



# Sapphire RISC-V SoC Hardware and Software User Guide

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UG-RISCV-SAPPHIRE-v4.2  
November 2022  
[www.elitestek.com](http://www.elitestek.com)



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# Introduction

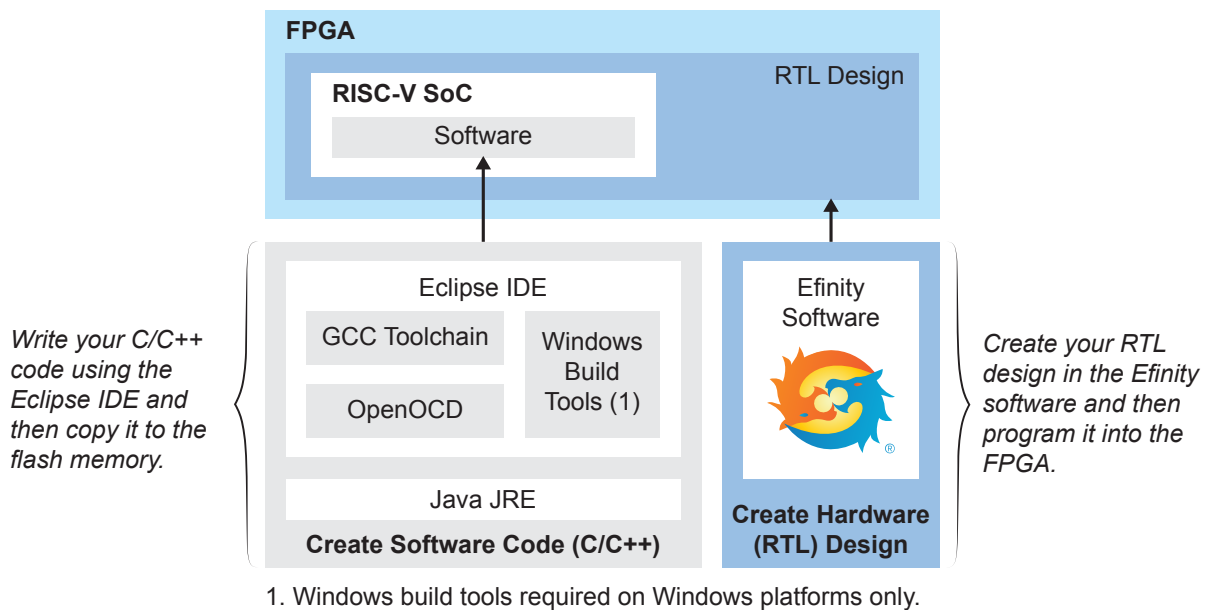
易灵思 provides a soft configurable RISC-V SoC, called Sapphire, that you can implement in Trion® or 钛金系列 FPGAs. This user guide describes how to:

- Build RTL designs using the Sapphire RISC-V SoC using an example design targeting an 易灵思® development board, and how to extend the example for your own application.
- Set up the software development environment using an example project, create your own software based on example projects, and use the API.



**Note:** The Sapphire SoC v2.0, released with the Efinity software v2021.2, has significant improvements from previous versions, and you cannot migrate an existing design to it automatically. 易灵思 recommends that you use v2.0 or higher for all new designs. You can continue to use previous versions with the Efinity software v2021.1. If you want to migrate an existing design to v2.0, refer to [Migrating to the Sapphire SoC v2.0 from a Previous Version](#) on page 61.

Figure 1: Designing Hardware and Software for the Sapphire RISC-V SoC



**Learn more:** Refer to the [Sapphire RISC-V SoC Data Sheet](#) for detailed specifications on the SoC.

## VexRiscv RISC-V Core

The Sapphire SoC is based on the VexRiscv core created by Charles Papon. The VexRiscv core is a 32-bit CPU using the ISA RISC-V32I with M, A, F, D, and C extensions, has six pipeline stages (fetch, injector, decode, execute, memory, and writeback), and a configurable feature set.

In the Sapphire SoC, the VexRiscv core is user configurable, and can support AXI4 and APB3 bus interfaces and instruction and data caches.

The VexRiscv core won first place in the RISC-V SoftCPU contest in 2018.<sup>(1)</sup>

<sup>(1)</sup> <https://www.businesswire.com/news/home/20181206005747/en/RISC-V-SoftCPU-Contest-Winners-Demonstrate-Cutting-Edge-RISC-V>

## Required Software

To write software for the Sapphire SoC, you need the following tools. The SDK is available as a single download in the Support Center for Windows and Ubuntu operating systems.

### Efinity® Software

易灵思® development environment for creating RTL designs targeting Trion® or 钛金系列 FPGAs. The software provides a complete RTL-to-bitstream flow, simple, easy to use GUI interface, and command-line scripting support.

Version: 2021.1 or higher

### RISC-V SDK

**Eclipse MCU**—Open-source Java-based development environment that uses plug-ins to extend and customize its functionality. The GNU MCU Eclipse plug-in lets you develop applications for ARM and RISC-V cores.

Version: 2020-09 (4.17.0)

Disk space required: 433 MB (Windows), 433 MB (Linux)

**xPack GNU RISC-V Embedded GCC**—Open-source, prebuilt toolchain from the xPack Project.

Version: 8.3.0-2.3

Disk space required: 1.53 GB (Windows), 1.5 GB (Linux)

**OpenOCD Debugger**—The open-source Open On-Chip Debugger (OpenOCD) software includes configuration files for many debug adapters, chips, and boards. Many versions of OpenOCD are available. The RISC-V flow requires a custom version of OpenOCD that includes the VexRiscv 32-bit RISC-V processor.

Version: 20200421

Disk space required: 9.4 MB (Windows), 7.4 MB (Linux)

**GNU MCU Eclipse Windows Build Tool (Windows Only)**—This open-source Windows-specific package helps to manage build projects and includes GNU make.

Version: 4.2.1-2-win32-x64

Disk space required: 4.99 MB

### Java JRE

Open-source Java 64-bit runtime environment; required for Eclipse.

Version: 8 Update 241

<https://www.java.com/en/download/manual.jsp> (Java 8 official release)

<https://developers.redhat.com/products/openjdk/download> (OpenJDK 8 or 11)

<http://jdk.java.net/16/> (OpenJDK 16)

## Required Hardware

- Trion® T120 BGA324 Development Board or 钛金系列 Ti60 F225 Development Board
- 5 or 12 V power cable
- Micro-USB cable
- Computer or laptop
- (Optional) USB to UART converter module for the Trion® T120 BGA324 Development Board<sup>(2)</sup>
- (Optional) FTDI chip cable, C232HM-DDHSL-0, if you want to use the OpenOCD debugger and Efinity® Debugger simultaneously



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**Note:** Some of the software examples provided with the SoC use a UART terminal to display messages. See [Set Up a USB-to-UART Module \(Trion\)](#) on page 55 and [Using the On-board UART \(\)](#) on page 55 for more information.

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<sup>(2)</sup> The 钛金系列 Ti60 F225 Development Board had an on-board USB-to-UART converter and does not require a separate module.

# Install Software and SoC

## Contents:

- [Install the Efinity Software](#)
- [Install the RISC-V SDK](#)
- [Install the Java JRE](#)

## Install the Efinity® Software

If you have not already done so, download the Efinity® software from the Support Center and install it. For installation instructions, refer to the [Efinity Software Installation User Guide](#).



**Warning:** Do not use spaces or non-English characters in the Efinity path.

## Install the RISC-V SDK

To install the SDK:

1. Download the file **riscv\_sdk\_windows-v<version>.zip** or **riscv\_sdk\_ubuntu-v<version>.zip** from the Support Center.
2. Create a directory for the SDK, such as **c:\riscv-sdk** (Windows) or **home/my\_name/riscv-sdk** (Linux).
3. Unzip the file into the directory you created. The complete SDK is distributed as compressed files. You do not need to run an installer.

### Windows directory structure:

- **SDK\_Windows**
  - **eclipse**—Eclipse application.
  - **GNU MCU Eclipse**—Windows build tools.
  - **openocd**—OpenOCD debugger.
  - **riscv-xpack-toolchain\_8.3.0-2.3\_windows**—GCC compiler.
  - **run\_eclipse.bat**—Batch file that sets variables and launches Eclipse.
  - **setup.bat**—Batch file to set variables for running OpenOCD on the command line to flash the binary.

### Ubuntu directory structure:

- **SDK\_Ubuntu<version>**
  - **eclipse**—Eclipse application.
  - **openocd**—OpenOCD debugger.
  - **riscv-xpack-toolchain\_8.3.0-2.3\_linux**—GCC compiler.
  - **run\_eclipse.sh**—Shell file that sets variables and launches Eclipse.
  - **setup.sh**—Shell file to set variables for running OpenOCD on the command line to flash the binary.



## Install the Java JRE

To install the JRE:

1. Download the 64-bit version of the JRE or JDK for your operating system from  
<https://www.java.com/en/download/manual.jsp> (Java 8 official release)  
<https://developers.redhat.com/products/openjdk/download> (OpenJDK 8 or 11)  
<http://jdk.java.net/16/> (OpenJDK 16)
2. Follow the installation instructions on the web site to install the JRE.



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**Note:** You need a 64-bit version of the Java JRE. If you use a 32-bit version, when you try to launch Eclipse you will get an error that Java quit with exit code 13.

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# IP Manager

## Contents:

- **Customizing the Sapphire SoC**
- **Modify the Bootloader**

The Efinity® IP Manager is an interactive wizard that helps you customize and generate 易灵思® IP cores. The IP Manager performs validation checks on the parameters you set to ensure that your selections are valid. When you generate the IP core, you can optionally generate an example design targeting an 易灵思 development board and/or a testbench. This wizard is helpful in situations in which you use several IP cores, multiple instances of an IP core with different parameters, or the same IP core for different projects.

The IP Manager consists of:

- IP Catalog—Provides a catalog of IP cores you can select. Open the IP Catalog using the toolbar button or using **Tools > Open IP Catalog**.
- IP Configuration—Wizard to customize IP core parameters, select IP core deliverables, review the IP core settings, and generate the custom variation.
- IP Editor—Helps you manage IP, add IP, and import IP into your project.

## Generating Sapphire SoC with the IP Manager

The following steps explain how to customize an IP core with the IP Configuration wizard.

1. Open the IP Catalog.
2. Choose an IP core and click **Next**. The **IP Configuration** wizard opens.
3. Enter the module name in the **Module Name** box.



**Note:** You cannot generate the core without a module name.

4. Customize the IP core using the options shown in the wizard. For detailed information on the options, refer to the IP core's user guide or on-line help.
5. (Optional) In the **Deliverables** tab, specify whether to generate an IP core example design targeting an 易灵思® development board and/or testbench. For SoCs, you can also optionally generate embedded software example code. These options are turned on by default.
6. (Optional) In the **Summary** tab, review your selections.
7. Click **Generate** to generate the IP core and other selected deliverables.
8. In the **Review configuration generation** dialog box, click **Generate**. The Console in the **Summary** tab shows the generation status.



**Note:** You can disable the **Review configuration generation** dialog box by turning off the **Show Confirmation Box** option in the wizard.

9. When generation finishes, the wizard displays the **Generation Success** dialog box. Click **OK** to close the wizard.

The wizard adds the IP to your project and displays it under **IP** in the Project pane.

## Generated RTL Files

The IP Manager generates these files and directories:

- **<module name>\_define.vh**—Contains the customized parameters.
- **<module name>\_tpl.v**—Verilog HDL instantiation template.
- **<module name>\_tpl.vhd**—VHDL instantiation template.

- **<module name>.v**—IP source code.
- **settings.json**—Configuration file.
- **<kit name>\_devkit**—Has generated RTL, example design, and Efinity® project targeting a specific development board.
- **Testbench**—Contains generated RTL and testbench files.



**Note:** Refer to the IP Manager chapter of the Efinity Software User Guide for more information about the Efinity IP Manager.

## Generated Software Code

If you choose to output embedded software, the IP Manager saves it into the `<project>/embedded_sw/<SoC module>` directory.

- **bsp**—Board specific package.
- **config**—Has the Eclipse project settings file and OpenOCD debug configuration settings files for Windows.
- **config\_linux**—Has the Eclipse project settings file and OpenOCD debug configuration settings files for Linux.
- **software**—Software examples.
- **tool**—Helper scripts.
- **cpu0.yaml**—CPU file for debugging.

## Instantiating the SoC

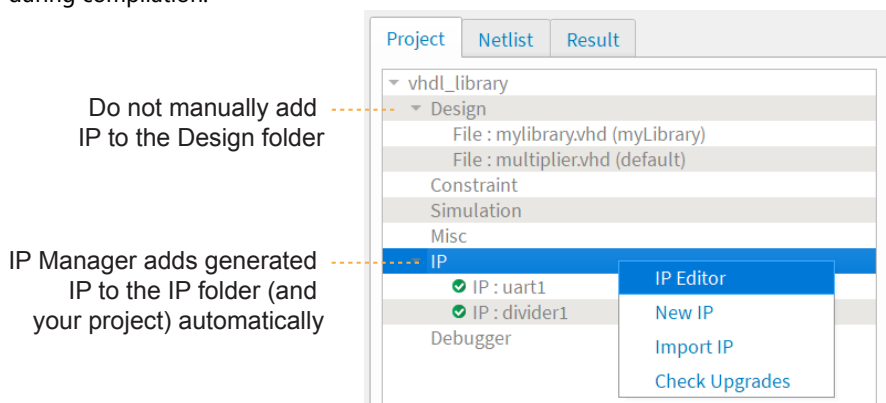
The IP Manager creates these template files in the `<project>/ip/<module name>` directory:

- `<module name>.v_tmpl.v` is the Verilog HDL module.
- `<module name>.v_tmpl.vhd` is the VHDL component declaration and instantiation template.

To use the IP, copy and paste the code from the template file into your design and update the signal names to instantiate the IP.



**Important:** When you generate the IP, the software automatically adds the module file (`<module name>.v`) to your project and lists it in the **IP** folder in the Project pane. Do not add the `<module name>.v` file manually (for example, by adding it using the Project Editor); otherwise the Efinity® software will issue errors during compilation.



## Customizing the Sapphire SoC

You customize the Sapphire SoC using the IP Configuration wizard. The parameters are arranged on tabs so you can click through them more easily.

**Table 1: Sapphire SoC Tab Parameters**

Parameter	Options	Description
Core Number	1 - 4	Enter the number of CPU cores. Default: 1
Frequency (MHz)	20 - 400	Enter the frequency in MHz. Default: 100
Peripheral Clock	On, off	Choose whether you want to run a dedicated clock for the APB3 slaves (SPI, I2C, GPIO, UART, and user timer) and AXI4 slave.
Peripheral Clock Frequency (MHz)	20 - 200	Enter the peripheral clock frequency in MHz.
Cache	On, off	Choose whether you want to include I\$ and D\$ caches.
Custom Instruction	On, off	Choose whether to enable the custom instruction interface.
Linux Memory Management Unit	On, off	Choose whether to enable the Linux MMU.
Floating-point Unit	On, off	Choose whether to enable the FPU.
Atomic Extension	On, off	Choose whether to enable atomic extension instruction support. If you enable the Linux MMU, this option must be enabled and is turned on by default.
Compressed Extension	On, off	For cacheless configurations only, choose whether to enable compressed instruction support.



**Important:** When running the SoC at high frequencies, 易灵思 recommends that you use the `TIMING_1` place and route optimization. To set this option:

1. Open the Project Editor.
2. Click the **Place and Route** tab.
3. Double-click the **Value** cell for `--optimization_level`.
4. Choose `TIMING_1`.
5. Click **OK** and then compile.

**Table 2: Sapphire Cache/Memory Tab Parameters**

Parameter	Options	Description
Data Cache Way	1, 2, 4, 8	Choose the number of ways for the data cache. Default: 1
Cache Size	1 KB, 2 KB, 4 KB, 8 KB, 16 KB, 32 KB	Choose the size of the data cache. Default: 4 KB
Instruction Cache Way	1, 2, 4, 8	Choose the number of ways for the instruction cache. Default: 1
Cache Size	1 KB, 2 KB, 4 KB, 8 KB, 16 KB, 32 KB	Choose the size of the instruction cache. Default: 4 KB
External Memory Interface	On, off	On: Instantiate the external memory interface. Off: Do not use the external memory interface.
AXI Interface Type	On, off	On: Use an AXI4 full duplex interface. Off: Use an AXI3 half duplex interface.
External Memory Data Width	32, 64, 128, 256, 512	Choose the data width for the AXI3 interface. Default: 128

Parameter	Options	Description
External Memory AXI3 Address Size	4 MB, 8 MB, 16 MB, 32 MB, 64 MB, 128 MB, 256 MB, 0.5 GB, 1 GB, 1.5 GB, 2 GB, 2.5 GB, 3 GB, 3.5 GB	Choose the address size for the AXI3 interface. Default: 3.5 GB
On-Chip RAM Size	1 KB, 2 KB, 4 KB, 8 KB, 16 KB, 24 KB, 32 KB, 48 KB, 64 KB, 80 KB, 96 KB, 128 KB, 144 KB, 160 KB, 192 KB, 224 KB, 256 KB, 384 KB, 512 KB	Choose the size of the internal BRAM. Default: 4 KB
Custom On-Chip RAM Application	On, off	On: Overwrite the default SPI flash bootloader with the user application. Off: Use the default SPI flash bootloader.
User Application Path	–	Enter the path to your target user application. The file must be in <b>.hex</b> format.

Table 3: Sapphire Debug Tab Parameters

Parameter	Options	Description
Soft Debug Tap	On, off	Choose whether you want to include a soft debug TAP for debugging. Off: Default. The SoC uses the JTAG User TAP interface block to communicate with the OpenOCD debugger. On: The SoC has a soft JTAG interface to communicate with the OpenOCD debugger. You need to use this setting if you want to use the soft JTAG interface instead of the JTAG User TAP.
FPGA Tap Port	1, 2, 3, 4	Choose which Tap port you want to target with the OpenOCD debugger. This option is only applicable when you are using the JTAG User Tap interface block to communicate with the OpenOCD debugger.
Target Board	Trion T120 BGA324 Development Board Trion T120 BGA576 Development Board Trion T20 BGA256 Development Board Xyloni Titanium Ti60 F225 Development Board Titanium Ti180 M484 Development Board Custom	Choose which board you want to target with OpenOCD. Choose <b>Custom</b> to target your own board.
Custom Target Board	–	Enter the name of your board.
Application Region Size	124KB, 252KB, 508KB, 1MB, 2MB, 4MB, 8MB, 16MB, 32MB, 64MB, 128MB, 256MB	Modify the linker script to outline the region for the user application. This option is only applicable for SoCs with external memory. For SoCs with internal memory, the region size is determined by the on-chip RAM size.
Application Stack Size	1KB, 2KB, 4KB, 8KB, 16KB, 32KB, 64KB, 128KB, 256KB, 512KB, 1MB, 2MB, 4MB, 8MB, 16MB, 32MB, 64MB, 128MB	Modify the linker script to specify the application stack size. This option is only applicable for SoCs with external memory. For SoCs with internal memory, the region size is automatically set to 1/8 of the on-chip RAM size.
OpenOCD Debug Mode	Turn on by default Turn off by default	Choose whether you want software applications to run in debug mode by default or not. See <a href="#">Debug with the OpenOCD Debugger</a> on page 28 for more details.

**Table 4: Sapphire UART Tab Parameters**

Where n is 0, 1, or 2

Parameter	Options	Description
UART n	On, off	On: Instantiate the interface. Off: Do not use the interface.
UART n Interrupt ID	1 - 36	Choose the interrupt ID for the UART. The IDs default to: UART 0: 1 UART 1: 2 UART 2: 3

**Table 5: Sapphire SPI Tab Parameters**

Where n is 0, 1, or 2.

Parameter	Options	Description
SPI n	On, off	On: Instantiate the interface. Off: Do not use the interface.
SPI n Interrupt ID	1 - 36	Choose the interrupt ID for the SPI. The IDs default to: SPI 0: 4 SPI 1: 5 SPI 2: 6

**Table 6: Sapphire I2C Tab Parameters**

Where n is 0, 1, or 2.

Parameter	Options	Description
I2C n	On, off	On: Instantiate the interface. Off: Do not use the interface.
I2C n Interrupt ID	1 - 36	Choose the interrupt ID for the I <sup>2</sup> C. The IDs default to: I2C 0: 8 I2C 1: 9 I2C 2: 10

**Table 7: Sapphire GPIO Tab Parameters**

Where n is 0 or 1.

Parameter	Options	Description
GPIO n	On, off	On: Instantiate the interface. Off: Do not use the interface.
GPIO n Bit Width	1, 2, 4, 8, 16	Choose the number of pins for the GPIO. Default: 4 (GPIO 0), 8 (GPIO 1)
GPIO n Interrupt ID 0	1 - 36	Choose the interrupt ID for the GPIO. The IDs default to: GPIO 0: 12 GPIO 1: 14
GPIO n Interrupt ID 1	1 - 36	Choose the interrupt ID for the GPIO. The IDs default to: GPIO 0: 13 GPIO 1: 15

**Table 8: Sapphire APB3 Tab Parameters**

Where n is 0, 1, 2, 3, or 4.

