PolarFire FPGA Temperature and Voltage Sensor

AN4682

Introduction

Each PolarFire® device is equipped with a Temperature and Voltage Sensor (TVS). TVS reports die temperature and voltage of device supply rails in digital form to the FPGA fabric.

TVS is implemented using a 4-channel ADC, and the channel information is given as follows:

- Channel 0—1V voltage supply
- Channel 1—1.8V voltage supply
- Channel 2—2.5V voltage supply
- Channel 3—Die temperature

The TVS outputs a 16-bit encoded value that represents voltage or temperature and the corresponding channel number. The temperature and voltage information is translated into standard temperature and voltage values. For more information, see PolarFire Family Security User Guide.

Table of Contents

1. PolarFire FPGA Temperature and Voltage Sensor

This demo highlights the TVS feature of the PolarFire using a UART-based application (GUI). The demo design continuously pumps the data from TVS channels to UART, displayed on the GUI. This demo design also shows how to simulate the TVS feature of the PolarFire device.

The demo design can be programmed using one of the following options:

- Using the job file: To program the device using the job file provided along with the design files, see 4. Appendix 1: Programming the Device Using FlashPro Express.
- Using Libero® SoC: To program the device using Libero SoC, see 2. Libero Design Flow. Use this option when the demo design is modified.

1.1 Design Requirements

The following table lists the hardware and software requirements for this demo design.

Table 1-1. Design Requirements

Requirement	Version
Operating system	64-bit Windows 7, 8, or 10
Hardware	
PolarFire® Evaluation Kit (MPF300-EVAL-KIT)	Rev D or later
Software	
Libero® SoC	**Note:** Refer to the `readme.txt` file provided in the design files for the software versions used with this reference design.
ModelSim	
FlashPro Express	

Important: Libero SmartDesign and configuration screen shots shown in this document are for illustration purpose only. For the latest updates, open the Libero design.

1.2 Prerequisites

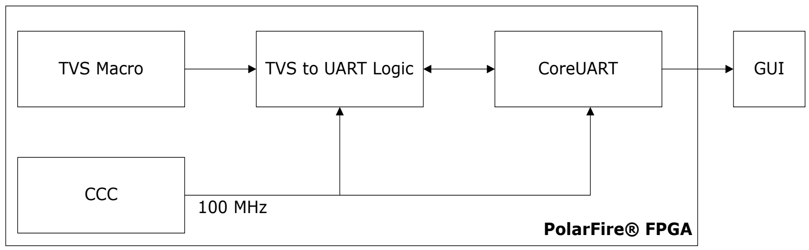
Before you begin, ensure that the following components are in place:

- For demo design files download link: www.microchip.com/en-us/application-notes/AN4682
- Download and install Libero SoC (as indicated in the website for this design) on the host PC from the following location: Libero SoC Installation link. The latest versions of ModelSim, Synplify Pro, and FTDI drivers are included in the Libero SoC installation package.

1.3 Demo Design

The following figure shows the top-level block diagram of the TVS design. All four channels of TVS are enabled in the design to monitor the die temperature and voltage rails. The Fabric logic captures the TVS channels outputs and sends them to UART IF through CoreUART IP.

Figure 1-1. TVS Block Diagram



The GUI receives TVS values per channel and decodes to display them as described:

Die Temperature

The temperature channel's 16-bit output value is represented in Kelvin and can be decoded as listed in the following table.

Table 1-2. Temperature Channel Value Decoding

Bit Number	Description
15	Reserved
[14:4]	Integer value of temperature
[3:0]	Fractional value of temperature

For example, suppose that the temperature channel's output value is 0x133B. In the binary format, the corresponding integer part is 00100110011 and the fractional part is 1011 which should be converted into decimal form as follows:

Integer part is calculated as:

$$\left(0\times2^{10}\right)+\left(0\times2^{9}\right)+\left(1\times2^{8}\right)+\left(0\times2^{7}\right)+\left(0\times2^{6}\right)$$
$$+\left(1\times2^{5}\right)+\left(1\times2^{4}\right)+\left(0\times2^{3}\right)+\left(0\times2^{2}\right)+\left(1\times2^{1}\right)+\left(1\times2^{0}\right)=307$$

Fractional part is calculated as:

$$\left(1\times2^{-1}\right)+\left(0\times2^{-2}\right)+\left(1\times2^{-3}\right)+\left(1\times2^{-4}\right)=0.6875$$

So, the temperature output value 0x133B is 307.6875 K.

Voltage

The data present at the VALUE and CHANNEL outputs are valid only when the VALID output is asserted. When a channel is disabled by de-asserting the corresponding channel enable input, then the channel data present on the outputs is not valid even if the VALID output is asserted. The voltage channel's 16-bit output value is represented in millivolts (mV) and can be decoded as listed in the following table.

Table 1-3. Voltage Channel Value Decoding

Bit Number	Description
15	Signed bit
[14:3]	Integer value of voltage
[2:0]	Fractional value of voltage

For example, suppose that the voltage channel's output value is 0x385E. In the binary format, the corresponding integer part is 011100001011 and the fractional part is 110 which should be converted to its decimal form as follows:

Integer part is calculated as:

$$\left(0\times2^{11}\right)+\left(1\times2^{10}\right)+\left(1\times2^{9}\right)+\left(1\times2^{8}\right)+\left(0\times2^{7}\right)$$
$$+\left(0\times2^{6}\right)+\left(0\times2^{5}\right)+\left(0\times2^{4}\right)+\left(1\times2^{3}\right)+\left(0\times2^{2}\right)+\left(1\times2^{1}\right)+\left(1\times2^{0}\right)=1803$$

Fractional part is calculated as:

