPHY, Total Endurance, TSHARC, USBCheck, VariSense, VectorBlox, VeriPHY, ViewSpan, WiperLock, XpressConnect, 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.

The Adaptec logo, Frequency on Demand, Silicon Storage Technology, and Symmcom are registered trademarks 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.

© 2021, Microchip Technology Incorporated, Printed in the U.S.A., All Rights Reserved.

ISBN: 978-1-5224-8434-9

Quality Management System

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

Worldwide Sales and Service

AMERICAS	ASIA/PACIFIC	ASIA/PACIFIC	EUROPE
<p>Corporate Office 2355 West Chandler Blvd. Chandler, AZ 85224-6199 Tel: 480-792-7200 Tel: 480-792-7277 Technical Support: www.microchip.com/support Web Address: www.microchip.com</p> <p>Atlanta Duluth, GA Tel: 678-957-9614 Fax: 678-957-1455</p> <p>Austin, TX Tel: 512-257-3370</p> <p>Boston Westborough, MA Tel: 774-760-0087 Fax: 774-760-0088</p> <p>Chicago Itasca, IL Tel: 630-285-0071 Fax: 630-285-0075</p> <p>Dallas Addison, TX Tel: 972-818-7423 Fax: 972-818-2924</p> <p>Detroit Novi, MI Tel: 248-848-4000</p> <p>Houston, TX Tel: 281-894-5983</p> <p>Indianapolis Noblesville, IN Tel: 317-773-8323 Fax: 317-773-5453 Tel: 317-536-2380</p> <p>Los Angeles Mission Viejo, CA Tel: 949-462-9523 Fax: 949-462-9608 Tel: 951-273-7800</p> <p>Raleigh, NC Tel: 919-844-7510</p> <p>New York, NY Tel: 631-435-6000</p> <p>San Jose, CA Tel: 408-735-9110 Tel: 408-436-4270</p> <p>Canada - Toronto Tel: 905-695-1980 Fax: 905-695-2078</p>	<p>Australia - Sydney Tel: 61-2-9868-6733</p> <p>China - Beijing Tel: 86-10-8569-7000</p> <p>China - Chengdu Tel: 86-28-8665-5511</p> <p>China - Chongqing Tel: 86-23-8980-9588</p> <p>China - Dongguan Tel: 86-769-8702-9880</p> <p>China - Guangzhou Tel: 86-20-8755-8029</p> <p>China - Hangzhou Tel: 86-571-8792-8115</p> <p>China - Hong Kong SAR Tel: 852-2943-5100</p> <p>China - Nanjing Tel: 86-25-8473-2460</p> <p>China - Qingdao Tel: 86-532-8502-7355</p> <p>China - Shanghai Tel: 86-21-3326-8000</p> <p>China - Shenyang Tel: 86-24-2334-2829</p> <p>China - Shenzhen Tel: 86-755-8864-2200</p> <p>China - Suzhou Tel: 86-186-6233-1526</p> <p>China - Wuhan Tel: 86-27-5980-5300</p> <p>China - Xian Tel: 86-29-8833-7252</p> <p>China - Xiamen Tel: 86-592-2388138</p> <p>China - Zhuhai Tel: 86-756-3210040</p>	<p>India - Bangalore Tel: 91-80-3090-4444</p> <p>India - New Delhi Tel: 91-11-4160-8631</p> <p>India - Pune Tel: 91-20-4121-0141</p> <p>Japan - Osaka Tel: 81-6-6152-7160</p> <p>Japan - Tokyo Tel: 81-3-6880-3770</p> <p>Korea - Daegu Tel: 82-53-744-4301</p> <p>Korea - Seoul Tel: 82-2-554-7200</p> <p>Malaysia - Kuala Lumpur Tel: 60-3-7651-7906</p> <p>Malaysia - Penang Tel: 60-4-227-8870</p> <p>Philippines - Manila Tel: 63-2-634-9065</p> <p>Singapore Tel: 65-6334-8870</p> <p>Taiwan - Hsin Chu Tel: 886-3-577-8366</p> <p>Taiwan - Kaohsiung Tel: 886-7-213-7830</p> <p>Taiwan - Taipei Tel: 886-2-2508-8600</p> <p>Thailand - Bangkok Tel: 66-2-694-1351</p> <p>Vietnam - Ho Chi Minh Tel: 84-28-5448-2100</p>	<p>Austria - Wels Tel: 43-7242-2244-39 Fax: 43-7242-2244-393</p> <p>Denmark - Copenhagen Tel: 45-4485-5910 Fax: 45-4485-2829</p> <p>Finland - Espoo Tel: 358-9-4520-820</p> <p>France - Paris Tel: 33-1-69-53-63-20 Fax: 33-1-69-30-90-79</p> <p>Germany - Garching Tel: 49-8931-9700</p> <p>Germany - Haan Tel: 49-2129-3766400</p> <p>Germany - Heilbronn Tel: 49-7131-72400</p> <p>Germany - Karlsruhe Tel: 49-721-625370</p> <p>Germany - Munich Tel: 49-89-627-144-0 Fax: 49-89-627-144-44</p> <p>Germany - Rosenheim Tel: 49-8031-354-560</p> <p>Israel - Ra'anana Tel: 972-9-744-7705</p> <p>Italy - Milan Tel: 39-0331-742611 Fax: 39-0331-466781</p> <p>Italy - Padova Tel: 39-049-7625286</p> <p>Netherlands - Drunen Tel: 31-416-690399 Fax: 31-416-690340</p> <p>Norway - Trondheim Tel: 47-72884388</p> <p>Poland - Warsaw Tel: 48-22-3325737</p> <p>Romania - Bucharest Tel: 40-21-407-87-50</p> <p>Spain - Madrid Tel: 34-91-708-08-90 Fax: 34-91-708-08-91</p> <p>Sweden - Gothenberg Tel: 46-31-704-60-40</p> <p>Sweden - Stockholm Tel: 46-8-5090-4654</p> <p>UK - Wokingham Tel: 44-118-921-5800 Fax: 44-118-921-5820</p>