Parameter	Options	Description
APB Slave Address Size	4 KB - 1 MB	Choose the APB slave size. This setting applies to all APB slaves. Default: 64KB

Parameter	Options	Description
APB3 Slave n	On, off	On: Instantiate the interface. Off: Do not use the interface.

**Table 9: Sapphire AXI4 Tab Parameters**

Where n is 0 or 1.

Parameter	Options	Description
AXI Slave	On, off	On: Instantiate the interface. Off: Do not use the interface.
AXI Slave Size	1 KB, 2 KB, 4 KB, 8 KB, 16 KB, 32 KB, 64 KB, 128 KB, 256 KB, 512 KB, 1 MB, 2 MB, 4 MB, 8 MB, 16 MB, 32 MB, 64 MB, 128 MB, 256 MB	Choose the size of the AXI slave.
AXI Master n	On, off	On: Instantiate the interface. Off: Do not use the interface.
AXI Master n Data Width	32, 64, 128, 256, 512	Choose the width of the AXI master. Do not specify an AXI master width that is larger than the external memory data width.

**Table 10: Sapphire User Interrupt Tab Parameters**

Where n is A, B, C, D, E, F, G, or H.

Parameter	Options	Description
User n Interrupt	On, off	On: Instantiate the interface. Off: Do not use the interface.
User n Interrupt ID	1 - 36	Choose the interrupt ID. The defaults are: User A Interrupt: 16 User B Interrupt: 17 User C Interrupt: 22 User D Interrupt: 23 User E Interrupt: 24 User F Interrupt: 25 User G Interrupt: 26 User H Interrupt: 27

**Table 11: Sapphire User Timer Tab Parameters**

Where n is 0, 1, or 2.

Parameter	Options	Description
User Timer n	On, off	On: Instantiate the interface. Off: Do not use the interface.
User Timer n Counter Width	12, 16, 32	Choose the counter bit width. Default: 12
User Timer n Prescaler Width	8, 16	Choose the prescaler bit width. Default: 8
User Timer n Interrupt ID	1 - 36	Choose the interrupt ID. The defaults are: User Timer 0: 19 User Timer 1: 20 User Timer 2: 21

Table 12: Sapphire Base Address Tab Parameters

Parameter	Options	Description
Address Assignment Method	AUTO, MANUAL	AUTO: Automatically assign an address to the enabled peripherals. MANUAL: The user can assign addresses to the enabled peripherals.
External Memory Base Address	–	Displays the base address. You cannot change it.
AXI Slave Base Address	–	Displays the base address when the <b>Address Assignment Method</b> is set to AUTO.
Peripheral and IO Base Address	–	When the <b>Address Assignment Method</b> is <b>Manual</b> , enter the base address value. The wizard automatically rounds the value to 16 MB aligned addresses during IP generation. For example, 0x41234567 is rounded to 0x41000000.
UARTn Address Offset	–	Displays the base address when the <b>Address Assignment Method</b> is set to AUTO.
SPI <sub>n</sub> Address Offset	–	When the <b>Address Assignment Method</b> is <b>Manual</b> , enter base address value. The wizard automatically rounds the value to 4 KB aligned addresses during IP generation. For example, 0x4123 is rounded to 0x41000.
I2C <sub>n</sub> Address Offset	–	
GPIO <sub>n</sub> Address Offset	–	
User Timern Address Offset	–	
APB3 <sub>n</sub> Address Offset	–	Displays the base address when the <b>Address Assignment Method</b> is set to AUTO. When the <b>Address Assignment Method</b> is <b>Manual</b> , enter base address value. The wizard automatically rounds the value to APB sized aligned addresses during IP generation. For example, if the APB size is 64 KB, 0x23456 is rounded to 0x20000.
On-Chip RAM Base Address	–	Displays the base address. You cannot change it.



## Modify the Bootloader

When you generate the Sapphire SoC, the IP Manager creates a pre-built bootloader **.bin** to target the on-chip RAM size you selected. If you assigned the peripheral addresses manually, you need to create a custom bootloader according to the following instructions.



**Note:** You need the embedded software example code to make these changes; if you have not already done so, generate it.

### Modify the Bootloader Software to Extend the External Memory Size

First you need to modify the bootloader code:

1. Open the **bootloaderConfig.h** file in the **embedded\_sw/<SoC module>/bsp/efinix/EfxSapphireSoc/app** directory.
2. Change the `#define USER_SOFTWARE_SIZE` parameter for the new on-chip RAM size and save.
3. In Eclipse, create a new project from the makefile in the **embedded\_sw/<SoC module>/software/standalone/bootloader** directory and compile it to generate the new **bootloader.hex** file.

Second, you update and re-generate the SoC in the IP Manager to point to your new **bootloader.hex** and change the application region size. The default maximum size is 124 KB.

1. In the Sapphire IP wizard, go to the **Cache/Memory** tab.
2. Turn on the **Custom On-Chip RAM Application** option.
3. Click the **Browse** button for the to select the new **bootloader.hex** you created in the previous set of steps.
4. Generate the SoC.

### Modify the Bootloader Software without External Memory Enabled

First, you need to modify the bootloader linker script:

1. Open the **bootloader.ld** file in the **embedded\_sw/<SoC module>/bsp/efinix/EfxSapphireSoc/linker** directory.
2. Replace the `MEMORY` and `PHDRS` code with the following code. The `<bootloader_address>` should be `0xF9000000 + (<memory size>-1024)`, where `<memory size>` is your SoC's on-chip RAM size.

```
MEMORY
{
    start (wxai!r) : ORIGIN = 0xF9000000, LENGTH = 512
    ram (wxai!r) : ORIGIN = <bootloader_address>, LENGTH = 1024
}

PHDRS
{
    start PT_LOAD;
    ram PT_LOAD;
}
```

Second you need to modify the bootloader code:

1. Open the **bootloaderConfig** file in the **embedded\_sw/<SoC module>/bsp/efinix/EfxSapphireSoc/app** directory.
2. Change the `#define USER_SOFTWARE_SIZE` parameter for the new on-chip RAM size and save.

Third, in Eclipse, create a new project from the makefile in the **embedded\_sw/<SoC module>/software/standalone/bootloader** directory and compile it.

# Program the Board with the Sapphire RTL Design

## Contents:

- **About the Example Design**
- **Enable the On-Board 10 MHz Oscillator (T120 BGA324 Board)**
- **Enable the LPDDR4x Memory (Ti180 M484 Board)**
- **Installing USB Drivers**
- **Program the Development Board**

Before working with software code, recommends that you program your board with an RTL design that instantiates the Sapphire SoC. When you generate the Sapphire SoC with the IP Manager, you can optionally generate an example Efinity® project and bitstream file to get you started quickly.

## About the Example Design

This example targets Trion and development boards:

- Trion® T120 BGA324 Development Board—The RTL design files are in the **T120F324\_devkit** directory.
- 钛金系列 Ti60 F225 Development Board—The RTL design files are in the **Ti60F225\_devkit** directory.
- 钛金系列 Ti180 M484 Development Board—The RTL design files are in the **Ti180M484\_devkit** directory.

When you generate the IP core, the IP Manager creates the example design (PLL settings, SDC timing constraints, and I/O assignments) using the settings you chose in the wizard, with a few exceptions:

- For the Trion board, the example design only supports external memory widths of 128 and 256 bits because the DDR controller only supports these widths. Therefore, do not choose 32 or 64 bits for the external memory.
- The example design automatically connects UART0, SPI0, I2C0, GPIO0, the soft TAP pins, and the PLL source clock pins to top-level ports, and it assigns I/O pins to them (if they are enabled). If you add more of these peripherals, you need to connect them manually and create the I/O assignments for them.
- The example design uses PLL settings that look for the best effort multiplier and divider values.



**Note:** The following description is for the example design using the default settings.

This example writes to and reads from the development board's memory module using the AXI interface:

- For the Trion® T120 BGA324 Development Board, the design uses the board's LPDDR3 DRAM module.
- For the 钛金系列 Ti60 F225 Development Board, the design uses the board's HyperRAM module.
- For the 钛金系列 Ti180 M484 Development Board, the design uses the board's LPDDR4 DRAM module.

The Sapphire SoC is configured for:

- 100 MHz frequency

- External memory interface is enabled with a width of 128 and size of 3.5 GB
- Caches are enabled with a size of 4 KB
- 4KB on-chip RAM size
- Soft Debug Tap is disabled
- UART 0 is enabled
- SPI 0 is enabled
- I2C 0 is enabled
- GPIO 0 is enabled
- APB3 0 is enabled
- AXI4 Slave is enabled
- AXI Master 0 is enabled
- User interrupt A is enabled

Figure 2: Example Design Block Diagram

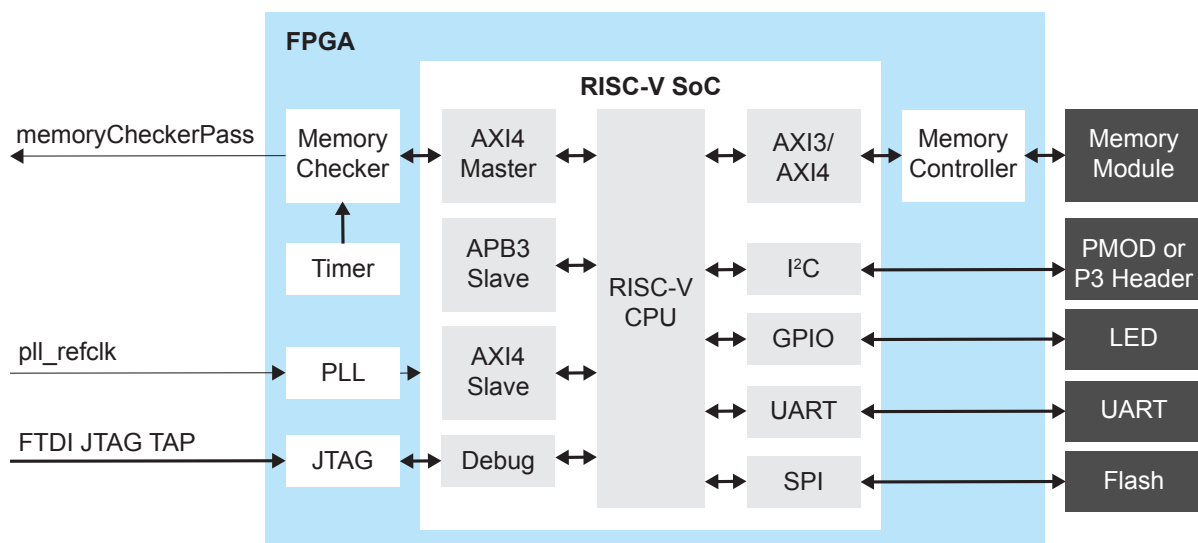


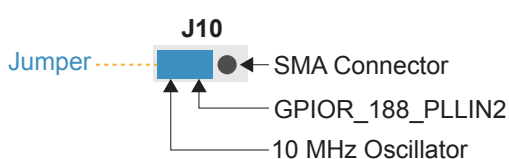
Table 13: Example Design Implementation

FPGA	Logic + Adders	Flipflops	Multipliers or DSP Blocks	Memory Blocks	f <sub>MAX</sub> (MHz)	Language	Efinity Version
T120 BGA324 C4	8,241	8,538	4	69	112	Verilog HDL	2022.1.226
Ti60 F225 C4	10,420	9,536	4	81	163	Verilog HDL	2022.1.226
Ti180 M484 C4	11,548	15,330	4	101	240	Verilog HDL	2022.1.226

## Enable the On-Board 10 MHz Oscillator (T120 BGA324 Board)

For the Trion® T120 BGA324 Development Board, the SoC design uses the on-board 10 MHz oscillator. To enable it, add a jumper to connect pins 2 and 3 on header J10.

Figure 3: Connect Pins 2 and 3 on J10



## Enable the LPDDR4x Memory (Ti180 M484 Board)

For the 钛金系列 Ti180 M484 Development Board, the SoC design uses LPDDR4x settings to drive the external mamory. To enable it, change the jumpers on PT12 and PT15 to connect pins 1 and 2 to provide 0.6 V to VDDQ and VDDQ\_PHY.

Figure 4: Connect Pins 1 and 2 on PT12 and PT15



## Installing USB Drivers

To program Trion® FPGAs using the Efinity® software and programming cables, you need to install drivers.

易灵思 development boards have FTDI chips (FT232H, FT2232H, or FT4232H) to communicate with the USB port and other interfaces such as SPI, JTAG, or UART.

### Installing Drivers on Windows

On Windows, you use software from Zadig to install drivers. Download the Zadig software (version 2.7 or later) from [zadig.akeo.ie](http://zadig.akeo.ie). (You do not need to install it; simply run the downloaded executable.)

Install the driver for the interfaces listed in the following table.

Board	Interface to Install Driver
Trion® T120 BGA324 Development Board	Install drivers for all interfaces (0 and 1).
钛金系列 Ti60 F225 Development Board	Install drivers for interfaces 0 and 1 only. Windows automatically installs a driver for interfaces 2 and 3 when you connect the board to your computer.
钛金系列 Ti180 M484 Development Board	Install driver for interface 1 only.

To install the driver:

1. Connect the board to your computer with the appropriate cable and power it up.
2. Run the Zadig software.



**Note:** To ensure that the USB driver is persistent across user sessions, run the Zadig software as administrator.

3. Choose **Options > List All Devices**.
4. Repeat the following steps for each interface. The interface names end with (Interface N), where N is the channel number.
  - Select **libusb-win32** in the **Driver** drop-down list.
  - Click **Replace Driver**.
5. Close the Zadig software.



**Note:** This section describes the instruction to install the libusb-win32 driver for each interface separately. If you have previously installed a composite driver or installed using libusbK drivers, you do not need to update or reinstall the driver. They should continue to work correctly.

## Installing Drivers on Linux

The following instructions explain how to install a USB driver for Linux operating systems.

1. Disconnect your board from your computer.
2. In a terminal, use these commands:

```
> sudo <installation directory>/bin/install_usb_driver.sh
> sudo udevadm control --reload-rules
```



**Note:** If your board was connected to your computer before you executed these commands, you need to disconnect and re-connect it.

## Program the Development Board

When you generate the Sapphire SoC in the IP Manager, you can optionally generate an example design targeting an 易灵思 development board. Example designs include a bitstream file, **soc.hex**, so you can get started quickly without having to compile the design.

**Table 14: Available Example Designs**

Board	Location
钛金系列 Ti60 F225 Development Board	Ti60F225_devkit
钛金系列 Ti180 M484 Development Board	Ti180M484_devkit <sup>(3)</sup>
Trion® T120 BGA324 Development Board	T120F324_devkit

Download the **.hex** file to the board using these steps:

Connect the board to your computer using a USB cable.



**Learn more:** Instructions on how to use the Efinity software and board documentation **are available in the Support Center.**

<sup>(3)</sup> The Efinity software v2022.1.226 does not support bitstream generation for the Ti180 M484 package. Therefore, the example does not include a **.hex** file. Check the Efinity release notes for the latest bitstream support.

## Chapter 4

# Simulate

The IP Manager automatically generates a testbench and top-level file for simulation based on the settings you made in the wizard, including the top-level file generation, I/O connection to the testbench, simulation models, and stimulus such as clock and reset. The testbench bypasses the SPI flash data retrieval step to speed up simulation.



**Note:** If you manually assign addresses to the peripherals, the default simulation may not function correctly.

1. Open a terminal.
2. Change to the **Testbench** directory for your SoC.
3. Set up the Efinity environment:
  - Linux: `source /<path to Efinity>/bin/setup.sh`
  - Windows: `c:\<path to Efinity>\bin\setup.bat`
4. Run the simulation using the default application with the command `Python3 run.py`.



**Note:** If you want to include the SPI flash retrieval step, run the simulation with the command:

```
Python3 run.py -f
```

A successful simulation returns the following messages

```
# 0 -----
# 0 [EFX_INFO]: Start executing helloWorld TEST
# 0 -----
# 51315 -----
# 51315 [EFX_INFO]: Receiving uart data from soc
# 51315 -----
# 2121065 -----
# 2121065 [EFX_INFO]: TEST PASSED
# 2121065 [EFX_INFO]: Hello World from Efinix!
# 2121065 -----
```

To simulate with a different application instead of the default, use the command:

```
Python3 run.py -b <path to application>/app.bin
```

When you use a non-default application, the testbench bypasses the default driver and monitor sequences and displays warning messages.

```
# 0 -----
# 0 [EFX_INFO]: Executing custom binary file...
# 0 [EFX_WARN]: Skipped testbench default driver and monitor sequences.
# 0 [EFX_INFO]: Running simulation...
# 0 -----
```

You need to develop your own sequence for your application.

# Launch Eclipse

## Contents:

- **Set Global Environment Variables**

The RISC-V SDK includes the **run\_eclipse.bat** file (Windows) or **run\_eclipse.sh** file (Linux) that adds executables to your path, sets up environment variables for the Sapphire BSP, and launches Eclipse. Always use this executable to launch Eclipse; do not launch Eclipse directly.

When you first start working with the Sapphire SoC, you need to configure your Eclipse workspace and environment. Setting up a global development environment for your workspace means you can store all of your Sapphire software code in the same place and you can set global environment variables that apply to all software projects in your workspace.

You should use a unique workspace for your Sapphire SoC projects. recommends using the **embedded\_sw/<SoC module>** directory as the workspace directory.



**Note:** With IP Manager, you can generate multiple SoCs with different options. Using the **embedded\_sw/<SoC module>** directory as your workspace means that you can explore more than one SoC by simply switching workspaces.

Follow these steps to launch Eclipse and set up your workspace:

1. Launch Eclipse using the **run\_eclipse.bat** file (Windows) or **run\_eclipse.sh** file.
2. If this is the first time you are running Eclipse, create a new workspace that points to the **embedded\_sw/<SoC module>** directory. Otherwise, choose **File > Switch Workspace > Other** to choose an existing workspace directory and click **Launch**.

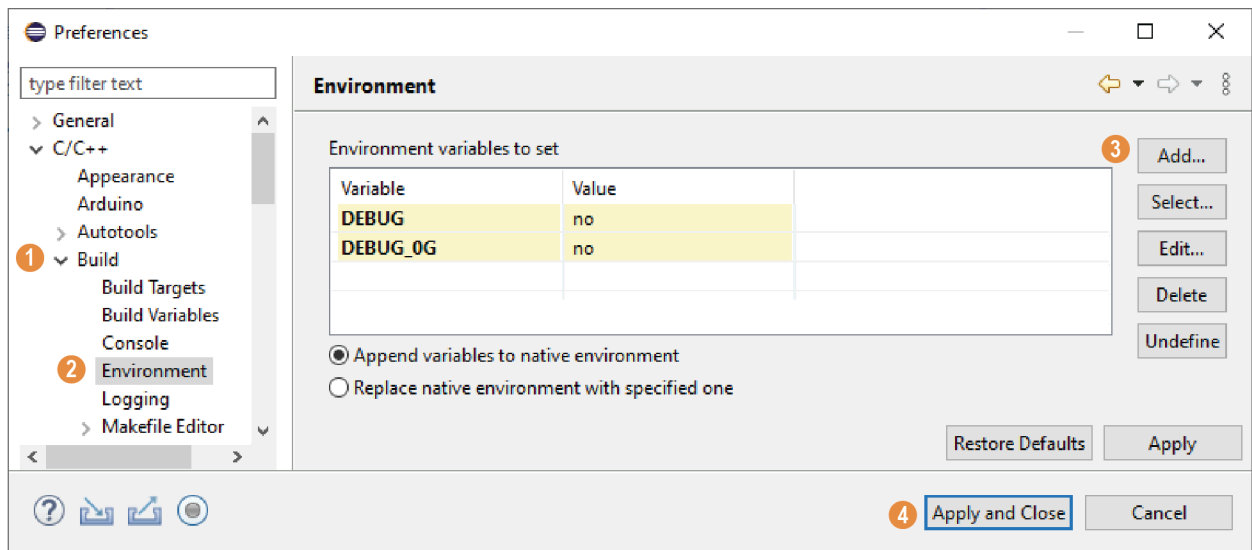
## Set Global Environment Variables

OpenOCD uses two environment variables, `DEBUG` and `DEBUG_OG`. It is simplest to set them as global environment variables for all projects in your workspace. Then, you can adjust them as needed for individual projects.



**Note:** When you configure the SoC in the IP Manager, you can choose whether to turn on debug mode by default or not. When you generate the SoC, the setting is saved in the **/embedded\_sw/bsp/efinix/EfxSapphireSoc/include/soc.mk** file. If you want to change the debug mode, you can change the setting in the IP Configuration wizard and re-generate the SoC, or use the following instructions to add the variables to your project and change them there.

Choose **Window > Preferences** to open the **Preferences** window and perform the following steps.



1. In the left navigation menu, expand **C/C++ > Build**.
2. Click **C/C++ > Build > Environment**.
3. Click **Add** and add the following environment variables:

Variable	Value	Description
DEBUG	no	Enables or disables debug mode. no: Debugging is turned off yes: Debugging is enabled
DEBUG_OG	no	Enables or disables optimization during debugging. Use an uppercase letter O not a zero.