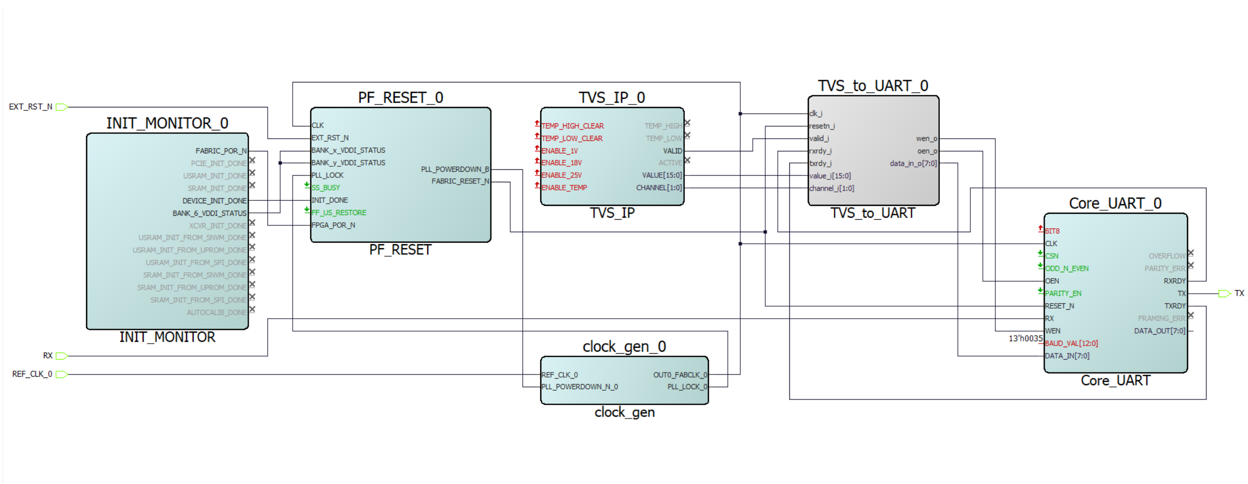
$$\left(1\times2^{-1}\right)+\left(1\times2^{-2}\right)+\left(0\times2^{-3}\right)=0.75$$

So, the voltage output value 0x385E is 1803.75 mV.

1.3.1 Design Implementation

The following figure shows the Libero SoC software design implementation of the TVS demo design.

Figure 1-2. TVS Demo Design



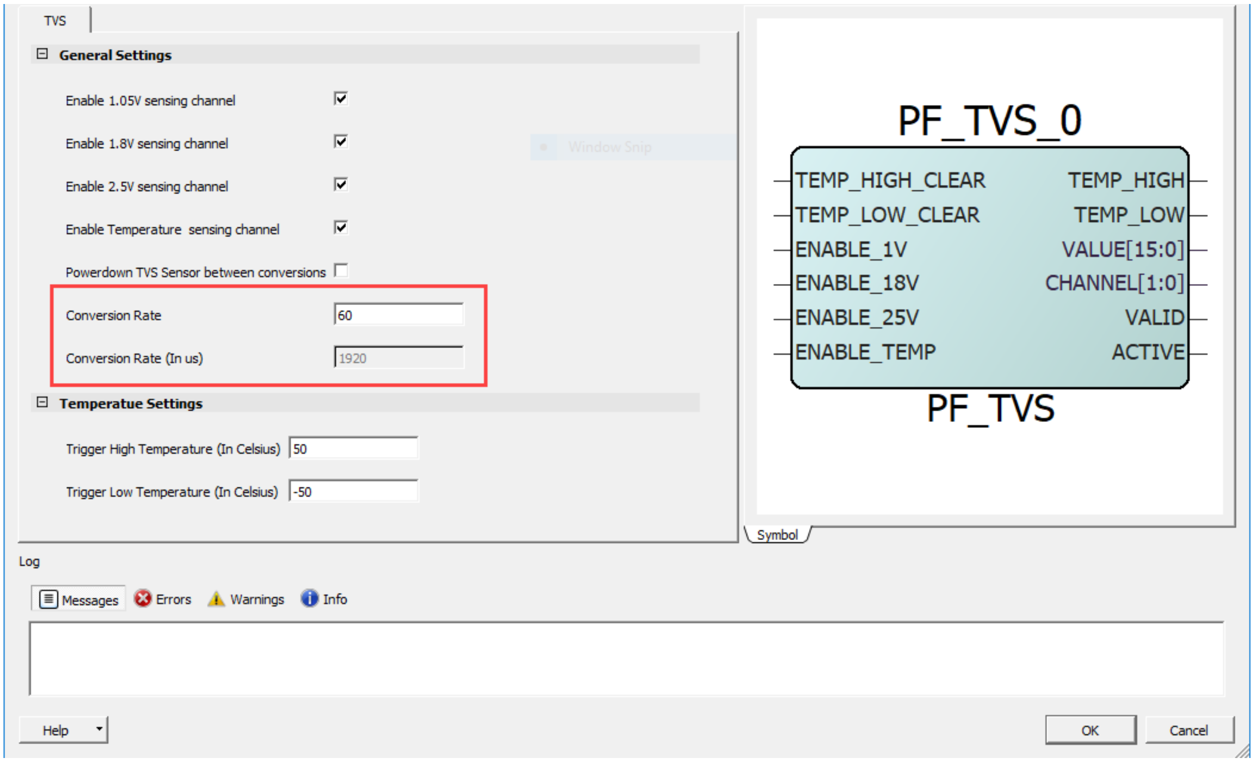
The top-level design includes the following components:

- TVS_IP_0 Macro
- Core_UART_0
- TVS_to_UART_0 logic
- clock_gen_0
- INIT_MONITOR_0 and PF_RESET_0

1.3.1.1 TVS_IP_0 Macro

The following figure shows the TVS interface configurator.

Figure 1-3. TVS Configurator



The GUI displays the die temperature in degree Celsius by converting Kelvin values.

Celsius value = Kelvin value - 273.15

1.3.1.2 TVS_to_UART_0

The TVS to UART logic captures the Temperature and Voltage values from the TVS macro and sends the data to Core_UART_0.

1.3.1.3 clock_gen_0

CCC is configured to generate the 100 MHz clock.

1.4 Simulation Flow

The TVS simulation model updates the TVS macro outputs based on reading instructions given in the `.mem` file or `.txt` file. The file name must be passed to the simulation model for the TVS outputs to toggle. The parameter used to store the `.mem` file name is called “TVS_MEMFILE”. Add the following `vsim` command to pass the file name.

```
-gTVS_MEMFILE="PATH_TO_FILE_RELATIVE_TO_SIMULATION_FOLDER"
```

.MEM File Format

The following format of the file is in hex:

```
<simulation time (τ) in hexadecimal>
```

```
<value of channel 0 at time τ>
```

```
<value of channel 1 at time τ>
```

```
<value of channel 2 at time τ>
```

```
<value of channel 3 at time τ>
```

The `.mem` file contains the simulation time followed by the digital values (16-bit) of the four ADC channels at that time. A value is required for the channel even if it is not used. The value can be 0. The simulation starts with all channel outputs being 0. The pattern can be repeated several times in the .mem file to reflect several values of the channel outputs. The content of the mem file is limited to 256 lines.

1.4.1 Simulating the Design

The Libero project includes a test-bench to simulate the TVS block. The testbench captures all four TVS channel values using CoreUART IP. The digital values for the four channels are passed through the `.mem` file.

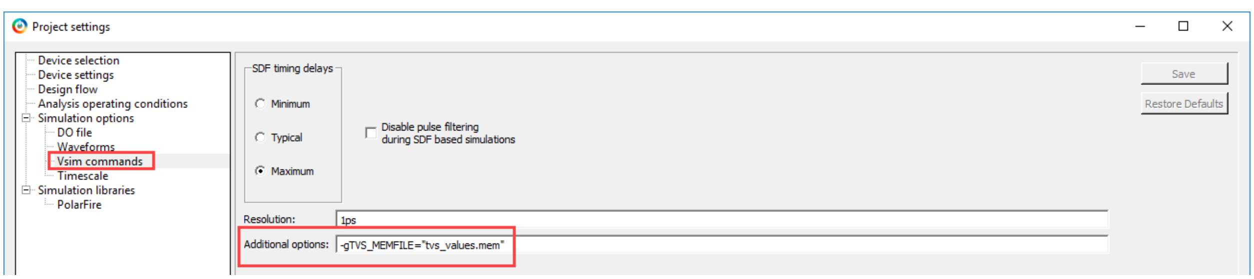
1.4.1.1 Simulation Settings

To pass the `.mem` file for simulation, perform the following steps:

1. Open the Libero® SoC project settings (**Project** > **Project Settings**).
2. Select Vsim commands under the **Simulation options**. Enter `-gTVS_MEMFILE="tvs_values.mem"` in the **Additional options** field, and then click **Save**.

A sample `tvs_values.mem` file is provided in the simulation folder. The `.mem` file must be available in simulation folder of the Libero project. The `tvs_values.mem` file captures the 16-bit digital output of the TVS block at different time instances.

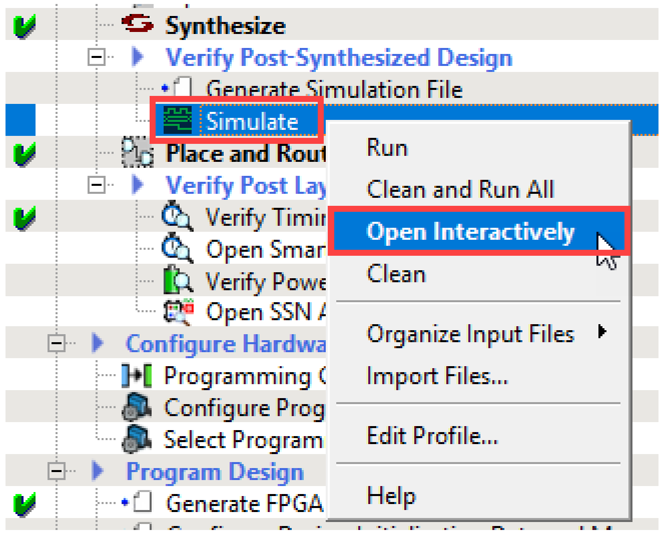
Figure 1-4. Simulation Options-Vsim Command



To simulate the design, perform the following steps:

1. In the **Design Flow** tab, right-click **Simulate** under **Verify Pre-Synthesis Design**, and then select **Open Interactively**.