4. Click **Apply and Close**.



# Create and Build a Software Project

## Contents:

- **Create a New Project**
- **Import Project Settings (Optional)**
- **Enable Debugging**
- **Build**

After you set up your Eclipse workspace, you are ready to create a new project and build it. These instructions walk you through the process using the **axiDemo** example project from the **software** directory.

## Create a New Project

In this step you create a new project from the **axiDemo** code example.

1. Launch Eclipse.
2. Select the Sapphire workspace if it is not open by default.
3. Make sure you are in the C/C++ perspective.  
Import the **axiDemo** example:
4. Choose **File > New > Makefile Project with Existing Code**.
5. Click **Browse** next to **Existing Code Location**.
6. Browse to the **software/standalone/axiDemo** directory and click **Select Folder**.
7. Select **<none>** in the **Toolchain for Indexer Settings** box.
8. Click **Finish**.

The **axiDemo** project folder displays in the Project Explorer. The folder has the makefile and **main.c** source code as well as launch scripts for the OpenOCD Debugger.

## Import Project Settings (Optional)

provides a C/C++ project settings file that defines the include paths and symbols for the C code. Importing these settings into your project lets you explore and jump through the code easily.



**Note:** You are not required to import the project settings to build. These settings simply make it easier for you to write and debug code.

To import the settings:

1. Choose **File > Import** to open the **Import** wizard.
2. Expand **C/C++**.
3. Choose **C/C++ > C/C++ Project Settings**.
4. Click **Next**.
5. Click **Browse** next to the **Settings file** box.
6. Browse to one of the following files and click **Open**:

Option	Description
Windows	embedded_sw\ <soc module="">\config\project_settings_soc.xml</soc>
Linux	embedded_sw/<SoC module>/config_linux/project_settings_soc.xml

- In the **Select Project** box, select the project name(s) for which you want to import the settings.
- Click **Finish**.

Eclipse creates a new folder in your project named **Includes**, which contains all of the files the project uses.

After you import the settings, clean your project (**Project** > **Clean**) and then build (**Project** > **Build Project**). The build process indexes all of the files so they are linked in your project.

## Enable Debugging

If you chose **OpenOCD Debug Mode** > **Turn On by default** when you configured the SoC, debugging is turned on and you can skip the instructions in this topic.

If you chose **OpenOCD Debug Mode** > **Turn Off by default** when you configured the SoC, debugging is turned off. Add the environment variables as described in **Set Global Environment Variables** on page 23 and then change the variables as needed.

- To run the program for normal operation, keep **DEBUG** set to **no**.
- To debug with the OpenOCD debugger, set **DEBUG** to **yes**.

In debug mode, the program suspends operation after loading so that you can set breakpoints or perform debug tasks.

To change the debug settings for your project, right-click the project name **axiDemo** in the Project Explorer and choose **Properties** from the pop-up menu.

- Expand **C/C++ Build**.
- Click **C/C++ Build** > **Environment**.
- Click the **Debug** variable.
- Click **Edit**.
- Change the **Value** to `yes`.
- Click **OK**.
- Click **Apply and Close**.



**Important:** When you change the debug value for a project you previously built, you must clean the project (**Project** > **Clean**) before building again. Otherwise, Eclipse gives a message in the Console that there is Nothing to be done for 'all'

## Build

Choose **Project** > **Build Project** or click the Build Project toolbar button.

The **makefile** builds the project and generates these files in the **build** directory:

- axiDemo.asm**—Assembly language file for the firmware.
- axiDemo.bin**—Download this file to the flash device on your board using OpenOCD. When you turn the board on, the SoC loads the application into the RISC-V processor and executes it.
- axiDemo.elf**—Use this file when debugging with the OpenOCD debugger.
- axiDemo.hex**—Hex file for the firmware. (Do not use it to program the FPGA.)

- **axiDemo.map**—Contains the SoC address map.

# Debug with the OpenOCD Debugger

## Contents:

- [Launch the Debug Script](#)
- [Debug](#)
- [Debug - Multiple Cores](#)

With the development board programmed and the software built, you are ready to configure the OpenOCD debugger and perform debugging. These instructions use the **axiDemo** example to explain the steps required.

## Launch the Debug Script

With the Efinity software v2022.1 and higher, debugging scripts are available for each software example in the `/embedded_sw/<module>/software/standalone/` directory and are imported into your project when you create a new project from an existing makefile. You can use these scripts to launch debug mode.

**Table 15: Debug Configurations**

Launch Script	Description
axiDemo_trion.launch	Debugging software on Trion® development boards.
axiDemo_ti.launch	Debugging software on 钛金系列 development boards
axiDemo_softTap.launch	Debugging software on Trion or 钛金系列 development boards with the soft JTAG TAP interface. For example, you would need to use the soft TAP if you want to use the OpenOCD debugger and the Efinity® Debugger at the same time. (See <a href="#">Using a Soft JTAG Core for Example Designs</a> on page 58.)

To debug the axiDemo project:

1. Right-click **axiDemo** > **axiDemo\_<family>.launch**.
2. Choose **Debug As** > > **axiDemo\_<family>**. Eclipse launches the OpenOCD debugger for the project.
3. Click **Debug**.

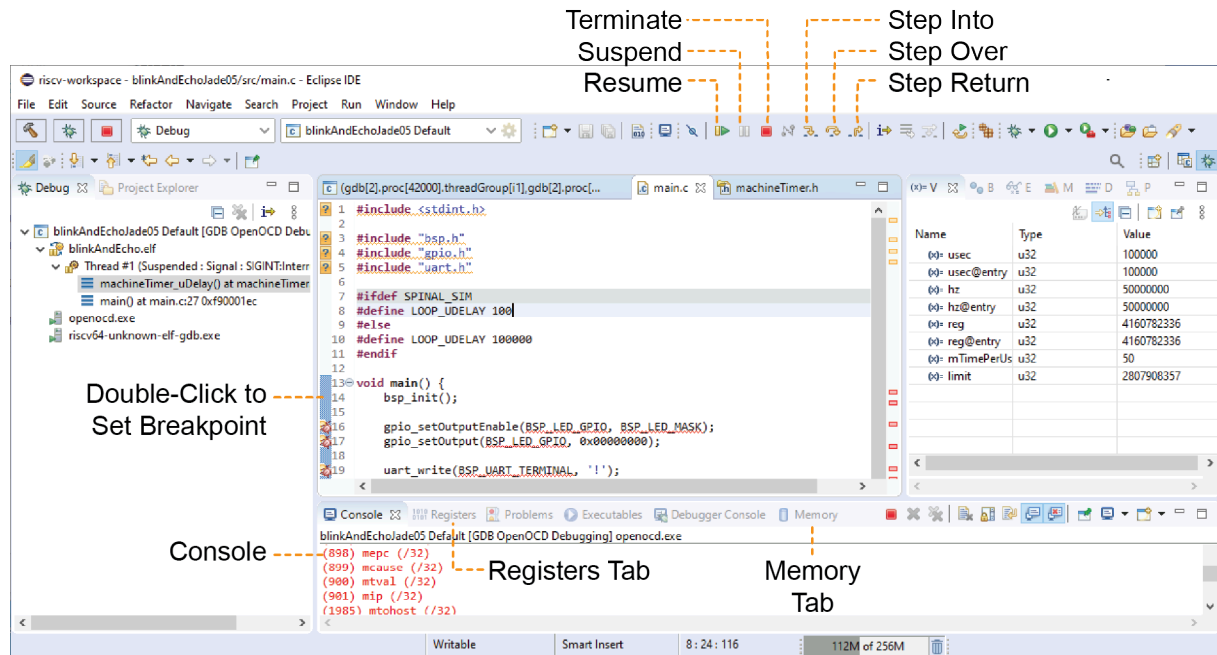
## Debug

After you click **Debug** in the Debug Configuration window, the OpenOCD server starts, connects to the target, starts the gdb client, downloads the application, and starts the debugging session. Messages and a list of VexRiscv registers display in the **Console**. The **main.c** file opens so you can debug each step.

1. Click the **Resume** button or press F8 to resume code operation. All of the LEDs on the board blink continuously in unison.
2. Click **Step Over** (F6) to do a single step over one source instruction.
3. Click **Step Into** (F5) to do a single step into the next function called.
4. Click **Step Return** (F7) to do a single step out of the current function.
5. Double-click in the bar to the left of the source code to set a breakpoint. Double-click a breakpoint to remove it.
6. Click the **Registers** tab to inspect the processor's registers.

7. Click the **Memory** tab to inspect the memory contents.
8. Click the **Suspend** button to stop the code operation.
9. When you finish debugging, click **Terminate** to disconnect the OpenOCD debugger.

Figure 5: Perform Debugging



**Learn more:** For more information on debugging with Eclipse, refer to [Running and debugging projects](#) in the Eclipse documentation.

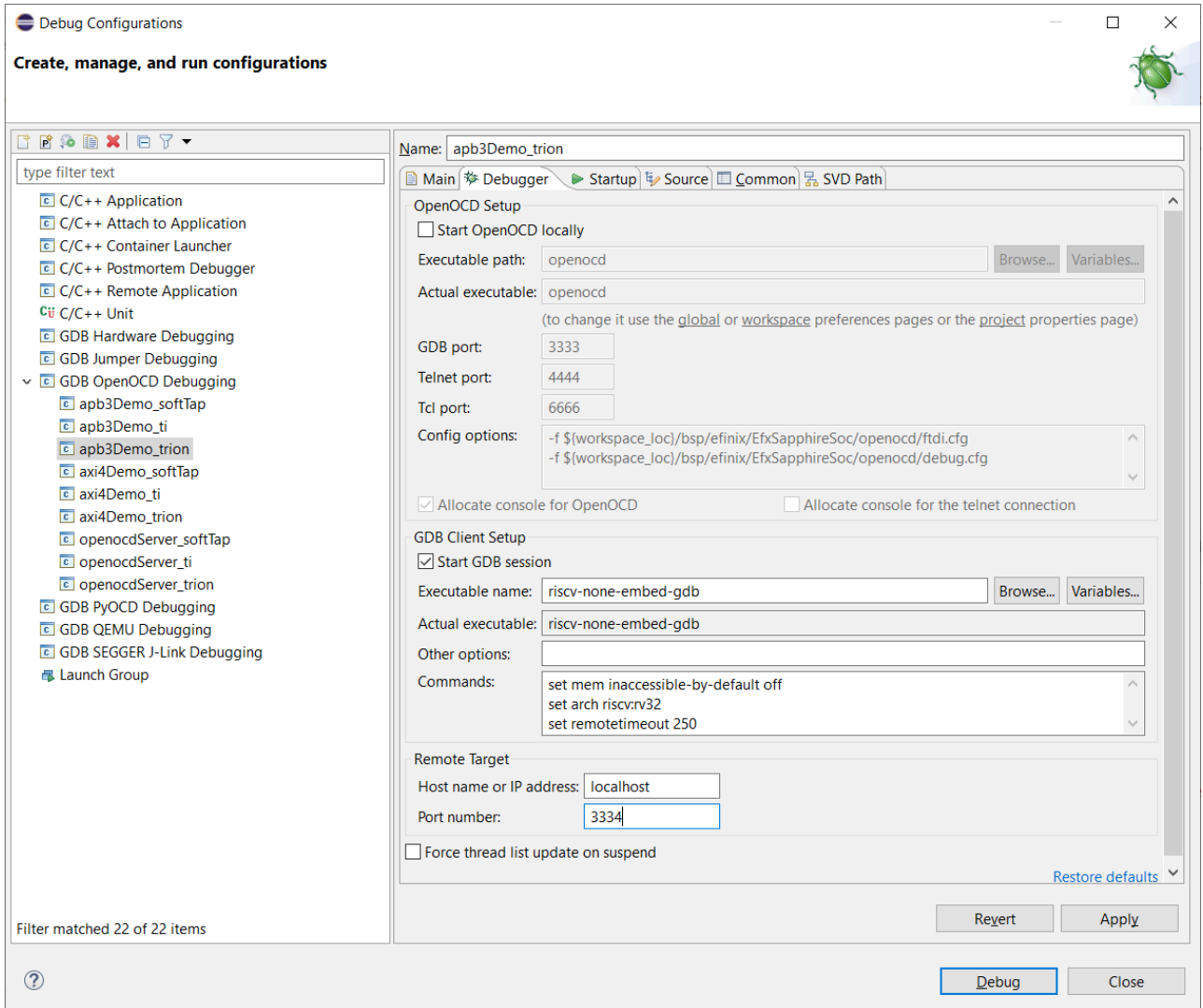
## Debug - Multiple Cores

By default, the OpenOCD debugger always targets the first core, core 0, when debugging. If your SoC has multiple cores, you can do standalone debugging with a core other than core 0. This debug method uses the `openocdServer` debug launch scripts, which are available in the `software/standalone/openocdServer` directory. The general procedure is:

1. Create an SoC with more than 1 core.
  2. Create a new project in Eclipse for your software code.
  3. Create a new project for the `openocdServer` files.
  4. Start the OpenOCD server.
    - a. Right-click `openocdServer` > `openocdServer_<family>.launch`.
    - b. Choose **Debug As** > > `openocdServer_<family>`.
  5. Modify the debug configuration for your application to use the OpenOCD server:
    - a. Right-click `<project folder>` > **Debug As** > **Debug Configurations**.
    - b. Choose **GDB OpenOCD Debugging** > `<launch script>` (e.g., `axiDemo_trion`).
    - c. Click the Debugger tab.
    - d. Turn off **Start OpenOCD locally**.
    - e. Under **Remote Target**, change the **Port number** for the core you are using (the default is 3333 for core 0).
- 3333: Core 0

- 3334: Core 1
  - 3335: Core 2
  - 3336: Core 3
6. Click **Debug**. Eclipse enters debug mode targeting the CPU that you specified with the port number.

**Figure 6: Modify Debug Configuration for another Core**



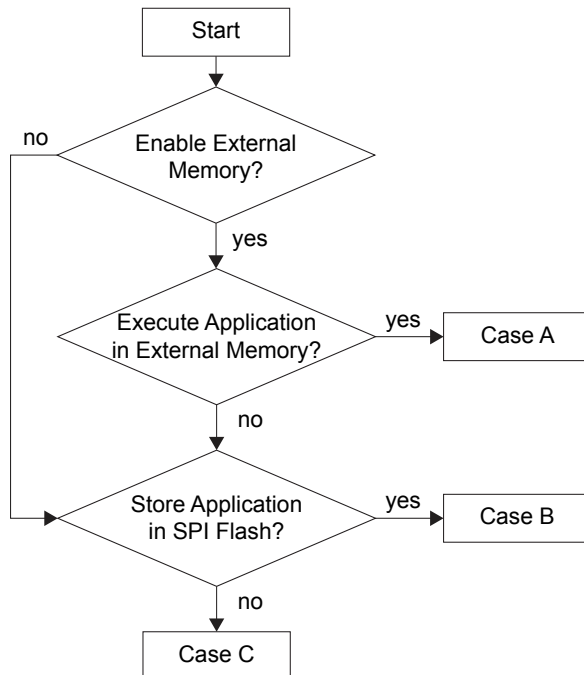
# Boot Sequence

## Contents:

- **Boot Sequence: Case A**
- **Boot Sequence: Case B**
- **Boot Sequence: Case C**
- **Booting Multiple Cores**

When the SoC loads and runs your software application, there are several boot sequence scenarios, depending on where the application is stored. With a bootloader, the embedded program loads the user binary from secondary memory to primary memory during boot up. If your software application is small enough (less than 4 KB), you can embed it in the on-chip RAM. It is recommended to follow the procedure in [Modify the Bootloader for building an embedded user application](#).

**Figure 7: Boot Sequence Flow Chart**



**Table 16: User Application**

Item	Case A	Case B	Case C
Bootloader needed?	Yes	Yes	No
Application storage	SPI flash	SPI flash	On-chip RAM
Execute location	External memory	On-chip RAM	On-chip RAM

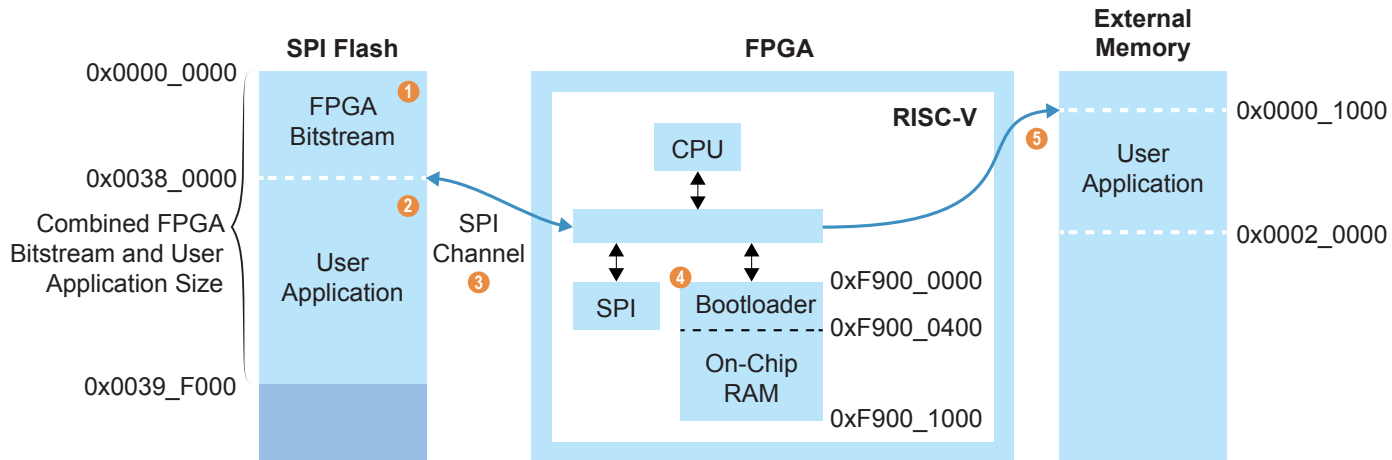
The following sections describe these cases in more detail.

The Sapphire SoC supports multiple cores; [Booting Multiple Cores](#) on page 34 describes the programming sequence.

## Boot Sequence: Case A

The following figure shows the interaction of the FPGA, SPI flash, and external memory during booting.

**Figure 8: Boot Sequence Diagram**



**Notes:**

1. The bitstream has a default start address of 0x0000\_0000 in the Efinity Programmer.
2. The application has a start address of 0x0038\_0000.
3. The bootloader reads the SPI flash data from 0x0038\_0000.
4. The CPU starts at 0xF900\_0000. The default On-Chip RAM size is 4 KB.
5. The bootloader copies the SPI flash data to external memory address 0x0000\_1000 and redirects the address to 0x0000\_1000 for execution.

The system starts from the PC's 0xF900\_0000, which is the starting address of the on-chip RAM. The bootloader, which reads a larger user application from the SPI flash, is embedded by default.

1. The PC starts at the system address 0xF900\_0000 of the on-chip RAM.
2. The bootloader starts reading the SPI Flash address 0x38\_0000 for the user application.
3. The bootloader writes the user application to external memory starting from system address 0x0000\_1000.
4. The bootloader finishes reading the user application from the SPI flash.
5. The PC jumps to system address 0x0000\_1000 and starts to execute the user application.
6. All accesses remain in the external memory space, which is malloc() by default (unless you specify the on-chip RAM space in the software code)



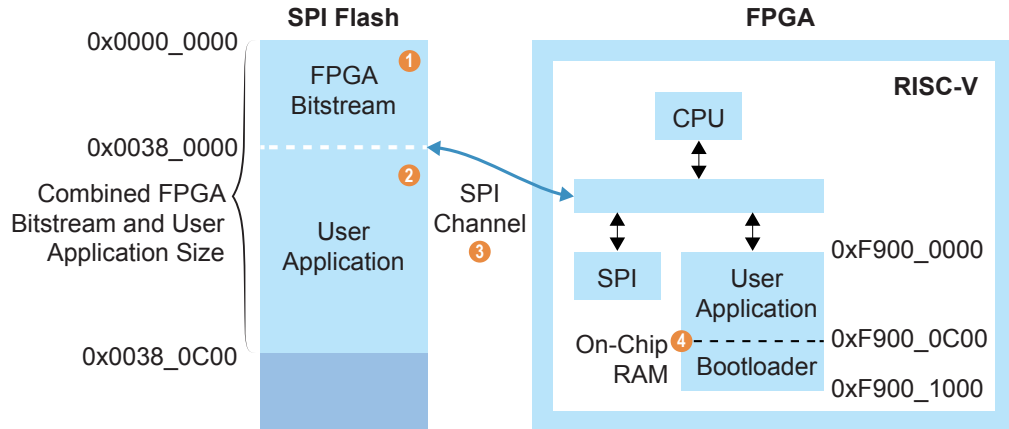
**Note:** For RISC-V SoC booting from a flash device, the GPIOs for the SPI signals (`system_spi_*`) should have the **Register Option** > **register** set in the Interface Designer. Refer to the IP Manager generated example design to see how you should set up the SPI channel.



## Boot Sequence: Case B

The following figure shows the interaction of the FPGA and SPI flash during booting.