Figure 1-5. Design Flow-Simulate

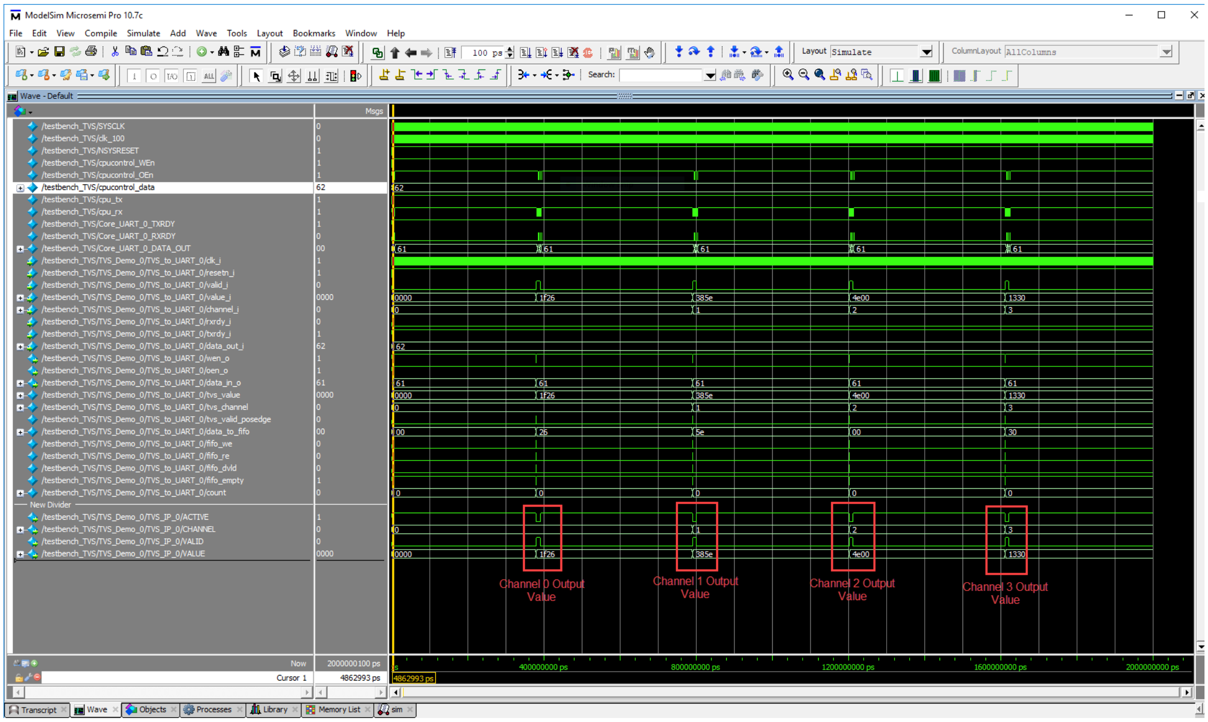


The Wave window appears when the simulation is completed, as shown in the following figure. Since all the four channels are enabled, the TVS circuit outputs a value of the four channels at a given point in time on the VALUE output along with the channel number on the CHANNEL output. The data present on the VALUE and CHANNEL outputs are valid only when the VALID output is asserted. Observe the following from the simulation results:

- After the channel is enabled for conversion, the TVS block takes 390 microseconds to complete the conversion.
- Each channel has a conversion delay of 410 microseconds.
- The conversion rate is equal to 1920 microseconds, which is same as the conversion rate set in the TVS configurator.
- TVS block generates the output values based on the values given in the `tvs_values.mem` file.

2. The following figure shows the UI of ModelSim Pro ME Wave window.

Figure 1-6. ModelSim Pro ME Wave Window



3. Close ModelSim Pro ME and the Libero project.

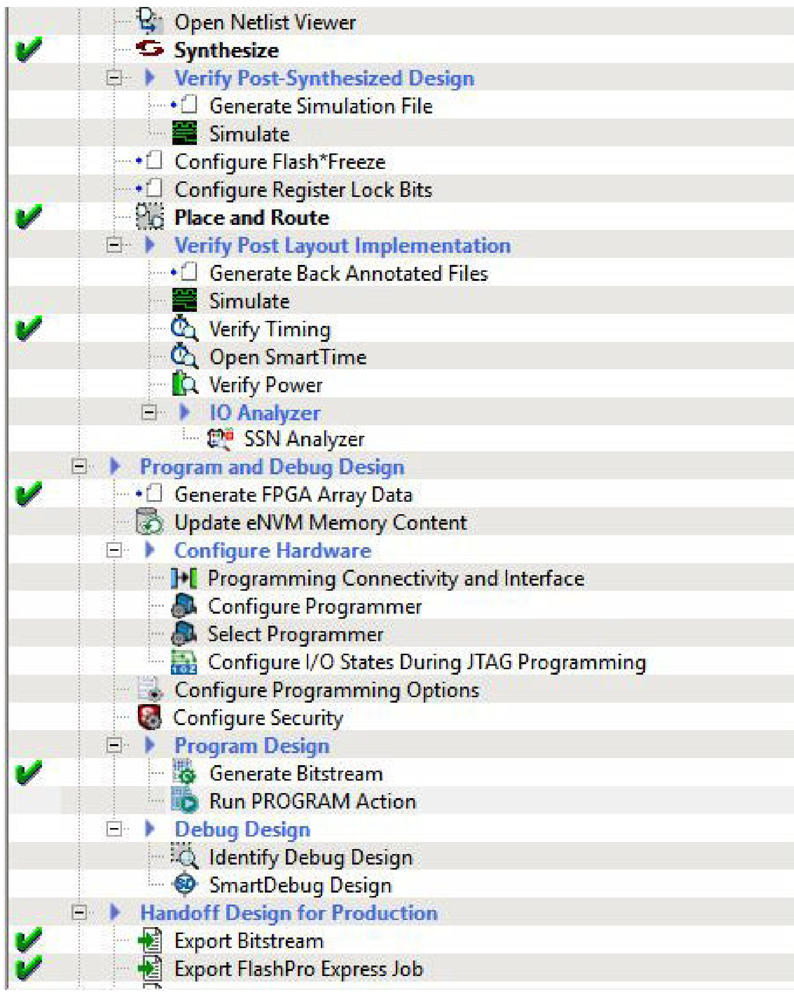
2. Libero Design Flow

This chapter describes the Libero design flow of the demo design. The Libero design flow involves the following steps:

- Synthesize
- Place and route
- Verify Timing
- Generate Bitstream
- Run PROGRAM Action

The following figure shows these options in the Design Flow tab.

Figure 2-1. Libero Design Flow Options



2.1 Synthesize

To synthesize the design, perform the following steps:

1. From the **Design Flow** window, double-click **Synthesize**.
   A green tick mark appears when the synthesis is successful, as shown in Figure 2-1.
2. Right-click **Synthesize** and select **View Report** to view the synthesis report and log files in the Reports tab.

2.2 Place and Route

1. From the **Design Flow** window, double click **Place and Route**.
   A green tick mark appears when the place and route is successful, as shown in Figure 2-1.
2. Right click **Place and Route** and select **View Report** to view the place and route report and log files in the **Reports** tab.

2.3 Verify Timing

To verify timing, perform the following steps:

1. From the **Design Flow** window, double click **Verify Timing**.
   When the design successfully meets the timing requirements, a green tick mark appears, as shown in Figure 2-1.
2. Right click **Verify Timing** and select **View Report** to view the verify timing report and log files in the **Reports** tab.

2.4 Generate FPGA Array Data

To generate FPGA array data, double click **Generate FPGA Array Data** from the **Design Flow** window.

A green tick mark is displayed after the successful generation of the FPGA array data, as shown in Figure 2-1.

2.5 Generate Bitstream

Perform the following steps to generate the bitstream:

1. Double click **Generate Bitstream** from the **Design Flow** tab.
   When the bitstream is successfully generated, a green tick mark appears, as shown in Figure 2-1.
2. Right click **Generate Bitstream** and select **View Report** to view the corresponding log file in the **Reports** tab.

2.6 Run PROGRAM Action

After generating the bitstream, the PolarFire device must be programmed. Perform the following steps to program the PolarFire device:

1. Ensure that the following Jumper Settings are set on the board.

Table 2-1. Jumper Settings

Jumper	Description	Default
J18, J19, J20, J21, and J22	Short pin 2 and 3 for programming the PolarFire FPGA through FTDI	Closed
J28	Short pin 1 and 2 for programming through the on-board FlashPro5	Open
J26	Short pin 1 and 2 for programming through the FTDI SPI	Closed
J4	Short pin 1 and 2 for manual power switching using SW3	Closed
J12	Short pin 3 and 4 for 2.5 V	Closed

2. Connect the power supply cable to the J9 connector on the board.
3. Connect the USB cable from the Host PC to J5 (FTDI port) on the board.
4. Power the board using the SW3 slide switch.
5. Double click **Run PROGRAM Action** from the **Libero** > **Design Flow tab**.
   A green tick mark appears when the device is programmed successfully, as shown in Figure 2-1.

3. Running the Demo

This chapter describes how to install and use the Graphic User Interface (GUI) to run the TVS demo. The PolarFire TVS demo application is a simple GUI that runs on the host PC to communicate with the PolarFire Device.

To install the GUI, perform the following steps:

1. Extract the contents of the `mpf_an4682_v2022p1_eval_df.rar` file. Double-click the `setup.exe` file from the `mpf_an4682_v2022p1_eval_df\GUI\TVS_Monitor_GUI_Installer` folder.
2. Follow the instructions displayed on the installation wizard.

After successful installation, TVS_Monitor_GUI appears on the **Start** menu of the host PC desktop.

To run the TVS demo, perform the following steps:

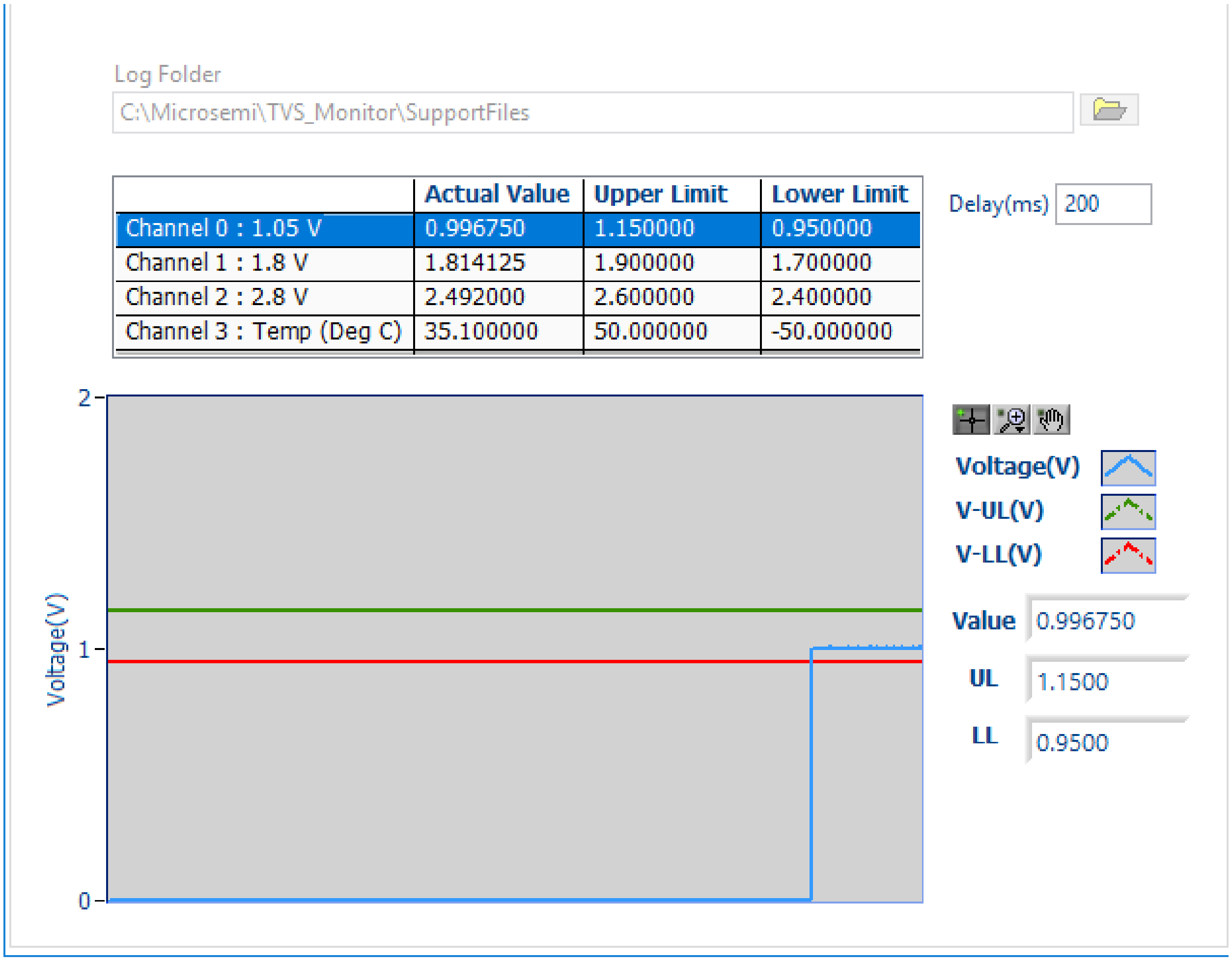
1. From the **Start** menu, click **TVS_Monitor_GUI** to launch the application. Ensure that the board is connected and appropriate **Log Folder** is selected.
2. Click **Connect**. On a successful connection, the GUI shows the temperature and voltage values. The Log file is created with the time stamp in the file name at the Log Folder location. By default, Log Folder points to the **SupportFiles** folder in the installation directory. Users can modify the Log Folder location before connecting to the board.