Figure 9: Boot Sequence Diagram



**Notes:**

1. The bitstream has a default start address of 0x0000\_0000 in the Efinity Programmer.
2. The application has a start address of 0x0038\_0000.
3. The bootloader reads the SPI flash data from 0x0038\_0000.
4. The bootloader copies the SPI flash data to the On-Chip RAM 0xF900\_0000 and redirects the address to 0xF900\_0000 for execution.
5. The last 1 KB of On-Chip RAM is reserved for the bootloader.

The boot sequence is:

1. The PC starts at the system address 0xF900\_0000 of the on-chip RAM.
2. The bootloader starts reading the SPI Flash address 0x0038\_0000.
3. The bootloader writes the user application to On-Chip RAM starting from system address 0xF900\_0000.
4. The bootloader finishes reading the user application from the SPI flash.
5. The PC jumps to system address 0xF900\_0000 and starts to execute the user application.

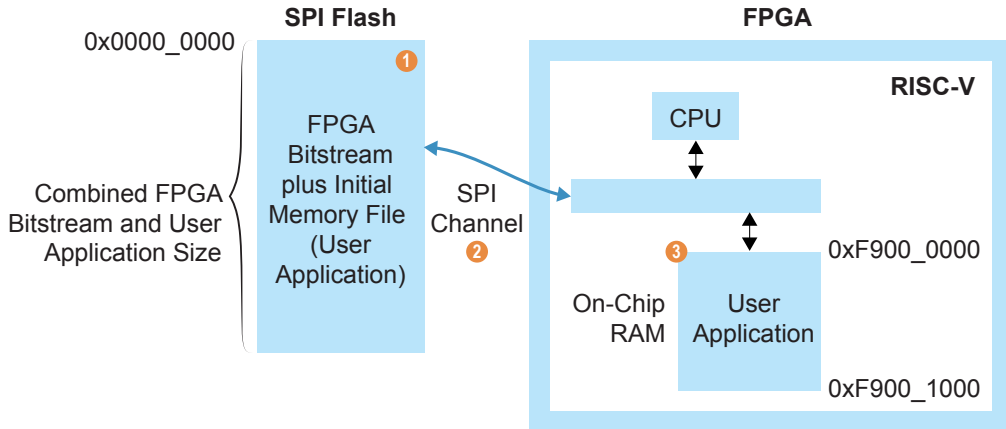


**Note:** For RISC-V SoC booting from a flash device, the GPIOs for the SPI signals (`system_spi_*`) should have the **Register Option** > **register** set in the Interface Designer. Refer to the IP Manager generated example design to see how you should set up the SPI channel.

## Boot Sequence: Case C

The following figure shows the interaction of the FPGA and SPI flash during booting.

Figure 10: Boot Sequence Diagram



### Notes:

1. The bitstream has a default start address of 0x0000\_0000 in the Efinity Programmer.
2. The application initial memory file is synthesized with the FPGA bitstream with address 0xF900\_0000 for the RISC-V application.
3. The CPU starts at 0xF900\_0000.

The boot sequence is:

1. The system starts from the PC's 0xF900\_0000, which is the starting address of the On-Chip RAM.
2. The user application is already compiled with the bitstream. It starts executing automatically from the FPGA's BRAM.

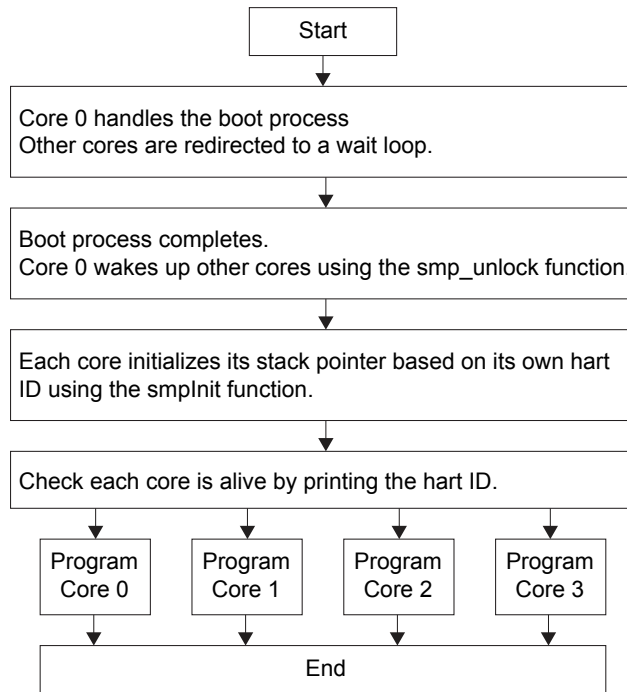
## Booting Multiple Cores

If you configure multiple cores, the Sapphire SoC has two or more identical processors that share a common main memory and the same set of hardware I/Os. The processors can execute programs simultaneously; one processor can access the processed data or result from other processors because they are connected in a shared backplane.

With symmetric multi-processing (SMP), you can share the workload across all of the processors, resulting in less time to get a result compared to using a single-core processor. Thus, SMP helps improve overall system throughput.

and performance. The following flow chart explains how to do multi-core programming in a baremetal environment.

**Figure 11: Boot Sequence for Multiple Cores**



**Table 17: SMP Helper Functions**

File	Description
<b>start.S</b>	Functions to lock and unlock additional cores directory. To enable these functions, you should include following flag in your makefile:  <code>CFLAGS+==--DSMP</code>
smpInit.S	Function to initialize the core.

These files are located in the **embedded\_sw/standalone/common/** directory.

Each core has a dedicated interrupt ID for the PLIC to determine which core will serve the external interrupts. Refer to **bsp/efinix/EfxSapphireSoc/include/soc.h** for the interrupt ID definitions for each core:

```

#define SYSTEM_PLIC_SYSTEM_CORES_0_EXTERNAL_INTERRUPT 0
#define SYSTEM_PLIC_SYSTEM_CORES_1_EXTERNAL_INTERRUPT 1
#define SYSTEM_PLIC_SYSTEM_CORES_2_EXTERNAL_INTERRUPT 2
#define SYSTEM_PLIC_SYSTEM_CORES_3_EXTERNAL_INTERRUPT 3
  
```

For the Clint timer interrupt, each core has a dedicated `MTIMECMP` register that you can use to set the trigger. You should provide the hart ID to the API to determine which core will receive the interrupt from the Clint timer. For example:

```

clint_setCmp(BSP_CLINT, TriggerValue, HartID);
  
```

Each core has a dedicated floating-point unit, Linux memory management unit, and custom instruction interface, if these features are enabled in IP Manager.

# Create Your Own RTL Design

## Contents:

- **Target another FPGA**
- **Target another 易灵思 Board**
- **Target Your Own Board**
- **Create a Custom AXI4 Slave Peripheral**
- **Create a Custom APB3 Peripheral**
- **Use another DDR DRAM Module (Trion Only)**
- **Use the I2C Interface for DDR Calibration**
- **Remove Unused Peripherals from the RTL Design**

After you have explored the Sapphire SoC using the included example Efinity® project, you can use these tips to modify the design for your own use.



**Note:** recommends that you use the provided example design project as a starting point instead of creating a new project.

## Target another FPGA

To change the design to target a different FPGA:

1. Edit the project to change the FPGA, package, and speed grade.
2. Update the interface design.
  - a. Open the Interface Designer. The software prompts you that a device change was detected. Click **Update Design**. The Interface Designer opens and shows invalid assignments in the Message Viewer.
  - b. Open the Resource Assigner.
  - c. Click the instance name in the Message Viewer. The software jumps to that assignment in the Resource Assigner. Pick a new resource and press enter.
  - d. Continue re-assigning pins until all assignments are valid.
  - e. Generate a constraint file and close the Interface Designer.
3. Compile your modified design.

## Target another 易灵思 Board

The Sapphire SoC BSP includes FTDI configuration files that specify the FTDI device VID and PID and board description for 易灵思 development boards.

When you configure the SoC, you can choose which 易灵思 board to target with the **Debug tab > Target OpenOCD** option. To target another board, change this option and re-generate the SoC files.

**Table 18: Provided FTDI Configuration Files**

File	Use for
ftdi.cfg	Trion development board
ftdi_ti.cfg	钛金系列 Ti60 F225 Development Board

If you do not want to re-generate the SoC, you can also change the target 易灵思 board manually by editing the `.cfg` file. However, if you want to target your own board, refer to [Target Your Own Board](#) on page 37 because the 易灵思 drivers specifically target the FTDI chips used on 易灵思 boards and your board will probably not have that chip.

To target a different 易灵思 development board manually, follow these steps with the development board attached to the computer:

1. Open the Efinity® Programmer.
2. Click the **Refresh USB Targets** button to display the board name in the **USB Target** drop-down list.
3. Make note of the board name.
4. In a text editor, open the `ftdi.cfg` or `ftdi_ti.cfg` file in the `embedded_sw/<SoC module>/bsp/efinix/EfxSapphireSoC/openocd` directory.
5. Change the `ftdi_device_desc` setting to match the board name. For example, use this code to change the name from Trion T120F324 Development Board to Trion T120F576 Development Board:

```
interface ftdi
ftdi_device_desc "Trion T120F324 Development Board"
#ftdi_device_desc "Trion T120F576 Development Board"
ftdi_vid_pid 0x0403 0x6010
```

6. Save the file.
7. Debug as usual in OpenOCD.

## Target Your Own Board

For your own board, you generally use an FTDI cable or another JTAG cable or module. You can also use an FTDI chip on your board.

### Using the FTDI C232HM-DDHSL-0 JTAG cable

The Sapphire SoC also includes a configuration file for the FTDI C232HM-DDHSL-0 JTAG cable (`c232hm_ddhsl_0.cfg`), which bridges between your computer's USB connector and the JTAG signals on the FPGA. If you use this cable to connect your board to your computer, you can simply use this configuration file instead of `ftdi.cfg` or `ftdi_ti.cfg`



**Note:** Refer to [Connect the FTDI Cable](#) on page 59 for instructions on using the cable.

### Using another JTAG Cable or Module

Generally, when debugging your own board you use a JTAG cable to connect your computer and the board. Therefore, you need to use the OpenOCD driver for that cable when debugging. OpenOCD includes a number of configuration files for standard hardware products. These files are located in the following directory:

**openocd/build-win64/share/openocd/scripts/interface** (Windows)

**openocd/build-x86\_64/share/openocd/scripts/interface** (Linux)

You can also write your own configuration file if desired.

Follow these instructions when debugging with your own board:

1. Connect your JTAG cable to the board and to your computer.
2. Copy the OpenOCD configuration file for your cable to the `bsp/efinix/EfxSapphireSoc/openocd` directory.
3. Follow the instructions for debugging, except target your configuration file instead of the `ftdi.cfg` (Trion) or `ftdi_ti.cfg` (钛金系列) file.

```
-f <path>/bsp/efinix/EfxSapphireSoc/openocd/<my cable>.cfg
```

## Using an FTDI Chip on your Board

When you configure the Sapphire SoC in the IP Configuration wizard, choose **Target OpenOCD > Custom**. Then, specify your board name. When you generate the SoC, the **ftdi.cfg** file is populated with your board name. Edit the file for your board's VID and PID.

## Create a Custom AXI4 Slave Peripheral

When you generate an example design for the Sapphire SoC, the IP Manager creates an example AXI4 peripheral and software code that you can use as a template to create your own peripheral. This example uses the simple dual-port RAM design to write to and read from the CPU through the AXI4 interface.

- Refer to the `axi4_slave` module in **design\_modules.v** in the **T120F324\_devkit** or **Ti60F225\_devkit** directory for the RTL design.
- Refer to **main.c** in the **embedded\_sw/<SoC module>/software/standalone/axiDemo/src** directory for the C code.

## Create a Custom APB3 Peripheral

When you generate an example design for the Sapphire SoC, the IP Manager creates an APB3 peripheral and software code that you can use as a template to create your own peripheral. This simple example shows how to implement an APB3 slave wrapper.

- Refer to the `apb3_slave` module in **design\_modules.v** in the **T120F324\_devkit** or **Ti60F225\_devkit** directory for the RTL design.
- Refer to **main.c** in the **embedded\_sw/<SoC module>/software/standalone/apb3Demo/src** directory for the C code.

## Use another DDR DRAM Module (Trion Only)

The Trion® T120 BGA324 Development Board has an LPDDR3 DRAM module with 256 Mbits x 16 bits supporting up to 4 Gb. If you want to target a different module, you need to update the DDR block in the Interface Designer to reflect the specifications for your module.



**Note:** Refer to the [Trion DDR DRAM Block User Guide](#) for more information on changing the DDR block.

## Use the I<sup>2</sup>C Interface for DDR Calibration

You can use the I<sup>2</sup>C interface to calibrate and reset the DDR DRAM interface on the Trion® T120 BGA324 Development Board or Trion® T120 BGA576 Development Board. If you want to use calibration:

1. In the Efinity Interface Designer, select the DDR block and turn on **Enable Control** in the Block Editor's **Control** tab. Save.
2. In your RTL design, connect the I<sup>2</sup>C interface to the DDR block's I<sup>2</sup>C interface. See the following example code:

```
// top level port
output ddr_inst1_CFG_SCL_IN,
output ddr_inst1_CFG_SDA_IN,
input  ddr_inst1_CFG_SDA_OEN,

// assignment
assign ddr_inst1_CFG_SDA_OEN_workaround = ddr_inst1_CFG_SDA_OEN;
```

```

assign ddr_inst1_CFG_SDA_IN = system_i2c_2_io_sda_write &&
    ddr_inst1_CFG_SDA_OEN_workaround;
assign ddr_inst1_CFG_SCL_IN = system_i2c_2_io_scl_write;

assign system_i2c_2_io_sda_read = system_i2c_2_io_sda_write &&
    ddr_inst1_CFG_SDA_OEN_workaround;
assign system_i2c_2_io_scl_read = system_i2c_2_io_scl_write;

// SoC connection
.system_i2c_2_io_sda_write      (system_i2c_2_io_sda_write),
.system_i2c_2_io_sda_read      (system_i2c_2_io_sda_read),
.system_i2c_2_io_scl_write     (system_i2c_2_io_scl_write),
.system_i2c_2_io_scl_read      (system_i2c_2_io_scl_read),

```

3. Connect the DDR control pins in the Interface Designer's DDR Block Editor.

## Remove Unused Peripherals from the RTL Design

The Sapphire SoC includes a variety of peripherals. If you do not want to use a peripheral, simply remove the signal name from within the parentheses () in the SapphireSoc SapphireSoc\_inst definition in the top-level Verilog HDL file. For example, the SoC instantiation has these signals:

```

.system_i2c_0_io_sda_write      (system_i2c_0_io_sda_write),
.system_i2c_0_io_sda_read      (system_i2c_0_io_sda_read),
.system_i2c_0_io_scl_write     (system_i2c_0_io_scl_write),
.system_i2c_0_io_scl_read      (system_i2c_0_io_scl_read),

```

To disable I<sup>2</sup>C 0, remove the signal name in () as shown below:

```

.system_i2c_0_io_sda_write      (),
.system_i2c_0_io_sda_read      (),
.system_i2c_0_io_scl_write     (),
.system_i2c_0_io_scl_read      (),

```

# Create Your Own Software

## Contents:

- [Deploying an Application Binary](#)
- [About the Board Specific Package](#)
- [Address Map](#)
- [Example Software](#)

Now that you have explored the methodology for designing with the Sapphire SoC, you can develop your own software applications.



**Note:** The Sapphire SoC does not currently support floating point calculations, such as sine and cosine.

## Deploying an Application Binary

During normal operation, your user binary application file (**.bin**) is stored in a SPI flash device. When the FPGA powers up, the Sapphire SoC copies your binary file from the SPI flash device to the DDR DRAM module, and then begins execution.

For debugging, you can load the user binary (**.elf**) directly into the Sapphire SoC using the OpenOCD Debugger. After loading, the binary executes immediately.



**Note:** The settings in the linker prevent user access to the address. This setting allows the embedded bootloader to work properly during a system reset after the user binary is executed but the FPGA is not reconfigured.

## Boot from a Flash Device

When the FPGA boots up, the Sapphire SoC copies your binary application file from a SPI flash device to the external memory module, and then begins execution. The SPI flash binary address starts at 0x0038\_0000.

To boot from a SPI flash device:

1. Power up your board. The FPGA loads the configuration image from the on-board flash device.
2. When configuration completes, the bootloader begins cloning a 124 KByte user binary file from the flash device at physical address 0x0038\_0000 to an off-chip DRAM logical address of 0x0000\_1000.



**Note:** It takes ~300 ms to clone a 124 KByte user binary (this is the default size).

3. The Sapphire SoC jumps to logical address 0x0000\_1000 to execute the user binary.



**Note:** Refer to [Boot Sequence](#) on page 31 for other possible boot scenarios.



## Boot from the OpenOCD Debugger

To boot from the OpenOCD debugger:

1. Power up your board. The FPGA loads the configuration image from the on-board flash device.
2. Launch Eclipse and set up the debug environment for your project.
3. The user binary is suspended on boot up. Click the Resume button to start the program.



**Note:** Refer to [Debug with the OpenOCD Debugger](#) on page 28 for complete instructions.

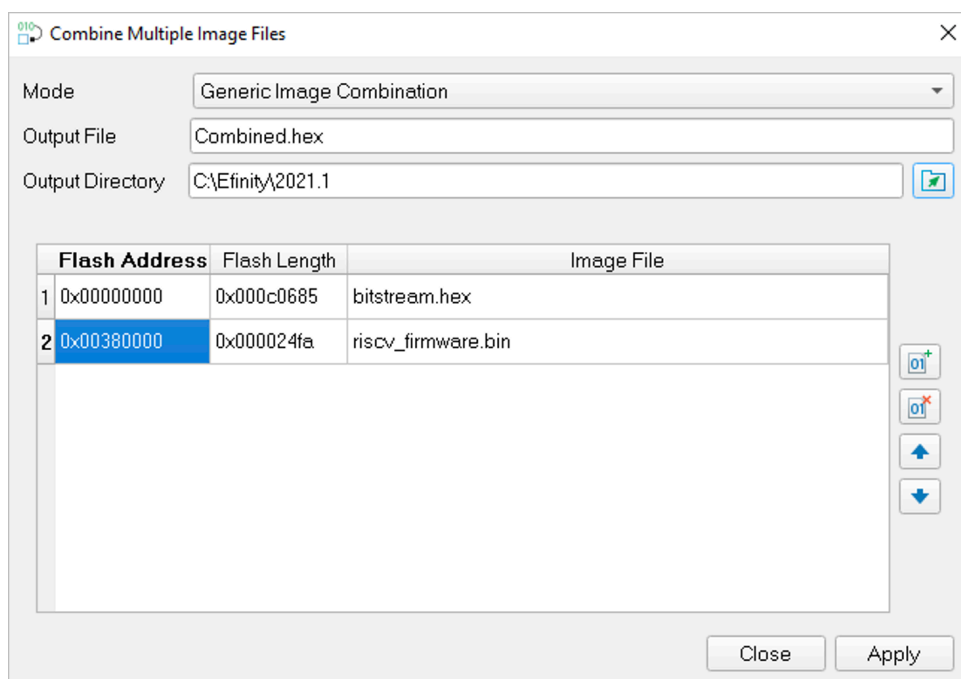
## Copy a User Binary to Flash (Efinity Programmer)

To boot from a flash device, you need to copy the application binary to the flash. If you want to store the binary in the same flash device that holds the FPGA bitstream, you can simply combine the two files and download the combined file to the flash device with the Efinity Programmer.

1. Open the Efinity Programmer.
2. Click the **Combine Multiple Image Files** button.
3. Choose **Mode** > **Generic Image Combination**.
4. Enter a name for the combined file in **Output File**.
5. Click the Add Image button. The **Open Image File** dialog box opens.
6. Browse to the bitstream file, select it, and click **Open**.
7. Click the Add Image button a second time.
8. Browse to the RISC-V application binary file, select it, and click **Open**.
9. Specify the **Flash Address** as follows:

File	Address
Bitstream	0x00000000
RISC-V application binary	0x00380000

**Figure 12: Combining a Bitstream and RISC-V Application Binary**



10. Click **Apply**. The software creates the combined **.hex** file in the specified **Output Directory** (the default is the project **outflow** directory).
11. Program the flash with the **.hex** file using **Programming Mode** > **SPI Active**.

## 12. Reset the FPGA or power cycle the board.



**Note:** You can also use two terminals to copy the application binary to flash. Refer to [Appendix: Copy a User Binary to the Flash Device \(2 Terminals\)](#) on page 100.

## About the Board Specific Package

The board specific package (BSP) defines the address map and aligns with the Sapphire SoC hardware address map. The BSP files are located in the **bsp/efinix/EfxSapphireSoC** subdirectory.

**Table 19: BSP Files**

File or Directory	Description
<b>app</b>	Files used by the example software and bootloader.
<b>include\soc.mk</b>	Supported instruction set.
<b>include\soc.h</b>	Defines the system frequency and address map.
<b>linker\default.ld</b>	Linker script for the main memory address and size.
<b>linker\default_i.ld</b>	Linker script for the internal memory address and size.
<b>linker\bootloader.ld</b>	Linker script for the bootloader address and size.
<b>openocd</b>	OpenOCD configuration files.