   Important: Ensure that the Log Folder is not a system-restricted location. In this case, the user must launch the GUI with admin privileges (right-click and **run as admin**).

3. Upper Limit, Lower Limit, and the minimum variation in logging for each channel are configurable in the `setup.ini` file. Channel values are logged in the log file if a variation exceeds the specified 'min var' values in the `setup.ini` file.

The following figure shows the standard temperature and voltage values of channel 0 (1.05 V). The plot corresponds to the values of Channel 0. Similarly, select the other channels and view their corresponding values and plots.

Figure 3-1. Selecting COM Port and Connecting-Channel 0



Important: The GUI updates the TVS channel values with the delay entered in the Delay (ms) field.

4. Appendix 1: Programming the Device Using FlashPro Express

To program the PolarFire device with the `.job` programming file using FlashPro Express. The `.job` file is available at the following design files folder location: `mpf_an4682_v2022p1_eval_df\Programming_Job`

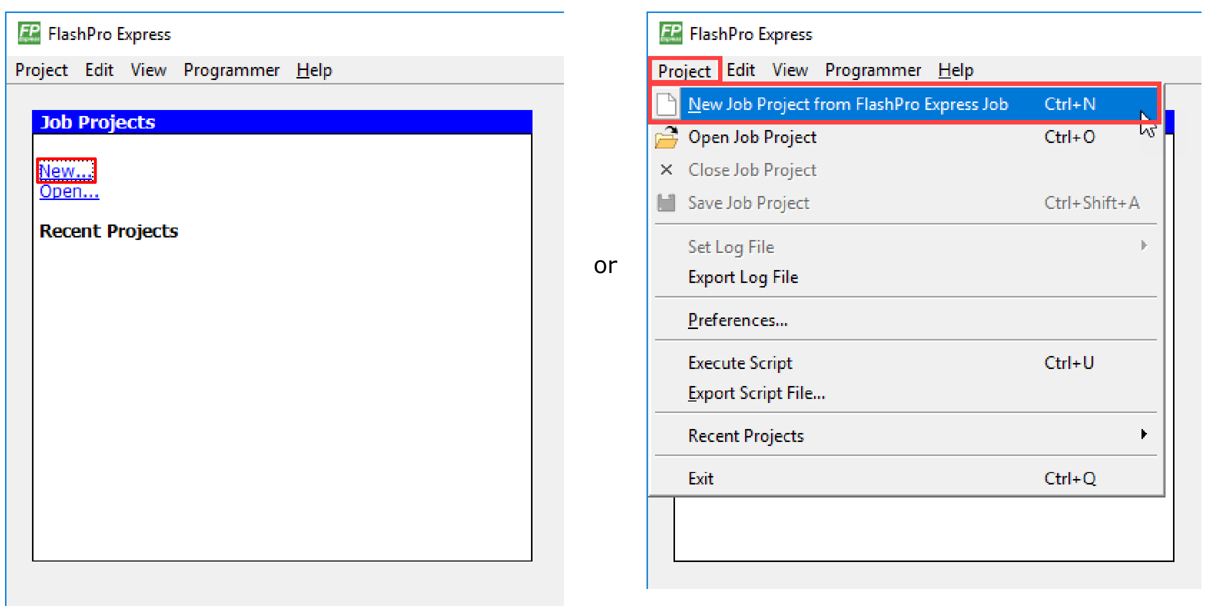
To program the device, perform the following steps:

1. Ensure that the jumper settings on the board are the same as listed in Table 2-1.

> **Important:** The power supply switch must be switched off while making the jumper connections.

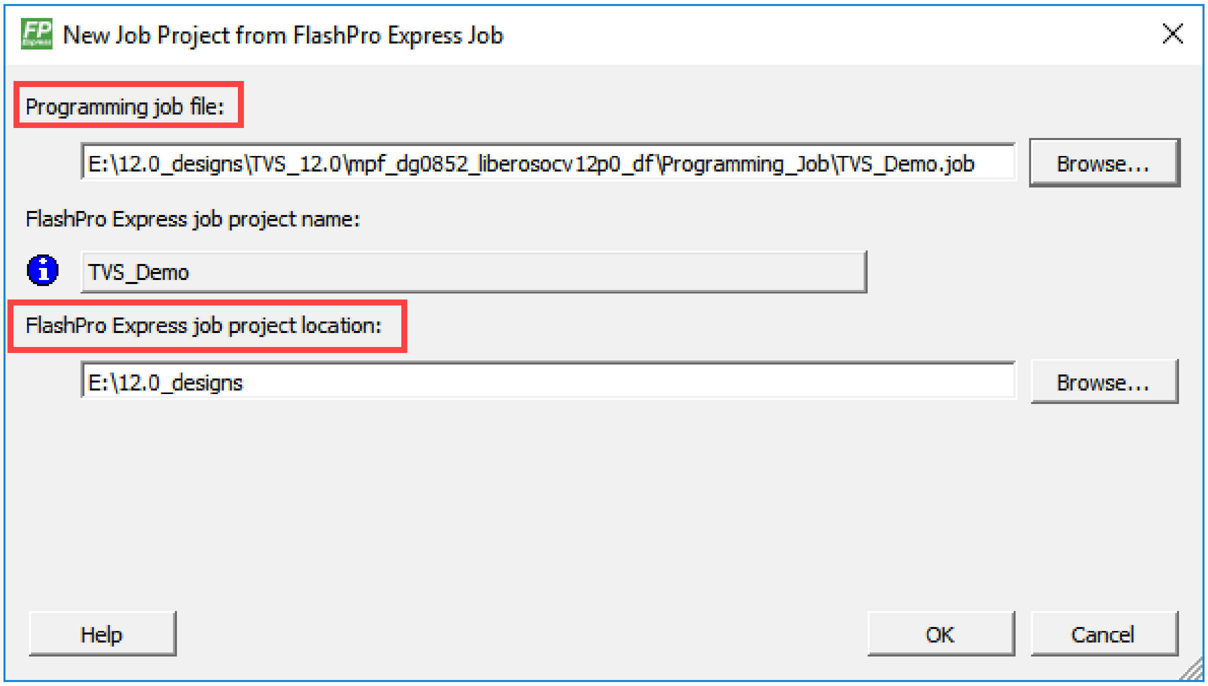
2. Connect the power supply cable to the J9 connector on the board.
3. Connect the USB cable from the Host PC to the J5 (FTDI port) on the board.
4. Power the board using the SW3 slide switch.
5. On the host PC, start the **FlashPro Express** software.
6. To create a new job project on the **Project** menu, click **New** or **New Job Project from FlashPro Express Job**, as shown in the following figures.

Figure 4-1. FlashPro Express Job Project



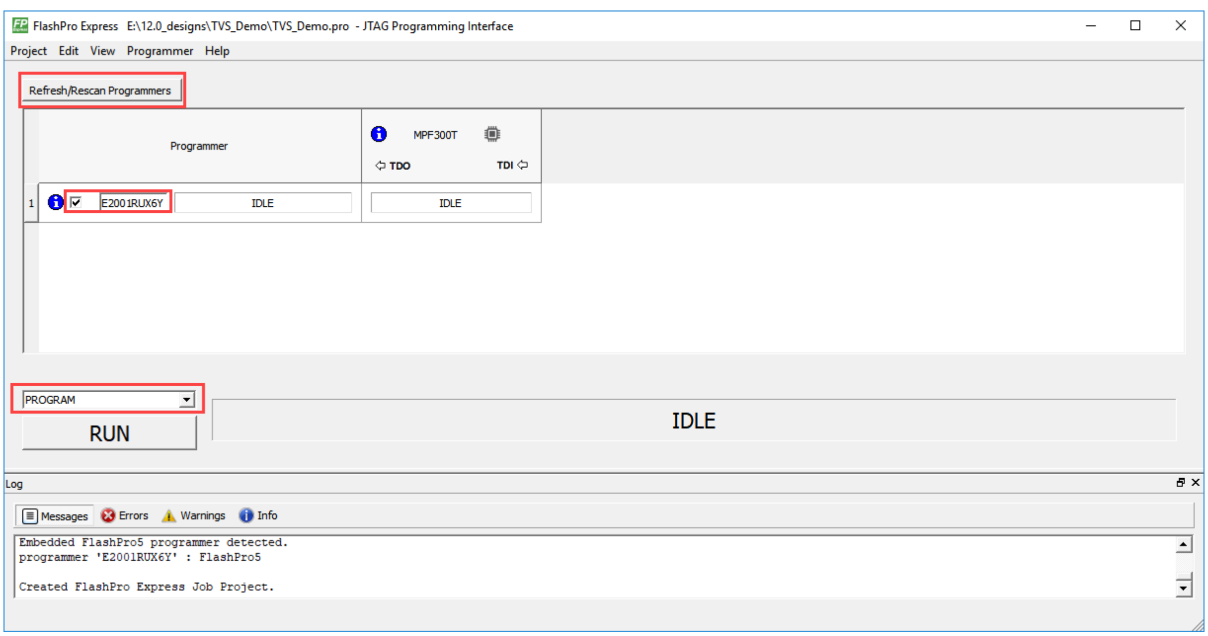
7. In the **New Job Project from FlashPro Express Job** dialog box, perform the following steps:
   - **Programming job file**: Click **Browse**, navigate to the location where the `.job` file is located and select the file. The default location is: <download_folder>\mpf_an4682_v2022p1_eval_df\Programming_Job.
   - **FlashPro Express job project location**: Select **Browse** and navigate to the location where you want to save the project.