## Address Map

Because the address range might be updated, recommends that you always refer to the parameter name when referencing an address in firmware, not by the actual address. The parameter names and address mappings are defined in `/embedded_sw/<module>/bsp/efinix/EfxSapphireSoc/include/soc.h`.



**Note:** If you need to update the address map, use the IP Configuration wizard to change the addressing and then re-generate the SoC. Using this method keeps the software `soc.h` and FPGA netlist definitions aligned.

**Table 20: Default Address Map, Interrupt ID, and Cached Channels**

The AXI user slave channel is in a cacheless region (I/O) for compatibility with AXI-Lite.

Device	Parameter	Size	Interrupt ID	Region
Off-chip memory	SYSTEM_DDR_BMB	4 MB to 3.5 GB	–	Cache
GPIO 0	SYSTEM_GPIO_0_IO_CTRL	4 K	[0]: 12 [1]: 13	I/O
GPIO 1	SYSTEM_GPIO_1_IO_CTRL	4 K	[0]: 14 [1]: 15	I/O
I <sup>2</sup> C 0	SYSTEM_I2C_0_IO_CTRL	4 K	8	I/O
I <sup>2</sup> C 1	SYSTEM_I2C_1_IO_CTRL	4 K	9	I/O
I <sup>2</sup> C 2	SYSTEM_I2C_2_IO_CTRL	4 K	10	I/O
Core timer	SYSTEM_CLINT_CTRL	4 K	–	I/O
PLIC	SYSTEM_PLIC_CTRL	4 K	–	I/O
SPI master 0	SYSTEM_SPI_0_IO_CTRL	4 K	4	I/O
SPI master 1	SYSTEM_SPI_1_IO_CTRL	4 K	5	I/O
SPI master 2	SYSTEM_SPI_2_IO_CTRL	4 K	6	I/O
UART 0	SYSTEM_UART_0_IO_CTRL	4 K	1	I/O
UART 1	SYSTEM_UART_1_IO_CTRL	4 K	2	I/O
UART 2	SYSTEM_UART_2_IO_CTRL	4 K	3	I/O
User timer 0	SYSTEM_USER_TIMER_0_CTRL	4 K	19	I/O
User timer 1	SYSTEM_USER_TIMER_1_CTRL	4 K	20	I/O
User timer 2	SYSTEM_USER_TIMER_2_CTRL	4 K	21	I/O
User peripheral 0	IO_APB_SLAVE_0_CTRL	4 K to 1 MB	–	I/O
User peripheral 1	IO_APB_SLAVE_1_CTRL	4 K to 1 MB	–	I/O
User peripheral 2	IO_APB_SLAVE_2_CTRL	4 K to 1 MB	–	I/O
User peripheral 3	IO_APB_SLAVE_3_CTRL	4 K to 1 MB	–	I/O
User peripheral 4	IO_APB_SLAVE_4_CTRL	4 K to 1 MB	–	I/O
On-chip BRAM	SYSTEM_RAM_A_BMB	1 - 512 KB	–	Cache
AXI user slave	SYSTEM_AXI_A_BMB	1 K to 256 MB	–	I/O
External interrupt	–	–	[0]: 16 [1]: 17 [2]: 22 [3]: 23 [4]: 24 [5]: 25 [6]: 26 [7]: 27	I/O

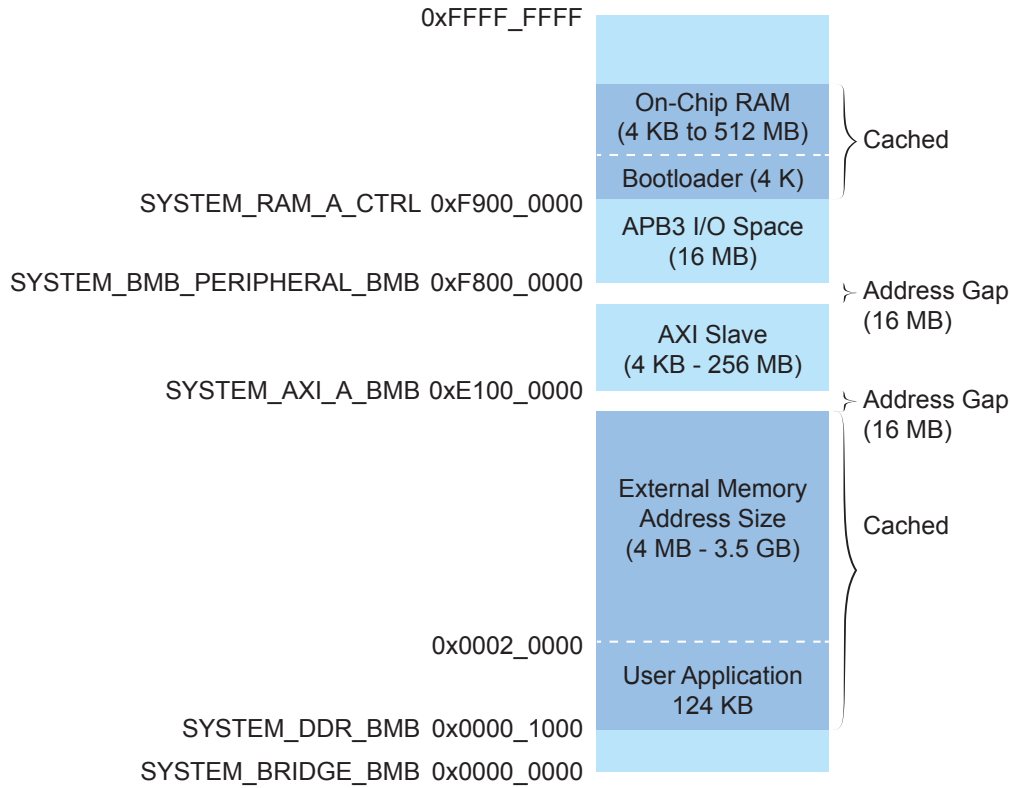
For the cached regions, the burst length is equivalent to an AXI burst length of 8. For the I/O region, the burst length is equivalent to an AXI burst length of 1. The AXI user slave is compatible with AXI-Lite by disconnecting unused outputs and driving a constant 1 to the input port.



**Note:** The RISC-V GCC compiler does not support user address spaces starting at 0x0000\_0000.

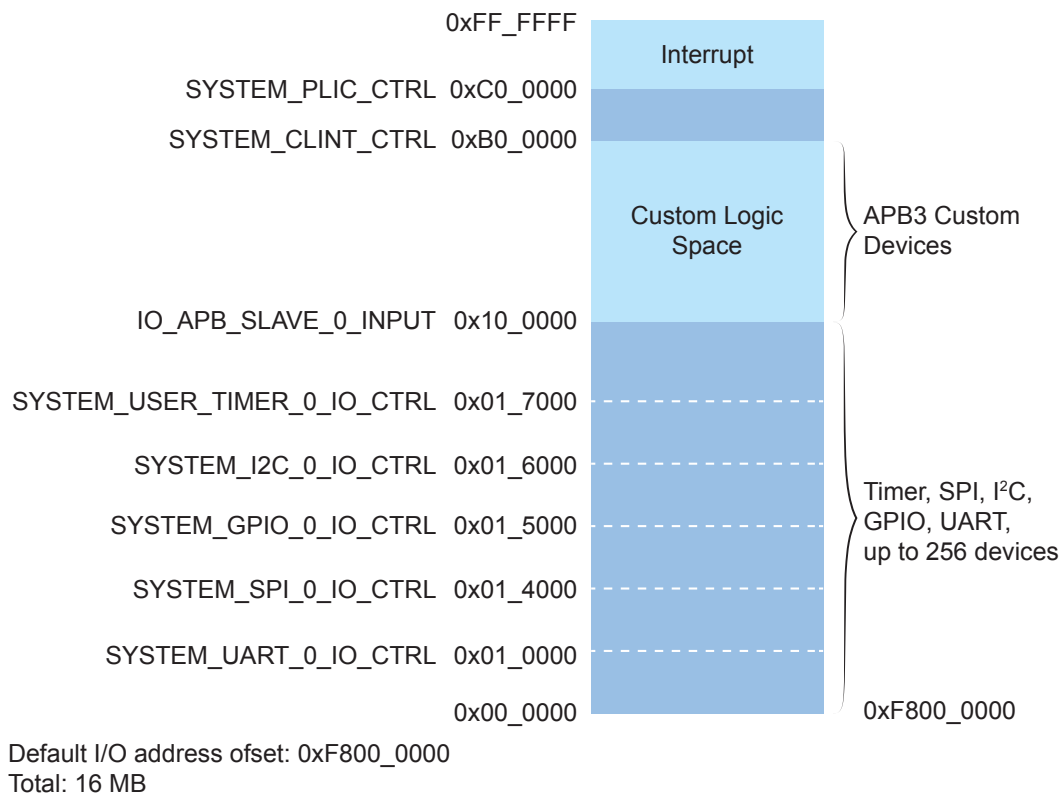
The following figure shows the default address map and the corresponding software parameters for modules in the memory space.

**Figure 13: Sapphire Memory Space**



The following figure shows the default address map and the corresponding software parameters for I/O.

**Figure 14: Sapphire I/O Space**



## Example Software

To help you get started writing software for the Sapphire, 易灵思 provides a variety of example software code that performs functions such as communicating through the UART, controlling GPIO interrupts, performing Dhrystone benchmarking, etc. Each example includes a **makefile** and **src** directory that contains the source code.



**Note:** Many of these examples display messages on a UART. Refer to the following topics for information on attaching a UART module and connecting to it in a terminal:

[Learn how to attach a UART module.](#)

[Learn how to open an Eclipse terminal and connect to the UART module.](#)

Table 21: Example Software Code

Directory	Description
<a href="#">apb3Demo</a>	This example shows how to implement an APB3 slave.
<a href="#">Axi4Demo</a>	This example illustrates how to implement a user AXI4 slave.
bootloader	This software is the bootloader for the system.
common	Provides linking for the makefiles.
<a href="#">compatibilityDemo</a>	This example shows how to migrate a software application from the Sapphire SoC v1.1 to v2.0 or higher.
<a href="#">coreTimerInterruptDemo</a>	This example shows how to use the clint timer with interrupt.
<a href="#">customInstructionDemo</a>	This example illustrates how to implement a custom instruction.
<a href="#">coremark</a>	This example is a synthetic computing benchmark program.
<a href="#">dhrystone</a>	This example is a synthetic computing benchmark program.
driver	This directory contains the system drivers for the peripherals (I <sup>2</sup> C, UART, SPI, etc.). Refer to <a href="#">API Reference</a> on page 75 for details.
<a href="#">fpuDemo</a>	This example shows how to use the floating-point unit.
<a href="#">gpioDemo</a>	This example shows how to control the GPIO and its interrupt.
<a href="#">i2cDemo</a>	This example shows how to connect to an MCP4725 digital-to-analog converter (DAC) using an I <sup>2</sup> C peripheral.
<a href="#">i2cSlaveDemo</a>	This example illustrates how an I <sup>2</sup> C slave communicates with the master.
<a href="#">memTest</a>	This code performs a memory address and data test.
<a href="#">nestedInterruptDemo</a>	This example shows how to set a higher priority to an interrupt routine, which allows the CPU to prioritize the task execution instead of other interrupts.
<a href="#">openocdServer</a>	This folder provides launch scripts for the openOCD server. Refer to <a href="#">Debug - Multiple Cores</a> on page 29 for details.
<a href="#">smpDemo</a>	This example illustrates how to use multiple cores to execute the Tiny encryption algorithm in parallel.
<a href="#">spiReadFlash</a>	This example shows how to read from a SPI flash device.
<a href="#">spiWriteFlash</a>	This example shows how to write to a SPI flash device.
<a href="#">spiDemo</a>	This code reads the device ID and JEDEC ID of a SPI flash device and echoes the characters on a UART.
<a href="#">uartEchoDemo</a>	This example shows how to use the UART.
<a href="#">uartInterruptDemo</a>	This example shows how to use a UART interrupt.
<a href="#">userInterruptDemo</a>	This example demonstrates user interrupts with UART messages.
<a href="#">userTimerDemo</a>	This example shows how to use the user timer with interrupt.

## Axi4Demo Design

This example (**axi4Demo** directory) performs a write and read test for the internal BRAM that is attached to an AXI interface. First, the software writes to the internal BRAM through the AXI interface. Next, it reads back the data and compares it to the expected value. If the data is correct, the software writes `Passed` to a UART terminal

The AXI bus interrupt pin triggers a software interrupt when write data to the AXI bus is `0xABCD`. The design displays these messages in a UART terminal:

```
axi4 slave demo !
Passed!
axi4 slave interrupt demo !
Entered AXI Interrupt Routine, Passed!
```

## apb3Demo

This simple software design illustrates how to use an APB3 slave peripheral.

The APB3 slave is attached to a pseudorandom number generator. When you run the application, the Sapphire SoC programs the APB3 slave to stop generating a new random number and reads the last random number generated. The test passes if the returned data is a non-zero value.

```
apb3 slave 0 demo !
Random number:
0xE1ECA84A
Passed!
```

## compatibilityDemo

This example (**compatibilityDemo** directory) shows how to migrate an application from the Sapphire Soc v1.1 to v2.0. To run your previously developed software applications on v2.0, include **compatibility.h** and **bsp.h** at the top of your code. These files map the v2.0 code and driver changes to the old SoC version.

This demo runs a machine timer with interrupt, which was available in v1.1. See [Migrating to the Sapphire SoC v2.0 from a Previous Version](#) on page 61 for additional migration details.

```
Hello world
BSP_MACHINE_TIMER 0
BSP_MACHINE_TIMER 1
BSP_MACHINE_TIMER 2
BSP_MACHINE_TIMER 3
```

## coreTimerInterruptDemo

This demo (**coreTimerInterruptDemo** directory) shows how to use the core timer and its interrupt function. This demo configures the core timer to generate an interrupt every 1 second. It prints messages on a terminal when the SoC is interrupted by the core timer.

```
core timer interrupt demo !
core timer interrupt 0
core timer interrupt 1
core timer interrupt 2
core timer interrupt 3
core timer interrupt 4
core timer interrupt 5
core timer interrupt 6
core timer interrupt 7
core timer interrupt 8
core timer interrupt 9
```

## coremark

This code (**coremark** directory) is a benchmark application to measure CPU performance. The final score is calculated based on the result of algorithm processing (e.g., list processing, matrix manipulation, state machine, and CRC). This application is configured to run 2,000 iterations with a runtime of approximately 20s.

When you run the application, it displays information similar to the following in a terminal:

```
coremark app is running, please wait...
2K performance run parameters for coremark.

CoreMark Size      : 666
Total ticks        : 1117963326
Total time (secs): 11.179633
Iterations/Sec     : 178.896745
Iterations         : 2000
Compiler version  : GCC8.3.0
Compiler flags    : -o3
Memory location   : STACK
seedcrc          : 0xe9f5
[0]crclist       : 0xe714
[0]crcmatrix     : 0x1fd7
[0]crcstate      : 0x8e3a
[0]crcfinal      : 0x4983

Correct operation validated. See README.md for run and reporting rules.

CoreMark 1.0 : 178.896745 / GCC8.3.0 / -o3
/ STACK
```

## customInstructionDemo

This demo (**customInstructionDemo** directory) shows how to use a custom instruction to accelerate the processing time of an algorithm. It demonstrates how performing an algorithm in hardware can provide significant acceleration vs, using software only. This demo uses the Tiny encryption algorithm to encrypt two 32-bit unsigned integers with a 128-bit key. The encryption is 1,024 cycles.

The demo first processes the algorithm with a custom instruction, and then to processes the same algorithm in software. Timestamps indicate how many clock cycles are needed to output results. If both methods output the same results, **Passed!** prints on a terminal. Otherwise, it prints **Failed**.

```
custom instruction demo !
please enable custom instruction plugin to run this demo

custom instruction processing clock cycles:1093
software processing clock cycles:36126

Passed!
```



## dhrystone Example

The Dhrystone example (**dhrystone** directory) is a classic benchmark for testing CPU performance. When you run this application, it performs dhrystone benchmark testing and displays messages and results on a UART terminal.

The following code shows example results:

```
Dhrystone Benchmark, Version C, Version 2.2
Program compiled without 'register' attribute
Using time(), HZ=12000000
Trying 500 runs through Dhrystone:
Final values of the variables used in the benchmark:
Int_Glob:      5
should be:    5
Bool_Glob:    1
should be:    1
...
Enum_Loc:     1
should be:    1
Str_1_Loc:    DHRYSTONE PROGRAM, 1'ST STRING
should be:    DHRYSTONE PROGRAM, 1'ST STRING
Str_2_Loc:    DHRYSTONE PROGRAM, 2'ND STRING
should be:    DHRYSTONE PROGRAM, 2'ND STRING

Microseconds for one run through Dhrystone: 40
Dhrystones per Second:                24472
User Time : 245176
Number Of Runs : 500
HZ : 12000000
DMIPS per Mhz:                        1.16
```

## fpuDemo

This example (**fpuDemo** directory) shows how to use the floating-point unit to perform various mathematical operations such as calculating sine, cosine, tangent, square root, and division. The demo records the number of clock cycles needed to complete each calculation. You can turn off the floating-point unit in the SoC's IP Configuration wizard to compare the FPU results with those obtained using the base I-extension.

The processing time to obtain the results are faster and the binary size is smaller when using the F/D-extension with floating-point unit.

```
fpu math demo !
rv32i (base-extension) is capable to perform floating-point calculation but
rv32i requires
more processing time and instruction to calculate the result enable fpu with d-
extension
will sharply improve processing time and decrease app binary size

sine processing clock cycles:879
cosine processing clock cycles:864
tangent processing clock cycles:1148
square root processing clock cycles:2171
division processing clock cycles:377

Input i (in rad): 0.5820
Sine result: 0.5497
Cosine result: 0.8353
Tangent result: 0.6581

Input x: 3828.1234
Square root result: 61.8718
Division result: 1040.5619
```

## gpioDemo

This example (**gpioDemo** directory) shows how to use the GPIO and its interrupt function. LED(s) on the development board blink for about 5 seconds and then

the application goes into interrupt mode. Toggle `system_gpio_0[0]` to let the GPIO go into the interrupt routine.

```
gpio 0 demo !
onboard LEDs blinking
gpio 0 interrupt demo !
Ti60 press and release onboard button sw6
T120 press and release onboard button sw7
gpio 0 interrupt routine
```

## i2cDemo Example

The I<sup>2</sup>C interrupt example (**i2cDemo** directory) provides example code for an I<sup>2</sup>C master writing data to and reading data from an off-chip MCP4725 device with interrupt. The Microchip MCP4725 device is a single channel, 12-bit, voltage output digital-to-analog converter (DAC) with an I<sup>2</sup>C interface.

The MCP4725 device is available on breakout boards from vendors such as Adafruit and SparkFun. You can connect the breakout board's SDA and SCL pins to a development board.

The code assumes that the I<sup>2</sup>C block is the only master on the bus, and it sends frames in blocks. When you run it, the application connects to the MCP4725 device and increases the DAC value. It also prints the message `Start` on a UART terminal.

In this example:

- `void trap()` traps entries on exceptions and interrupt events
- `void externalInterrupt()` triggers an interrupt event

## i2cSlaveDemo Design

This example illustrates how an I<sup>2</sup>C slave communicates with the master. It uses a 16-bit address and 16-bit data register for read and write. The slave is ready to access the master after the `Init Done` message displays on the UART.

## memTest Example

The memory test example (**memTest** directory) provides example code that performs a memory test on the external memory module and reports the results on a UART terminal. A successful test prints:

```
Memory test
Passed
```

If the memory test fails, the application prints `Failed at address <address>`.

## nestedInterruptDemo

This demonstration (**nestedInterruptDemo** directory) illustrates how to escalate from an interrupt routine and to execute higher priority routine. The program returns to the lower priority routine after the higher priority routine finished executing. This demo instantiates two user timers; timer 0 has higher priority than timer 1. Timer 0 interrupts the CPU multiple times. The CPU then executes the timer 0 interrupt routine in the middle of executing the timer 1 interrupt routine.

The demo outputs the following messages to a terminal:

```
T1S
T0S-HP
T0E-HP
T0S-HP
T0E-HP
T0S-HP
T0E-HP
T0S-HP
T0E-HP
T0S-HP
T0E-HP
T0S-HP
```

```

TOE-HP
TOS-HP
TOE-HP
TOS-HP
TOE-HP
TOS-HP
TOE-HP
TOS-HP
TOE-HP
TOS-HP
TOE-HP
TOS-HP
TOE-HP
TOS-HP
T1E

```

## openocdServer

This code (**openocdServer** directory) contains OpenOCD debug scripts to launch the OpenOCD server without the debugger. This script is intended for multi-core debug in standalone environment. Refer to **Debug - Multiple Cores** on page 29 for more details.

## smpDemo

This demo (**smpDemo** directory) illustrates how to use multiple cores to process multiple encryption at the same time in parallel. Each core is assigned an encryption algorithm with an input keys (each core has a different key). Core 0 prints the final encrypted values after the other cores complete the encryption. If a single core performed the encryption, it would take four times more clock cycles to complete the process.



**Note:** Step-by-step debugging is not available in multi-core symmetric processing mode.

The demo outputs the following messages to a terminal:

```

smpDemo with multiple cpu processing
synced!
processing clock cycles:24353

hart 0 encrypted output A:167C6CC6
hart 0 encrypted output B:465E6781
hart 1 encrypted output A:E39A3A87
hart 1 encrypted output B:70CF21D1
hart 2 encrypted output A:CBA365FF
hart 2 encrypted output B:003FDFA8
hart 3 encrypted output A:93D5278B
hart 3 encrypted output B:62F40A6F

```

## spiReadFlashDemo Example

The read flash example (**spiReadFlashDemo** directory) shows how to read data from the SPI flash device on the development board. The software reads 124K of data starting at address 0x380000, which is the default location of the user binary in the flash device. The application displays messages on a UART terminal:

```

Read Flash Start
Addr 00380000 : =FF
Addr 00380001 : =FF
Addr 00380002 : =FF
...
Addr 0039EFFF : =FF
Addr 0039EFFF : =FF
Read Flash End

```

## spiWriteFlashDemo Example

The read flash example (**spiWriteFlashDemo** directory) shows how to write data to the SPI flash device on the development board. The software writes data starting at address 0x380000, which is the default location of the user binary in the flash device. The application displays address and data messages on a UART terminal:

```
Write Flash Start
WR Addr 00380000 : =00
WR Addr 00380001 : =01
WR Addr 00380002 : =02
...
WR Addr 003800FD : =FD
WR Addr 003800FE : =FE
WR Addr 003800FF : =FF
Write Flash End
```

## spiDemo Example

The SPI example (**spiDemo** directory) provides example code for reading the device ID and JEDEC ID of the SPI flash device on the development board.

- The default base address map of the SPI flash master is 0xF801\_4000.
- The default `SCK` frequency is half of the SoC system clock frequency.
- The default base address of the UART is 0xF801\_0000 with a default baud rate of 115200.

The application displays the results on a UART terminal. It continues to print to the terminal until you suspend or stop the application.

```
spi 0 demo !
Device ID : 17
CMD 0x9F : EF4018
CMD 0x9F : EF4018
...
```

## uartEchoDemo

This demo (**uartEchoDemo** directory) shows how to use the UART to print messages on a terminal. The characters you type on a keyboard are echoed back to the terminal from the SoC and printed on the terminal.

```
uart echo demo !
start typing on terminal to send character...
echo character:l
echo character:k
echo character:m
```

## UartInterruptDemo Example

The `UartInterruptDemo` example shows how to use a UART interrupt to indicate task completion when sending or receiving data over a UART. The UART can trigger a interrupt when data is available in the UART receiver FIFO or when the UART transmitter FIFO is empty. In this example, when you type a character in a UART terminal, the data goes to the UART receiver and fills up FIFO buffer. This action interrupts the processor and forces the processor to execute an interrupt/priority routine that allows the UART to read from the buffer and send a message back to the terminal.

The application displays messages on a UART terminal:

```
RX FIFO not empty interrupt
RX FIFO not empty interrupt
RX FIFO not empty interrupt
```

## userInterruptDemo Example

This demo (**userInterruptDemo** directory) shows how to handle a user interrupt that accepts an interrupt signal from user logic. In this demo, ten seconds after the Sapphire SoC comes out of reset, the user interrupt gets a trigger from the external module. Operation jumps from the main routine to the interrupt routine. When the interrupt code finishes executing, it jumps back to the main routine.

The application displays the messages on a UART terminal:

```
User Interrupt Demo, waiting for user interrupt...
Entered User Interrupt A Routine
```

## userTimerDemo

This demo (**userTimerDemo** directory) shows how use the user timer and its interrupt function. This demo configures the user timer and its prescaler setting, which you use to further scale down the frequency used by the timer's counter. When the timer's counter reaches the targeted tick value, it generates an interrupt signal to interrupt the controller to let the SoC jump from the main routine to the interrupt routine.

```
user timer 0 demo !
user timer 0 interrupt routine
user timer 0 interrupt routine
user timer 0 interrupt routine
user timer 0 interrupt routine
```

## FreeRTOS Examples

The Sapphire SoC supports the popular FreeRTOS real-time operating system, and includes example software projects targeting the RTOS. For more details on using FreeRTOS, go to their web site at <https://www.freertos.org>.

### Download the FreeRTOS

The freeRTOS examples require you to download FreeRTOS.

1. Download the FreeRTOS zip file from <https://www.freertos.org>. recommends using FreeRTOS v10.4.1.
2. Unzip the files into the **embedded\_sw/<SoC module>/software** directory.

After you have downloaded the FreeRTOS, you use the software projects in the same manner as the other example software.

### freertosDemo

This example shows how the FreeRTOS scheduler handles two program executions using task and queue allocation. Generally, the FreeRTOS queue is used as a thread FIFO buffer and for intertask communication. This example creates two tasks and one queue; the queue sends and receives traffic. The receive traffic (or receive queue) blocks the program execution until it receives a matching value from the send traffic (or send queue).

Tasks in the send queue sit in a loop that blocks execution for 1,000 milliseconds before sending the value 100 to the receive queue. Once the value is sent, the task loops, i.e., blocks for another 1,000 milliseconds.

When the receive queue receives the value 100, it begins executing its task, which sends the message `Blink` to the UART peripheral and toggles an LED on the development board.

```
Hello world, this is FreeRTOS
Blink
Blink
Blink
```

## freertosDemo2

This example shows how FreeRTOS scheduler handles two program executions using a binary semaphore. The semaphore holds the hardware resource until one of the tasks execute, which then releases it to the next task. If the hardware resource is running a task, no other task can use that resource. In this example, two tasks use the same UART peripheral to print messages. By using a semaphore, the two tasks have alternate access to the UART peripheral.

```
Hello world, this is FreeRTOS
Inside uart task 1 loop
Inside uart task 2 loop
Inside uart task 1 loop
Inside uart task 2 loop
Inside uart task 1 loop
Inside uart task 2 loop
```

## freertosUartInterruptDemo Example

This demo illustrates the same operation as the [uartInterruptDemo](#), but it executes using the FreeRTOS software framework. The tasks and queues are allocated to an interrupt routine so that the FreeRTOS scheduler can control the execution with the given priority.

The application displays messages on a UART terminal:

```
Hello world
RX FIFO not empty interrupt
RX FIFO not empty interrupt
RX FIFO not empty interrupt
```

# Using a UART Module

## Contents:

- [Using the On-board UART \(\)](#)
- [Set Up a USB-to-UART Module \(Trion\)](#)
- [Open a Terminal](#)
- [Enable Telnet on Windows](#)

A number of the software examples display messages on a UART terminal. If you are using a development board, you can simply connect a USB cable to the board and to your computer. For Trion development boards, you need to use a USB-to-UART converter.

## Using the On-board UART ()

The 钛金系列 Ti60 F225 Development Board has a USB-to-UART converter connected to the Ti60's GPIO\_L\_01 and GPIO\_L\_02 pins. To use the UART, simply connect a USB cable to the FTDI USB connector on the 钛金系列 Ti60 F225 Development Board and to your computer.



**Note:** The board has an FTDI chip to bridge communication from the USB connector. FTDI interface 2 communicates with the on-board UART. You do not need to install a driver for this interface because when you connect the 钛金系列 Ti60 F225 Development Board to your computer, Windows automatically installs a driver for it.

### Finding the COM Port (Windows)

1. Type Device Manager in the Windows search box.
2. Expand **Ports (COM & LPT)** to find out which COM port Windows assigned to the UART module. You should see 2 devices listed as USB Serial Port (COMn) where n is the assigned port number. Note the COM number for the first device; that is the UART.

### Finding the COM Port (Linux)

In a terminal, type the command:

```
ls /dev/ttyUSB*
```

The terminal displays a list of attached devices.

```
/dev/ttyUSB0 /dev/ttyUSB1 /dev/ttyUSB2 /dev/ttyUSB3
```

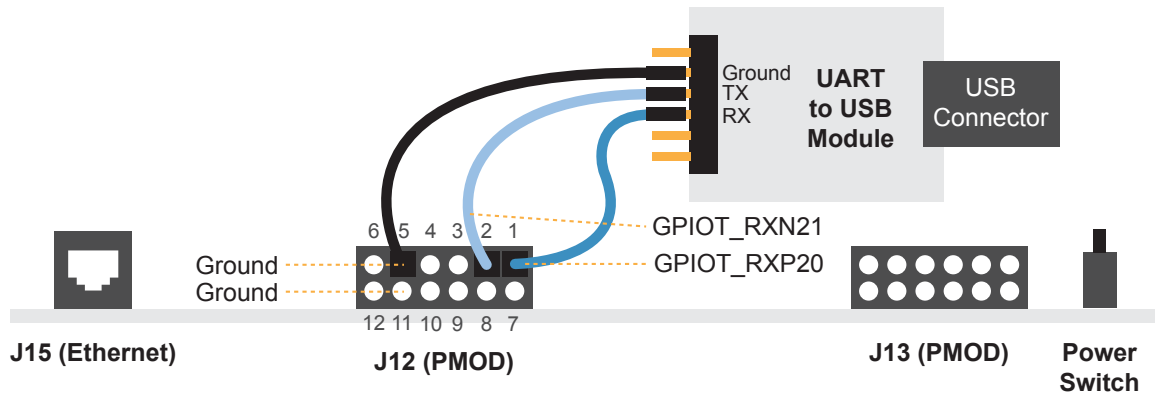
The UART is /dev/ttyUSB2.

## Set Up a USB-to-UART Module (Trion)

The Trion® T120 BGA324 Development Board does not have a USB-to-UART converter, therefore, you need to use a separate USB-to-UART converter module.

A number of modules are available from various vendors; any USB-to-UART module should work.

**Figure 15: Connect the UART Module to PMOD Connector J12**



1. Connect the UART module to the PMOD port J12
  - RX—GPIOT\_RXP20, which is pin 1 on PMOD J12
  - TX—GPIOT\_RXN21, which is pin 2 on PMOD J12
  - Ground—Use ground pin 5 or 11 on PMOD J12.
2. Plug the UART module into a USB port on your computer. The driver should install automatically if needed.

### Finding the COM Port (Windows)

1. Type Device Manager in the Windows search box.
2. Expand **Ports (COM & LPT)** to find out which COM port Windows assigned to the UART module; it is listed as USB Serial Port (COMn) where n is the assigned port number. Note the COM number.

### Finding the COM Port (Linux)

In a terminal, type the command:

```
dmesg | grep ttyUSB
```

The terminal displays a series of messages about the attached devices.

```
usb <number>: <adapter> now attached to ttyUSB<number>
```

There are many USB-to-UART converter modules on the market. Some use an FTDI chip which displays a message similar to:

```
usb 3-3: FTDI USB Serial Device converter now attached to ttyUSB0
```

However, the Trion® T120 BGA324 Development Board also has an FTDI chip and gives the same message. So if you have both the UART module and the board attached at the same time, you may receive three messages similar to:

```
usb 3-3: FTDI USB Serial Device converter now attached to ttyUSB0
usb 3-2: FTDI USB Serial Device converter now attached to ttyUSB1
usb 3-2: FTDI USB Serial Device converter now attached to ttyUSB2
```

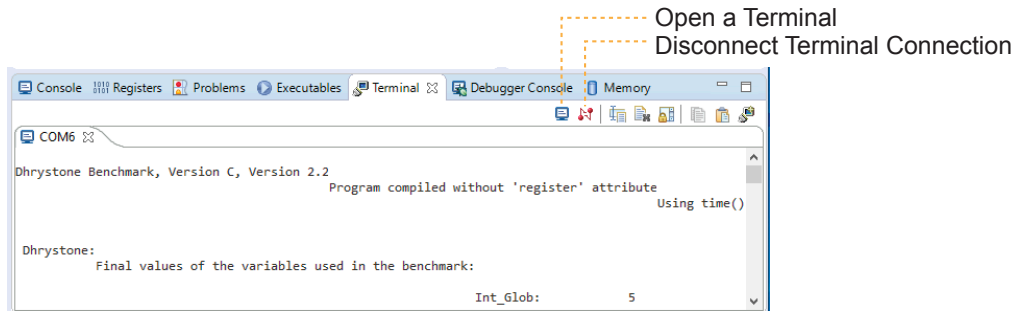
In this case the second 2 lines (marked by `usb 3-2`) are the development board and the first line (`usb 3-3`) is the UART module.

## Open a Terminal

You can use any terminal program, such as Putty, termite, or the built-in Eclipse terminal, to connect to the UART. These instructions explain how to use the Eclipse terminal; the others are similar.



1. In Eclipse, choose **Window > Show View > Terminal**. The Terminal tab opens.



2. Click the Open a Terminal button.
3. In the **Launch Terminal** dialog box, enter these settings:

Option	Setting
Choose terminal	Serial Terminal
Serial port	COMn (Windows) or ttyUSBn (Linux) where n is the port number for your UART module.
Baud rate	115200
Data size	8
Parity	None
Stop bits	1
Encoding	Default (ISO-8859-1)

4. Click **OK**. The terminal opens a connection to the UART.
5. Run your application. Messages are printed in the terminal.
6. When you are finished using the application, click the Disconnect Terminal Connection button.

## Enable Telnet on Windows

Windows does not have telnet turned on by default. Follow these instructions to enable it:

1. Type `telnet` in the Windows search box.
2. Click **Turn Windows features on or off (Control panel)**. The **Windows Features** dialog box opens.
3. Scroll down to **Telnet Client** and click the checkbox.
4. Click **OK**. Windows enables telnet.
5. Click **Close**.

# Using a Soft JTAG Core for Example Designs

## Contents:

- **Connect the FTDI Cable**

The Efinity<sup>®</sup> Debugger uses the hard JTAG TAP interface. Out of the box, the Sapphire SoC example design also uses the hard JTAG TAP interface for OpenOCD. If you try to use the same USB connection to the development board for both applications at the same time, they will conflict. To solve this problem, you use a soft JTAG block to handle the OpenOCD JTAG communication. With this method, you use an FTDI chip cable to connect the board to your computer (the Efinity<sup>®</sup> Debugger uses the USB cable).

The simplest way to implement a soft JTAG interface is to use the IP Manager to output an example design that enables the soft JTAG interface. The IP Manager automatically connects the soft JTAG pins to PMOD J12 when you turn on the Soft Debug Tap option.



**Note:** recommends you use the C232HM-DDHSL-0 FTDI chip cable rather than a JTAG mini-module because the software generated by the IP Manager includes the debug configuration file for the cable.

## Connect the FTDI Cable

When you turn on the Enable Soft JTAG TAP option in the IP Configuration wizard, the example design assigns the JTAG pins to resources in the interface design. Use the following figures to connect the cable to the JTAG pins.



**Note:** If you have not already done so, install the driver for the FTDI cable as described in [Installing USB Drivers](#) on page 20.

### Connecting to the 钛金系列 Ti60 F225 Development Board

Figure 16: Connecting the C232HM-DDHSL-0 Cable

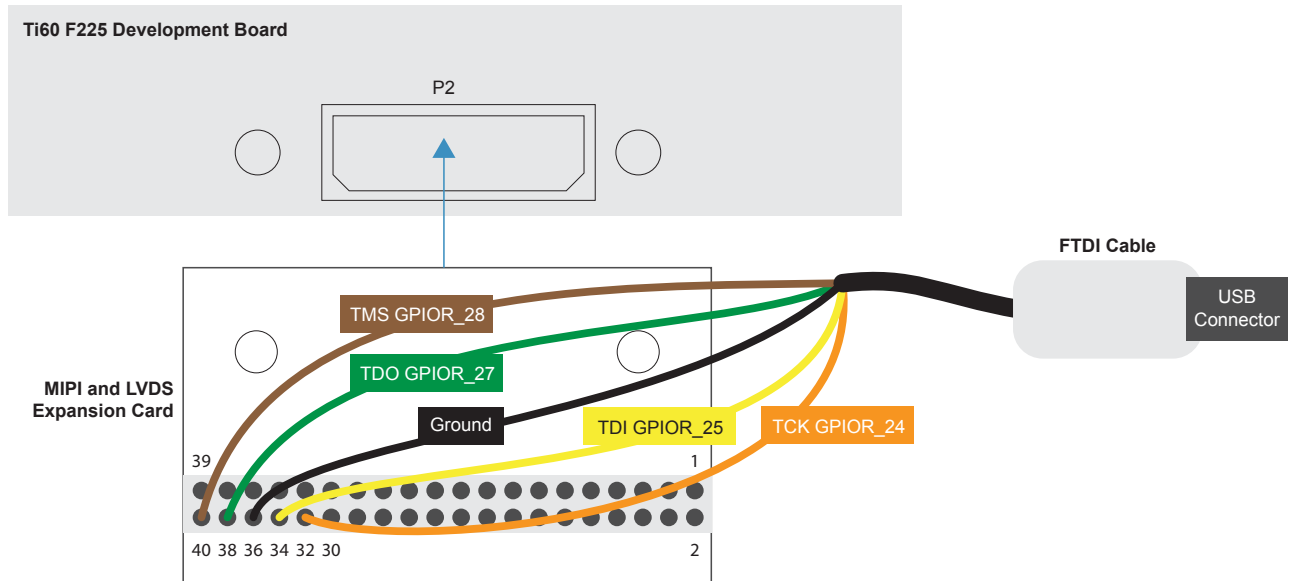


Table 22: FDTI to Daughter Card Connections

Port	Resource	MIPI and LVDS Expansion Daughter Card (P2) Pin
TCK	GPIOR_24	32
TDI	GPIOR_25	34
TDO	GPIOR_27	38
TMS	GPIOR_28	40
GND	-	36

## Connecting to the Trion® T120 BGA324 Development Board

Figure 17: Connecting the C232HM-DDHSL-0 Cable

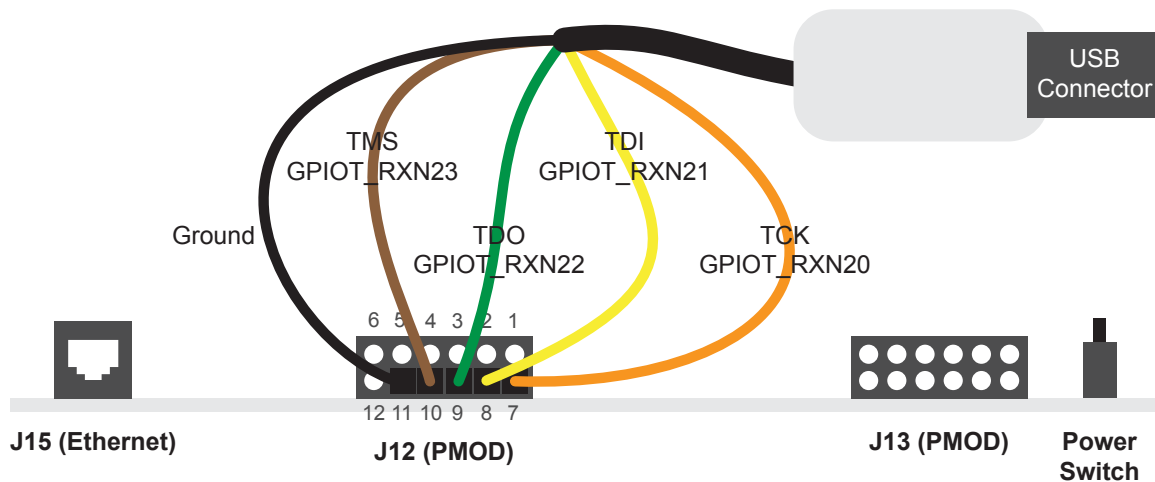


Table 23: FDTI to PMOD Connections

Port	Resource	PMOD (J12) Pin
TCK	GPIOT_RXN20	7
TDI	GPIOT_RXN21	8
TDO	GPIOT_RXN22	9
TMS	GPIOT_RXN23	10
GND	–	5 or 11

## Debugging in Eclipse

1. Open your Eclipse project.
2. Run or debug the software with the OpenOCD debugger using the **default\_softTap** launch configuration.
3. Refer to **Debug with the OpenOCD Debugger** on page 28 for complete instructions.
4. Open the Debugger to perform hardware debugging.

# Migrating to the Sapphire SoC

## Contents:

- [Migrating to the Sapphire SoC v2.0 from a Previous Version](#)
- [Migrating Ruby, Jade, and Opal to the Sapphire SoC](#)

## Migrating to the Sapphire SoC v2.0 from a Previous Version

The Sapphire SoC v2.0 available in the Efinity software v2021.2 has many new features compared to previous versions, and the **IP Configuration** wizard and drivers are updated to reflect these new features. Therefore, you cannot automatically migrate an existing design to v2.0. If you want to migrate to v2.0, the following sections provide some guidelines.



**Note:** recommends that you use v2.0 for all new designs.

### IP Configuration Wizard

The configuration options for the Sapphire SoC v2.0 support new features such as more configurable caching, FPU, MMU, and a peripheral clock. Use the following settings to create a v2.0 SoC that is similar to previous versions.