Figure 4-2. New Job Project from FlashPro Express Job



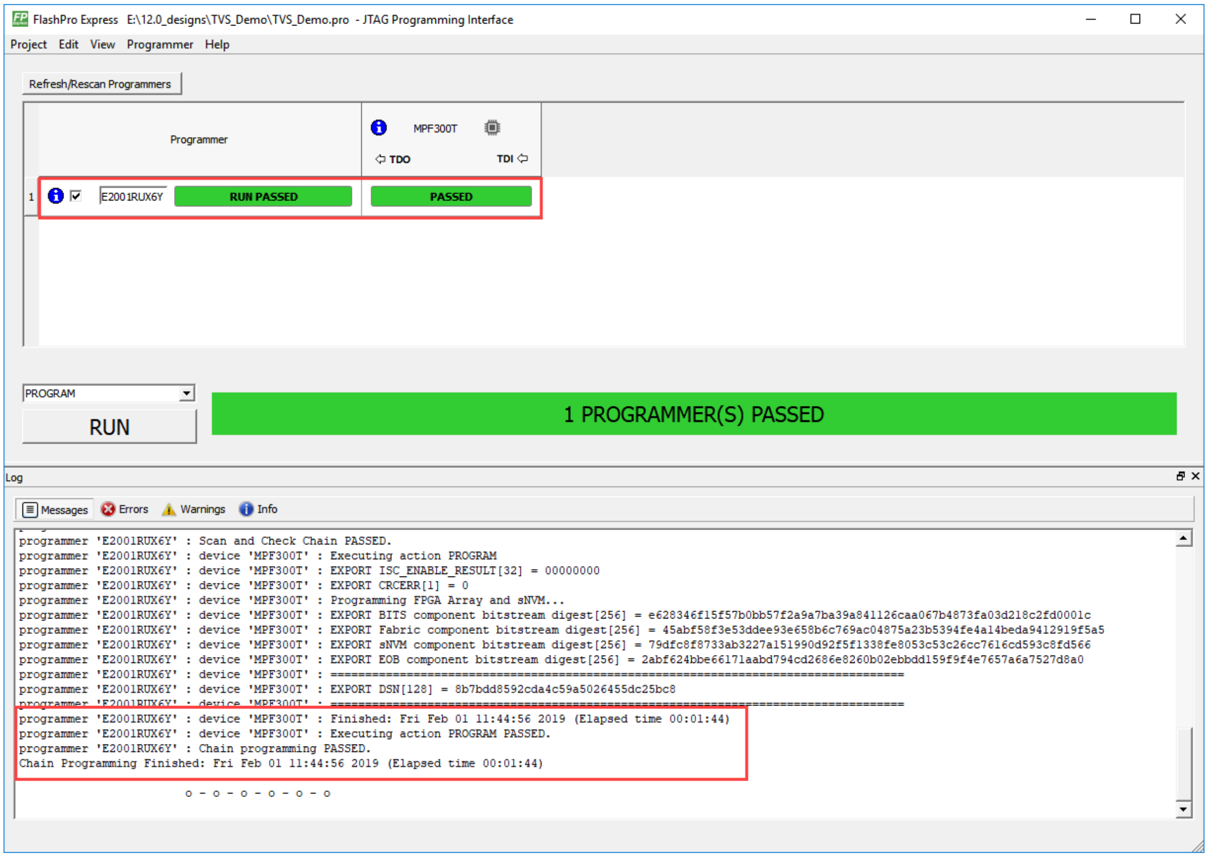
8. Click **OK**. The required programming file is selected and ready to be programmed in the device. The FlashPro Express window appears. Verify that a programmer number appears in the Programmer field. If it does not, verify the board connections and click **Refresh/Rescan Programmers**.

Figure 4-3. Programming the Device



9. To program the device, click **RUN**. When the device is programmed successfully, a **RUN PASSED** status is displayed, as shown in the following figure. To run the TVS demo, see 3. Running the Demo.

Figure 4-4. FlashPro Express-RUN PASSED



10. Close FlashPro Express, click **Project** > **Exit**.

5. Appendix 2: Running the TCL Script

TCL scripts are provided in the design files folder under the directory `TCL_Scripts`. If required, the design flow can be reproduced from Design Implementation to the job file generation.

To run the TCL, perform the following steps:

1. Launch the Libero software.
2. Click **Project** > **Execute Script....**.
3. In the downloaded `TCL_Scripts` directory, select `script.tcl` and click **Browse**.
4. Click **Run**.

After successful execution of TCL script, the Libero project is created within `TCL_Scripts` directory. For more information about TCL scripts, see **mpf_an4682_v2022p1_eval_df/TCL_Scripts/readme.txt**.

For more details on TCL commands, see Tcl Commands Reference Guide. Contact Technical Support for any queries about running the TCL script.

6. Revision History

The revision history describes the changes that were implemented in the document. The changes are listed by revision, starting with the most current publication.

Table 6-1. Revision History

Revision	Date	Description
B	05/2024	The following is the list of changes in revision B of the document: • In the 1.3. Demo Design section as follows: – Updated the temperature channel's output value – Added the calculation part which illustrates how to calculate temperature and voltage output value
A	07/2022	The following is the list of changes in revision A of the document: • The document was migrated to the Microchip template • The document number was updated to DS00004682A from 50200852 • The document ID was updated to AN4682 from DG0852 • Updated the Figure 1-2 • Removed Resource Utilization section
3.0	—	The following is a summary of the changes made in this revision. Added 5. Appendix 2: Running the TCL Script. Updated Figure 2, page 4. Updated Figure 1-3.
2.0	—	The following is a summary of the changes made in this revision. Updated the document for Libero SoC v12.2. Removed the references to Libero version numbers.
1.0	—	The first publication of this document.

Microchip FPGA Support

Microchip FPGA products group backs its products with various support services, including Customer Service, Customer Technical Support Center, a website, and worldwide sales offices. Customers are suggested to visit Microchip online resources prior to contacting support as it is very likely that their queries have been already answered.

Contact Technical Support Center through the website at www.microchip.com/support. Mention the FPGA Device Part number, select appropriate case category, and upload design files while creating a technical support case.

Contact Customer Service for non-technical product support, such as product pricing, product upgrades, update information, order status, and authorization.

- From North America, call **800.262.1060**
- From the rest of the world, call **650.318.4460**
- Fax, from anywhere in the world, **650.318.8044**

Microchip Information

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 products:

- 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, within operating specifications, and under normal conditions.
- Microchip values and aggressively protects its intellectual property rights. Attempts to breach the code protection features of Microchip product is strictly prohibited and may violate the Digital Millennium Copyright Act.
- 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. Microchip is committed to continuously improving the code protection features of our products.

Legal Notice

Trademarks

ISBN: 978-1-6683-4529-0

Quality Management System

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

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:
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 - Hod Hasharon
Tel: 972-9-775-5100

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: 47-72884388

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