Table 24: IP Configuration Settings

Tab	Option	Setting	Notes
SOC	Peripheral Clock	DISABLE	In v1.x, the APB3 peripherals are driven by the system clock. In v2.0, set this option to DISABLE.
	Custom Instruction	DISABLE	Not supported in v1.x
	Linux Memory Management Unit	DISABLE	
	Floating-point Unit	DISABLE	
	Atomic extension	DISABLE	
Cache/Memory	Data Cache Way	1	In v1.0, the SoC has a fixed I\$ and D\$ cache way (1 way) and size (4 KB). In v1.1, the wizard supports 1 ways and 1 KB, 2 KB, 4 KB, 8 KB, 16 KB, or 32 KB
	Data Cache Size	4 KB (v1.0) 1 KB, 2 KB, 4 KB, 8 KB, 16 KB, or 32 KB (v1.1)	
	Instruction Cache Way	1	
	Instruction Cache Size	4 KB (v1.0) 1 KB, 2 KB, 4 KB, 8 KB, 16 KB, or 32 KB (v1.1)	
	External Memory AXI3 Interface	DISABLE (v1.0) ENABLE or DISABLE (v1.1)	In v1.x, an external memory interface is not supported with a cacheless CPU
	On-Chip RAM Size	1 KB, 2 KB, 4 KB, 8 KB, 16 KB, 32 KB, 64 KB, 128 KB, 256 KB, or 512 KB	The v1.x SoC supports fewer sizes for On-Chip RAM. Choose one of these options in v2.0 for compatibility.

Tab	Option	Setting	Notes
Debug	Target OpenOCD	See v2.0 options	This option is not supported in v1.0. This option is the same in v1.1 and v2.0.
	Custom Target OpenOCD	See v2.0 options	This option is not supported in v1.0. This option is the same in v1.1 and v2.0.
	OpenOCD Debug Mode	Any	This option is not supported in v1.x. However, you can choose either option because it sets Eclipse environment variables and does not affect the SoC.

### Debug Configuration

The **default\_softTap** debug configuration file is updated in v2.0. Therefore, you cannot use the **default\_softTap** generated with v1.1 with v2.0. If you are using v2.0, you need to remove the old **default\_softTap** debug configuration from your Eclipse project and import the v2.0 one. See **Appendix: Import the Debug Configuration** on page 99 for instructions.

### Application Software

In v2.0, there are several changes to the generated embedded software:

- **SoC device names and definitions**—The device names and definitions in the **soc.h** file are updated. The v2.0 embedded software includes the file **compability.h**, which converts the naming from v1.x to v2.0. Include **compability.h** at the top of your software application code to convert the names. You can also reference the example **compabilityDemo** in the **/embedded\_sw/<module name>/software/standalone** folder.
- **Core timer driver**—The machine timer is replaced with the Clint timer, which is a native CPU timer. The software driver code is slightly different than the code for the machine timer. To convert from the machine timer function to the Clint timer function, include the **compability.h** and **bsp.h** at the top of your software application code.



**Note:** **compabilityDemo** on page 47 provides an example of how to use **compability.h** and **bsp.h**.

## Migrating Ruby, Jade, and Opal to the Sapphire SoC

The Ruby, Jade, and Opal SoCs are end of life in the Efinity software v2022.1. The following sections provide the parameters you should set in the Sapphire SoC IP Configuration wizard to get the same functionality as Ruby, Jade, or Opal.

### Ruby Configuration

Parameter		Setting	Address
SOC	Core Number	1	
	Frequency	Configurable	
	Peripheral Clock	No	
	Cache	Yes	
	Custom Instruction	No	
	Linux Memory Management Unit	No	
	Floating-point unit	No	
	Atomic Extension	No	
Cache/Memory	Data Cache Way	1	
	Data Cache Size	4KB	
	Instruction Cache Way	1	
	Instruction Cache Size	4KB	
	External Memory Interface	Yes	
	AXI Interface Type	AXI3	
	External Memory Data Width	128	
	External Memory Address Size	3.5GB	
	On-Chip RAM Size	Configurable	0xf9000000
	Custom On-Chip RAM Application	No	
	Debug	Soft Debug Tap	Configurable
FPGA Tap Port		Configurable	
Target Board		Configurable	
Application Region Size		-	
Application Stack Size		-	
Application Debug Mode		-	
UART	UART0	Yes	0xf8010000
	UART0 Interrupt ID	1	
	UART1	Yes	0xf8011000
	UART1 Interrupt ID	2	
	UART2	No	
	UART2 Interrupt ID	-	
SPI	SPI0	Yes	0xf8014000
	SPI0 Interrupt ID	4	
	SPI1	Yes	0xf8015000

Parameter		Setting	Address
	SPI1 Interrupt ID	5	
	SPI2	Yes	0xf8016000
	SPI2 Interrupt ID	6	
I2C	I2C0	Yes	0xf8018000
	I2C0 Interrupt ID	8	
	I2C1	Yes	0xf8019000
	I2C1 Interrupt ID	9	
	I2C2	Yes	0xf801A0000
	I2C2 Interrupt ID	10	
GPIO	GPIO0	Yes	0xf8000000
	GPIO0 Width	16	
	GPIO0 Interrupt ID	12, 13	
	GPIO1	No	
	GPIO1 Width	-	
	GPIO1 Interrupt ID	-	
APB3	APB3 Slave Size	64KB	
	APB0	Yes	0xf8800000
	APB1	Yes	0xf8810000
	APB2	No	
	APB3	No	
	APB4	No	
AXI4	AXI Slave	Yes	0xfa000000
	AXI Slave Size	16MB	
	AXI Master 0	Yes	
	AXI Master 0 Data Width	32	
	AXI Master 1	-	
	AXI Master 1 Data Width	-	
User Interrupt	User Interrupt A	Yes	
	User Interrupt A ID	25	
	User Interrupt B	No	
	User Interrupt B ID	-	
	User Interrupt C	No	
	User Interrupt C ID	-	
	User Interrupt D	No	
	User Interrupt D ID	-	
	User Interrupt E	No	
	User Interrupt E ID	-	
	User Interrupt F	No	
	User Interrupt F ID	-	
	User Interrupt G	No	
	User Interrupt G ID	-	
	User Interrupt H	No	
	User Interrupt H ID	-	



Parameter		Setting	Address
User Timer	User Timer 0	No	
	User Timer 0 Counter Width	-	
	User Timer 0 Prescaler Width	-	
	User Timer 0 Interrupt ID	-	
	User Timer 1	No	
	User Timer 1 Counter Width	-	
	User Timer 1 Prescaler Width	-	
	User Timer 1 Interrupt ID	-	
	User Timer 2	No	
	User Timer 2 Counter Width	-	
	User Timer 2 Prescaler Width	-	
	User Timer 2 Interrupt ID	-	

### Jade Configuration

Parameter		Setting	Address
SOC	Core Number	1	
	Frequency	Configurable	
	Peripheral Clock	No	
	Cache	Yes	
	Custom Instruction	No	
	Linux Memory Management Unit	No	
	Floating-point unit	No	
	Atomic Extension	No	
Cache/Memory	Data Cache Way	1	
	Data Cache Size	4KB	
	Instruction Cache Way	1	
	Instruction Cache Size	4KB	
	External Memory Interface	No	
	AXI Interface Type	-	
	External Memory Data Width	-	
	External Memory Address Size	-	
	On-Chip RAM Size	Configurable	0xf9000000
	Custom On-Chip RAM Application	No	
	Debug	Soft Debug Tap	Configurable
FPGA Tap Port		Configurable	
Target Board		Configurable	

Parameter		Setting	Address
	Application Region Size	-	
	Application Stack Size	-	
	Application Debug Mode	-	
UART	UART0	Yes	0xf8010000
	UART0 Interrupt ID	1	
	UART1	No	
	UART1 Interrupt ID	-	
	UART2	No	
	UART2 Interrupt ID	-	
SPI	SPI0	Yes	0xf8014000
	SPI0 Interrupt ID	4	
	SPI1	Yes	0xf8015000
	SPI1 Interrupt ID	5	
	SPI2	-	
	SPI2 Interrupt ID	-	
I2C	I2C0	Yes	0xf8018000
	I2C0 Interrupt ID	8	
	I2C1	Yes	0xf8019000
	I2C1 Interrupt ID	9	
	I2C2	No	
	I2C2 Interrupt ID	-	
GPIO	GPIO0	Yes	0xf8000000
	GPIO0 Width	16	
	GPIO0 Interrupt ID	12, 13	
	GPIO1	No	
	GPIO1 Width	-	
	GPIO1 Interrupt ID	-	
APB3	APB3 Slave Size	64KB	
	APB0	Yes	0xf8800000
	APB1	No	
	APB2	No	
	APB3	No	
	APB4	No	
AXI4	AXI Slave	No	
	AXI Slave Size	-	
	AXI Master 0	-	
	AXI Master 0 Data Width	-	
	AXI Master 1	-	
	AXI Master 1 Data Width	-	
User Interrupt	User Interrupt A	Yes	
	User Interrupt A ID	25	
	User Interrupt B	No	

Parameter		Setting	Address
	User Interrupt B ID	-	
	User Interrupt C	No	
	User Interrupt C ID	-	
	User Interrupt D	No	
	User Interrupt D ID	-	
	User Interrupt E	No	
	User Interrupt E ID	-	
	User Interrupt F	No	
	User Interrupt F ID	-	
	User Interrupt G	No	
	User Interrupt G ID	-	
	User Interrupt H	No	
	User Interrupt H ID	-	
	User Timer	User Timer 0	No
User Timer 0 Counter Width		-	
User Timer 0 Prescaler Width		-	
User Timer 0 Interrupt ID		-	
User Timer 1		No	
User Timer 1 Counter Width		-	
User Timer 1 Prescaler Width		-	
User Timer 1 Interrupt ID		-	
User Timer 2		No	
User Timer 2 Counter Width		-	
User Timer 2 Prescaler Width		-	
User Timer 2 Interrupt ID		-	

### Opal Configuration

Parameter		Setting	Address
SOC	Core Number	1	
	Frequency	Configurable	
	Peripheral Clock	No	
	Cache	No	
	Custom Instruction	-	
	Linux Memory Management Unit	-	
	Floating-point unit	-	
	Atomic Extension	-	
Cache/Memory	Data Cache Way	-	
	Data Cache Size	-	

Parameter		Setting	Address
	Instruction Cache Way	-	
	Instruction Cache Size	-	
	External Memory Interface	No	
	AXI Interface Type	-	
	External Memory Data Width	-	
	External Memory Address Size	-	
	On-Chip RAM Size	Configurable	0xf9000000
	Custom On-Chip RAM Application	No	
Debug	Soft Debug Tap	Configurable	
	FPGA Tap Port	Configurable	
	Target Board	Configurable	
	Application Region Size	-	
	Application Stack Size	-	
	Application Debug Mode	-	
UART	UART0	Yes	0xf8010000
	UART0 Interrupt ID	1	
	UART1	No	
	UART1 Interrupt ID	-	
	UART2	No	
	UART2 Interrupt ID	-	
SPI	SPI0	Yes	0xf8014000
	SPI0 Interrupt ID	4	
	SPI1	No	
	SPI1 Interrupt ID	-	
	SPI2	-	
	SPI2 Interrupt ID	-	
I2C	I2C0	Yes	0xf8018000
	I2C0 Interrupt ID	8	
	I2C1	No	
	I2C1 Interrupt ID	-	
	I2C2	No	
	I2C2 Interrupt ID	-	
GPIO	GPIO0	Yes	0xf8000000
	GPIO0 Width	8	
	GPIO0 Interrupt ID	12, 13	
	GPIO1	No	
	GPIO1 Width	-	
	GPIO1 Interrupt ID	-	
APB3	APB3 Slave Size	64KB	
	APB0	Yes	0xf8800000
	APB1	No	

Parameter		Setting	Address
	APB2	No	
	APB3	No	
	APB4	No	
AXI4	AXI Slave	No	
	AXI Slave Size	-	
	AXI Master 0	-	
	AXI Master 0 Data Width	-	
	AXI Master 1	-	
	AXI Master 1 Data Width	-	
	User Interrupt	User Interrupt A	Yes
User Interrupt A ID		25	
User Interrupt B		No	
User Interrupt B ID		-	
User Interrupt C		No	
User Interrupt C ID		-	
User Interrupt D		No	
User Interrupt D ID		-	
User Interrupt E		No	
User Interrupt E ID		-	
User Interrupt F		No	
User Interrupt F ID		-	
User Interrupt G		No	
User Interrupt G ID		-	
User Interrupt H		No	
User Interrupt H ID		-	
User Timer	User Timer 0	No	
	User Timer 0 Counter Width	-	
	User Timer 0 Prescaler Width	-	
	User Timer 0 Interrupt ID	-	
	User Timer 1	No	
	User Timer 1 Counter Width	-	
	User Timer 1 Prescaler Width	-	
	User Timer 1 Interrupt ID	-	
	User Timer 2	No	
	User Timer 2 Counter Width	-	
	User Timer 2 Prescaler Width	-	
	User Timer 2 Interrupt ID	-	

# Troubleshooting

## Contents:

- **Error 0x80010135: Path too long (Windows)**
- **OpenOCD Error: timed out while waiting for target halted**
- **Memory Test**
- **OpenOCD error code (-1073741515)**
- **OpenOCD Error: no device found**
- **OpenOCD Error: failed to reset FTDI device: LIBUSB\_ERROR\_IO**
- **OpenOCD Error: target 'fpga\_spinal.cpu0' init failed**
- **Eclipse Fails to Launch with Exit Code 13**
- **Efinity Debugger Crashes when using OpenOCD**
- **Undefined Reference to 'cosf'**
- **Exception in thread "main"**

## Error 0x80010135: Path too long (Windows)

When you unzip the SDK on Windows, you may get the error message:

```
An unexpected error is keeping you from copying the file. If you continue to receive this error, you can use the error code to search for help with this problem.
```

```
Error 0x80010135: Path too long
```

This error occurs if you try to unzip the SDK files into a deep folder hierarchy instead of one that is close to the root level. Instead unzip to **c:\riscv-sdk**.

## OpenOCD Error: timed out while waiting for target halted

The OpenOCD debugger console may display this error when:

- There is a bad contact between the FPGA header pins and the programming cable.
- The FPGA is not configured with a Sapphire SoC design.
- You may not have the correct PLL settings to work with the Sapphire SoC.
- Your computer does not have enough memory to run the program.

To solve this problem:

- Make sure that all of the cables are securely connected to the board and your computer.
- Check the JTAG connection.

## Memory Test

Your user binary may not boot correctly if there is a memory corruption problem (that is, the communication between the DDR hard controller and memory module is not functioning). This issue can appear when booting using the SPI flash or OpenOCD debugger. The following instructions provide a debugging flow to determine whether your system has this problem. You use two command prompts or shells to perform the test:

- The first terminal opens an OpenOCD connection to the SoC.
- The second connects to the first terminal for performing the test.



**Important:** If you are using the OpenOCD debugger in Eclipse, terminate any debug processes before performing this test.

### Set Up Terminal 1

1. Open a Windows command prompt or Linux shell.
2. Change to **SDK\_Windows** or **SDK\_Ubuntu**.
3. Execute the **setup.bat** (Windows) or **setup.sh** (Linux) script.
4. Change to the directory that has the **cpu0.yaml** file.
5. Type the following commands to set up the OpenOCD server:

Windows:

```
openocd.exe -f bsp\efinix\EfxSapphireSoc\openocd\ftdi.cfg
-c "set CPU0_YAML cpu0.yaml"
-f bsp\efinix\EfxSapphireSoc\openocd\flash.cfg
```

Linux:

```
openocd -f bsp/efinix/EfxSapphireSoc/openocd/ftdi.cfg
-c "set CPU0_YAML cpu0.yaml"
-f bsp/efinix/EfxSapphireSoc/openocd/flash.cfg
```

The OpenOCD server connects and begins listening on port 4444.

## Set Up Terminal 2

1. Open a second command prompt or shell.
2. Enable telnet if it is not turned on. **Turn on telnet (Windows)**
3. Open a telnet host on port 4444 with the command `telnet localhost 4444`.
4. To test the on-chip RAM, use the `mdw` command to get the bootloader binary. Type the command `mdw <address> <number of 32-bit words>` to display the content of the memory space. For example: `mdw 0xF900_0000 32`.
5. To test the DRAM:
  - Use the `mww` command to write to the memory space: `mww <address> <data>`. For example: `mww 0x00001000 16`.
  - Then, use the `mdw` command to write to the memory space: `mdw <address> <data>`. For example: `mdw 0x00001000 16`. If the memory space has collapsed, the console shows all 0s.

## Close Terminals

When you finish:

- Type `exit` in terminal 2 to close the telnet session.
- Type Ctrl+C in terminal 1 to close the OpenOCD session.



**Important:** OpenOCD cannot be running in Eclipse when you are using it in a terminal. If you try to run both at the same time, the application will crash or hang. Always close the terminals when you are done flashing the binary.

## Reset the FPGA

Press the reset button on your development board:

- Trion® T120 BGA324 Development Board—SW2
- 钛金系列 Ti60 F225 Development Board—SW3

## OpenOCD error code (-1073741515)

The OpenOCD debugger may fail with error code -1073741515 if your system does not have the **libusb0.dll** installed. To fix this problem, install the DLL. This issue only affects Windows systems.

## OpenOCD Error: no device found

The FTDI driver included with the Sapphire SoC specifies the FTDI device VID and PID, and board description. In some cases, an early revision of the 易灵思 development board may have a different name than the one given in the driver file. If the board name does not match the name in the driver, OpenOCD will fail with an error similar to the following:

```
Error: no device found
Error: unable to open ftdi device with vid 0403, pid 6010, description 'Trion T20
Development
Board', serial '*' at bus location '*'
```

To fix this problem, follow these steps with the development board attached to the computer:

1. Open the Efinity Programmer.
2. Click the **Refresh USB Targets** button to display the board name in the **USB Target** drop-down list.
3. Make note of the board name.
4. In a text editor, open the **ftdi.cfg** (Trion) or **ftdi\_ti.cfg** (钛金系列) file in the `/bsp/efinix/EFXSapphireSoC/openocd` directory.



5. Change the `ftdi_device_desc` setting to match your board name. For example, use this code to change the name from Trion T20 Development Board to Trion T20 Developer Board:

```
interface ftdi
ftdi_device_desc "Trion T20 Developer Board"
#ftdi_device_desc "Trion T20 Development Board"
ftdi_vid_pid 0x0403 0x6010
```

6. Save the file.
7. Debug as usual in OpenOCD.

## OpenOCD Error: failed to reset FTDI device: LIBUSB\_ERROR\_IO

This error is typically caused because you have the wrong Windows USB driver for the development board. If you have the wrong driver, you will get an error similar to:

```
Error: failed to reset FTDI device: LIBUSB_ERROR_IO
Error: unable to open ftdi device with vid_0403, pid 6010, description
'Trion T20 Development Board', serial '*' at bus location '*'
```

## OpenOCD Error: target 'fpga\_spinal.cpu0' init failed

You may receive this error when trying to debug after creating your OpenOCD debug configuration. The Eclipse Console gives an error message similar to:

```
Error cpuConfigFile C:\RiscVsoc_Jadesoc_jade_swcpu0.yaml not found
Error: target 'fpga_spinal.cpu0' init failed
```

This error occurs because the path to the **cpu0.yaml** file is incorrect, specifically the slashes for the directory separators. You should use:

- a single forward slash (/)
- 2 backslashes (\\)

For example, either of the following are good:

```
C:\\RiscV\\soc_Jade\\soc_jade_sw\\cpu0.yaml
C:/RiscV/soc_Jade/soc_jade_sw/cpu0.yaml
```

## Eclipse Fails to Launch with Exit Code 13

The Eclipse software requires a 64-bit version of the Java JRE. If you use a 32-bit version, when you try to launch Eclipse you will get an error that Java quit with exit code 13.

If you are downloading the JRE using a web browser from [www.java.com](http://www.java.com), it defaults to getting the 32-bit version. Instead, go to <https://www.java.com/en/download/manual.jsp> to download the 64-bit version.

## Efinity® Debugger Crashes when using OpenOCD

The Efinity® Debugger crashes if you try to use it for debugging while also using OpenOCD. Both applications use the same USB connection to the development board, and conflict if you use them at the same time. To avoid this issue:

- Do not use the two debuggers at the same time.
- Use an FTDI cable and a soft JTAG core for OpenOCD debugging. See [Using a Soft JTAG Core for Example Designs](#) on page 58 for details.

## Undefined Reference to 'cosf'

You may receive an error similar to this when using calculating square root, sine, or cosine with floating-point numbers in your application. The Sapphire SoC does not currently support floating point.

## Exception in thread "main"

When you generate the SoC with a custom user application, you may receive messages similar to the following when you compile your software application:

```
Exception in thread "main"
java.lang.ArrayIndexOutOfBoundsException: Index 29361152 out of bounds for
length 1024
at spinal.lib.misc.HexTools$$anonfun$initRam$1.apply$mcVII
$sp(HexTools.scala:53)
```

This can happen when you have an SoC with external memory interface. The default linker script targets the external memory region during application compilation. You should compile your application to target on-chip RAM instead by following these steps:

1. Open the file <project>/**embedded\_sw**/**<module>**/**software/standalone/common/bsp.mk**.
2. Change line 7 from

```
LDSCRIPT ?= ${BSP_PATH}/linker/default.ld
```

to

```
LDSCRIPT ?= ${BSP_PATH}/linker/default_i.ld
```

3. Recompile the application.

If these steps do not solve the issue, contact the Efinix support team via our forum in the Support Center.

# API Reference

## Contents:

- **Control and Status Registers**
- **GPIO API Calls**
- **I2C API Calls**
- **I/O API Calls**
- **Core Local Interrupt Timer API Calls**
- **User Timer API Calls**
- **PLIC API Calls**
- **SPI API Calls**
- **SPI Flash Memory API Calls**
- **UART API Calls**
- **Handling Interrupts**

The following sections describe the API for the code in the **driver** directory.

## Control and Status Registers

### csr\_clear()

Usage	<code>csr_clear(csr, val)</code>
Include	<b>driver/riscv.h</b>
Description	Clear a CSR.

### csr\_read()

Usage	<code>csr_read(csr)</code>
Include	<b>driver/riscv.h</b>
Description	Read from a CSR.
Example	<code>csrr (t0, mepc)</code>

### csr\_read\_clear()

Usage	<code>csr_read_clear(csr, val)</code>
Include	<b>driver/riscv.h</b>
Description	CSR read and clear bit.

### csr\_read\_set()

Usage	<code>csr_read_set(csr, val)</code>
Include	<b>driver/riscv.h</b>
Description	CSR read and set bit.

### csr\_set()

Usage	<code>csr_set(csr, val)</code>
Include	<b>driver/riscv.h</b>
Description	CSR set bit.

## csr\_swap()

Usage	<code>csr_swap(csr, val)</code>
Include	<b>driver/riscv.h</b>
Description	Swaps values in the CSR.

## csr\_write()

Usage	<code>csr_write(csr, val)</code>
Include	<b>driver/riscv.h</b>
Description	Write to a CSR.
Example	<code>csrw (mepc, t0); // Write regfile[t0] in mepc</code>

## opcode\_R()

Usage	<code>opcode_R(opcode, func3, func7, rs1, rs2)</code>
Include	<b>driver/riscv.h</b>
Description	Define an opcode for the custom instruction.
Example	<code>#define tea_1(rs1, rs2) opcode_R(CUSTOM0, 0x00, 0x00, rs1, rs2)</code>

# GPIO API Calls

## gpio\_getFilteringHit()

Usage	<code>gpio_getFilteringHit(reg)</code>
Parameters	[IN] reg struct of I <sup>2</sup> C setting value
Include	<b>driver/i2c.h</b>
Description	Read the 32-bit I <sup>2</sup> C register filter hit with a call back function.
Example	<pre>if(gpio_getFilteringHit(I2C_CTRL) == 1) // Check filter hit value, bit [7] from slave address, // read = '1' write = '0'</pre>

## gpio\_getFilteringStatus()

Usage	<code>gpio_getFilteringStatus(reg)</code>
Parameters	[IN] reg struct of I <sup>2</sup> C setting value
Include	<b>driver/i2c.h</b>
Description	Read the 32-bit I <sup>2</sup> C register filter hit with a call back function.
Example	<pre>if(gpio_getFilteringStatus (I2C_CTRL) == 1) // Check filter hit status, bit [7] from slave address, read = '1' write = '0'</pre>

## gpio\_getInput()

Usage	<code>gpio_getInput(GPIO_Reg, value)</code>
Parameters	[IN] GPIO_Reg struct of GPIO register [IN] value GPIO pin bitwise
Include	<b>driver/gpio.h</b>
Description	Get input from a GPIO.

## gpio\_getInterruptFlag()

Usage	<code>gpio_getInterruptFlag(reg)</code>
Parameters	[IN] reg struct of I <sup>2</sup> C setting value
Include	<b>driver/i2c.h</b>
Description	Read the 32-bit I <sup>2</sup> C register interrupt flag with a call back function.
Example	<pre> Int flag = gpio_getInterruptFlag(I2C_CTRL) &amp; I2C_INTERRUPT_DROP; // Get Drop interrupt flag from Interrupt register //[2] I2C_INTERRUPT_TX_DATA //[3] I2C_INTERRUPT_TX_ACK //[7] I2C_INTERRUPT_DROP //[16] I2C_INTERRUPT_CLOCK_GEN_BUSY //[17] I2C_INTERRUPT_FILTER </pre>

## gpio\_getMasterStatus()

Usage	<code>gpio_getMasterStatus(reg)</code>
Parameters	[IN] reg struct of I <sup>2</sup> C setting value
Include	<b>driver/i2c.h</b>
Description	Read the 32-bit I <sup>2</sup> C register master status with a call back function.
Example	<pre> int status = gpio_getMasterStatus(I2C_CTRL) &amp; I2C_MASTER_BUSY; // Get master busy status from status register [0] I2C_MASTER_BUSY [4] I2C_MASTER_START [5] I2C_MASTER_STOP [6] I2C_MASTER_DROP </pre>

## gpio\_getOutput()

Usage	<code>gpio_getOutput(GPIO_Reg, value)</code>
Parameters	[IN] GPIO_Reg struct of GPIO register [IN] value GPIO pin bitwise
Include	<b>driver/gpio.h</b>
Description	Read the output pin.

## gpio\_getOutputEnable()

Usage	<code>gpio_getOutputEnable(GPIO_Reg, value)</code>
Parameters	[IN] GPIO_Reg struct of GPIO register [IN] value GPIO pin bitwise
Include	<b>driver/gpio.h</b>
Description	Read GPIO output enable.

## gpio\_setOutput()

Usage	<code>gpio_setOutput(GPIO_Reg, value)</code>
Parameters	[IN] GPIO_Reg struct of GPIO register [IN] value GPIO pin bitwise
Include	<b>driver/gpio.h</b>
Description	Set GPIO as 1 or 0.

### gpio\_setOutputEnable()

Usage	<code>gpio_setOutputEnable(GPIO_Reg, value)</code>
Parameters	[IN] GPIO_Reg struct of GPIO register [IN] value GPIO pin bitwise
Include	<b>driver/gpio.h</b>
Description	Set GPIO as an output enable.

### gpio\_setInterruptRiseEnable()

Usage	<code>gpio_setInterruptRiseEnable(GPIO_Reg, value)</code>
Parameters	[IN] GPIO_Reg struct of GPIO register [IN] value GPIO pin bitwise
Include	<b>driver/gpio.h</b>
Description	Set an interrupt on the rising edge of the GPIO.

### gpio\_setInterruptFallEnable()

Usage	<code>gpio_setInterruptFallEnable(GPIO_Reg, value)</code>
Parameters	[IN] GPIO_Reg struct of GPIO register [IN] value GPIO pin bitwise
Include	<b>driver/gpio.h</b>
Description	Set an interrupt on the falling edge of the GPIO.

### gpio\_setInterruptHighEnable()

Usage	<code>gpio_setInterruptHighEnable(GPIO_Reg, value)</code>
Parameters	[IN] GPIO_Reg struct of GPIO register [IN] value GPIO pin bitwise
Include	<b>driver/gpio.h</b>
Description	Set an interrupt when the GPIO is high.

### gpio\_setInterruptLowEnable()

Usage	<code>gpio_setInterruptLowEnable(GPIO_Reg, value)</code>
Parameters	[IN] GPIO_Reg struct of GPIO register [IN] value GPIO pin bitwise
Include	<b>driver/gpio.h</b>
Description	Set an interrupt when the GPIO is low.

## I<sup>2</sup>C API Calls

### i2c\_applyConfig()

Usage	<code>void i2c_applyConfig(u32 reg, I2c_Config *config)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C setting value [IN] <code>config</code> struct of I <sup>2</sup> C configuration
Include	<b>driver/i2c.h</b>
Description	Apply I <sup>2</sup> C configuration to register or for initial configuration.

## i2c\_clearInterruptFlag()

Usage	<code>void i2c_clearInterruptFlag(u32 reg, u32 value)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C setting value [IN] <code>value</code> I <sup>2</sup> C interrupt register
Include	<b>driver/i2c.h</b>
Description	Clear the I <sup>2</sup> C interrupt flag.

## i2c\_disableInterrupt()

Usage	<code>void i2c_disableInterrupt(u32 reg, u32 value)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C setting value [IN] <code>value</code> I <sup>2</sup> C interrupt register: [0] I2C_INTERRUPT_RX_DATA [1] I2C_INTERRUPT_RX_ACK [2] I2C_INTERRUPT_TX_DATA [3] I2C_INTERRUPT_TX_ACK [4] I2C_INTERRUPT_START [5] I2C_INTERRUPT_RESTART [6] I2C_INTERRUPT_END [7] I2C_INTERRUPT_DROP [16] I2C_INTERRUPT_CLOCK_GEN_BUSY [17] I2C_INTERRUPT_FILTER
Include	<b>driver/i2c.h</b>
Description	Disable I <sup>2</sup> C interrupt.
Example	<pre>i2c_disableInterrupt(I2C_CTRL, I2C_INTERRUPT_TX_ACK); // Enable I2C interrupt with interrupt TX Ack</pre>

## i2c\_enableInterrupt()

Usage	<code>void i2c_enableInterrupt(u32 reg, u32 value)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C setting value [IN] <code>value</code> I <sup>2</sup> C interrupt register: [0] I2C_INTERRUPT_RX_DATA [1] I2C_INTERRUPT_RX_ACK [2] I2C_INTERRUPT_TX_DATA [3] I2C_INTERRUPT_TX_ACK [4] I2C_INTERRUPT_START [5] I2C_INTERRUPT_RESTART [6] I2C_INTERRUPT_END [7] I2C_INTERRUPT_DROP [16] I2C_INTERRUPT_CLOCK_GEN_BUSY [17] I2C_INTERRUPT_FILTER
Include	<b>driver/i2c.h</b>
Description	Enable I <sup>2</sup> C interrupt.
Example	<pre>i2c_enableInterrupt(I2C_CTRL, I2C_INTERRUPT_FILTER   I2C_INTERRUPT_DROP); // Enable I2C interrupt with interrupt filter and drop</pre>

## i2c\_filterEnable()

Usage	<code>void i2c_filterEnable(u32 reg, u32 filterId, u32 config)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C setting value [IN] <code>filterID</code> filter configuration ID number [IN] <code>config</code> struct of I <sup>2</sup> C configuration
Include	<b>driver/i2c.h</b>
Description	Enable the filter configuration.

## i2c\_listenAck()

Usage	<code>void i2c_listenAck(u32 reg)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C register
Include	<b>driver/i2c.h</b>
Description	Listen acknowledge from the slave.

## i2c\_masterBusy()

Usage	<code>void i2c_masterBusy(u32 reg)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C register
Include	<b>driver/i2c.h</b>
Description	Get the I <sup>2</sup> C busy status.

## i2c\_masterStatus()

Usage	<code>int i2c_masterStatus(u32 reg)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C register
Include	<b>driver/i2c.h</b>
Description	Get the I <sup>2</sup> C status.

## i2c\_masterDrop()

Usage	<code>void i2c_masterDrop(u32 reg)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C register
Include	<b>driver/i2c.h</b>
Description	Change the I <sup>2</sup> C master to the drop state.
Example	<code>i2c_masterDrop(I2C_CTRL);</code>

## i2c\_masterStart()

Usage	<code>void i2c_masterStart(u32 reg)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C register
Include	<b>driver/i2c.h</b>
Description	Change the I <sup>2</sup> C master to the start status.

## i2c\_masterStartBlocking()

Usage	<code>void i2c_masterStartBlocking(u32 reg)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C register
Include	<b>driver/i2c.h</b>
Description	Asserts a start condition.



## i2c\_masterStop()

Usage	<code>void i2c_masterStop(u32 reg)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C register
Include	<b>driver/i2c.h</b>
Description	Change the I <sup>2</sup> C master to the stop status.

## i2c\_masterStopBlocking()

Usage	<code>void i2c_masterStartBlocking(u32 reg)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C register
Include	<b>driver/i2c.h</b>
Description	Asserts a stop condition.

## i2c\_masterStopWait()

Usage	<code>void i2c_masterStopWait(u32 reg)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C register
Include	<b>driver/i2c.h</b>
Description	The stop condition is wait busy..

## i2c\_setFilterConfig()

Usage	<code>void i2c_setFilterConfig(u32 reg, u32 filterId, u32 config)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C setting value [IN] <code>filterID</code> filter configuration ID number [IN] <code>config</code> struct of I <sup>2</sup> C configuration: <ul style="list-style-type: none"> <li>• [9:0] I2C slave address</li> <li>• [14] I2C_FILTER_10BITS</li> <li>• [15] I2C_FILTER_ENABLE</li> </ul>
Include	<b>driver/i2c.h</b>
Description	Set the filter configuration.
Example	<pre>i2c_setFilterConfig(I2C_CTRL, 0, 0x30   I2C_FILTER_ENABLE); // Enable filter with ID=0 slave addr = 0x30 default 7 bit filter</pre>

## i2c\_txAck()

Usage	<code>void i2c_txAck(u32 reg)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C register
Include	<b>driver/i2c.h</b>
Description	Transmit acknowledge.

## i2c\_txAckBlocking()

Usage	<code>void i2c_txAckBlocking(u32 reg)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C register
Include	<b>driver/i2c.h</b>
Description	Assert an ACK on the SDA pin.

### i2c\_txAckWait()

Usage	<code>void i2c_txAckWait(u32 reg)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C register
Include	<b>driver/i2c.h</b>
Description	Wait for an acknowledge to transmit.

### i2c\_txByte()

Usage	<code>void i2c_txByte(u32 reg, u8 byte)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C register [IN] <code>byte</code> 8 bits data to send out
Include	<b>driver/i2c.h</b>
Description	Transfers one byte to the I <sup>2</sup> C slave.

### i2c\_txByteRepeat()

Usage	<code>void i2c_txByteRepeat(u32 reg, u8 byte)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C register [IN] <code>byte</code> 8 bits data to send out
Include	<b>driver/i2c.h</b>
Description	Send a byte and then wait until it is fully transmitted on the I <sup>2</sup> C bus.

### i2c\_txNack()

Usage	<code>void i2c_txNack(u32 reg)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C register
Include	<b>driver/i2c.h</b>
Description	Transfers a NACK.

### i2c\_txNackRepeat()

Usage	<code>void i2c_txNackRepeat(u32 reg)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C register
Include	<b>driver/i2c.h</b>
Description	Send a NACK and then wait until it is fully transmitted on the I <sup>2</sup> C bus.

### i2c\_txNackBlocking()

Usage	<code>void i2c_txNackBlocking(u32 reg)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C register
Include	<b>driver/i2c.h</b>
Description	Assert a NACK on the SDA pin.

### i2c\_rxAck()

Usage	<code>int i2c_rxAck(u32 reg)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C register
Returns	[OUT] 1 bit acknowledge
Include	<b>driver/i2c.h</b>
Description	Receive an acknowledge from the I <sup>2</sup> C slave.

## i2c\_rxData()

Usage	<code>unit32_t i2c_rxData(u32 reg)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C register
Returns	[OUT] 1 byte data from I <sup>2</sup> C slave
Include	<b>driver/i2c.h</b>
Description	Receive one byte data from I <sup>2</sup> C slave.

## i2c\_rxNack()

Usage	<code>int i2c_rxNack(u32 reg)</code>
Parameters	[IN] <code>reg</code> struct of I <sup>2</sup> C register
Returns	[OUT] 1 bit no acknowledge
Include	<b>driver/i2c.h</b>
Description	Receive no acknowledge from the I <sup>2</sup> C slave.

## I/O API Calls

### read\_u8()

Usage	<code>u8 read_u8(u32 address)</code>
Include	<b>driver/io.h</b>
Parameters	<code>[IN] address</code> SoC address
Description	Read address with unsigned 8 bits.

### read\_u16()

Usage	<code>u16 read_u16(u32 address)</code>
Include	<b>driver/io.h</b>
Parameters	<code>[IN] address</code> SoC address
Description	Read address with unsigned 16 bits.

### read\_u32()

Usage	<code>u32 read_u32(u32 address)</code>
Include	<b>driver/io.h</b>
Parameters	<code>[IN] address</code> SoC address
Description	Read address with unsigned 32 bits.

### write\_u8()

Usage	<code>void write_u8(u8 data, u32 address)</code>
Include	<b>driver/io.h</b>
Parameters	<code>[IN] data</code> SoC address data <code>[IN] address</code> SoC address
Description	Write 8 bits unsigned data to the specified address.

### write\_u16()

Usage	<code>void write_u16(u16 data, u32 address)</code>
Include	<b>driver/io.h</b>
Parameters	<code>[IN] data</code> SoC address data <code>[IN] address</code> SoC address
Description	Write 16 bits unsigned data to the specified address.

### write\_u32()

Usage	<code>void write_u32(u32 data, u32 address)</code>
Include	<b>driver/io.h</b>
Parameters	<code>[IN] data</code> SoC address data <code>[IN] address</code> SoC address
Description	Write 32 bits unsigned data to the specified address.

## write\_u32\_ad()

Usage	<code>void write_u32_ad(u32 address, u32 data)</code>
Include	<b>driver/io.h</b>
Parameters	[IN] <code>address</code> SoC address [IN] <code>data</code> SoC address data
Description	Write 32 bits unsigned data to the specified address.

# Core Local Interrupt Timer API Calls

## clint\_setCmp()

Usage	<code>void clint_setCmp(u32 p, u64 cmp, u32 hart_id)</code>
Include	<b>driver/clint.h</b>
Parameters	[IN] <code>p</code> timer interrupt [IN] <code>cmp</code> timer compare register [IN] <code>hart_id</code> hart ID
Description	Set a timer value to trigger an interrupt.

## clint\_getTime()

Usage	<code>u64 clint_getTime(u32 p)</code>
Include	<b>driver/clint.h</b>
Parameters	[IN] <code>p</code> timer interrupt
Returns	[OUT] timer value
Description	Gets the timer value.

## clint\_uDelay()

Usage	<code>u64 clint_uDelay(u32 usec, u32 hz, u32 reg)</code>
Include	<b>driver/clint.h</b>
Parameters	[IN] <code>usec</code> microseconds [IN] <code>hz</code> core frequency [IN] <code>reg</code> timer interrupt
Description	Use the timer to make a delay.

## User Timer API Calls

### prescaler\_setValue()

Usage	<code>void prescaler_setValue(u32 reg, u32 value)</code>
Include	<b>driver/prescaler.h</b>
Parameters	[IN] <code>reg</code> struct of user timer register [IN] <code>prescaler</code> prescaler value
Description	Set the user timer prescaler value.

### timer\_setConfig()

Usage	<code>void timer_setConfig(u32 reg, u32 value)</code>
Include	<b>driver/timer.h</b>
Parameters	[IN] <code>reg</code> struct of user timer register [IN] <code>value</code> user timer configuration value
Description	Set the user timer configuration.

### timer\_setLimit()

Usage	<code>void timer_setLimit(u32 reg, u32 value)</code>
Include	<b>driver/timer.h</b>
Parameters	[IN] <code>reg</code> struct of user timer register [IN] <code>value</code> user timer configuration value
Description	Set the limit value for the timer to generate an interrupt.

### timer\_getValue()

Usage	<code>void timer_getValue(u32 reg)</code>
Include	<b>driver/timer.h</b>
Parameters	[IN] <code>reg</code> struct of user timer register
Returns	Timer value
Description	Get the timer value.

### timer\_clearValue()

Usage	<code>void timer_clearValue(u32 reg)</code>
Include	<b>driver/timer.h</b>
Parameters	[IN] <code>reg</code> struct of user timer register
Description	Clear the timer value and set it to 0.

## PLIC API Calls

### pllic\_set\_priority()

Usage	<code>void pllic_set_priority(u32 pllic, u32 gateway, u32 priority)</code>
Include	<b>driver/pllic.h</b>
Parameters	[IN] <code>pllic</code> PLIC register structure [IN] <code>gateway</code> interrupt type [IN] <code>priority</code> interrupt priority
Description	Set the interrupt priority.

### pllic\_set\_enable()

Usage	<code>void pllic_set_enable(u32 pllic, u32 target, u32 gateway, u32 enable)</code>
Include	<b>driver/pllic.h</b>
Parameters	[IN] <code>pllic</code> PLIC register structure [IN] <code>target</code> HART number [IN] <code>gateway</code> interrupt type [IN] <code>enable</code>
Description	Set the interrupt enable.

### pllic\_set\_threshold()

Usage	<code>void pllic_set_threshold(u32 pllic, u32 target, u32 threshold)</code>
Include	<b>driver/pllic.h</b>
Parameters	[IN] <code>pllic</code> PLIC register structure [IN] <code>target</code> HART number [IN] <code>threshold enable = 1</code>
Description	Masks individual interrupt sources for the HART.

### pllic\_claim()

Usage	<code>u32 pllic_claim(u32 pllic, u32 target)</code>
Include	<b>driver/pllic.h</b>
Parameters	[IN] <code>pllic</code> PLIC register structure [IN] <code>target</code> HART number
Description	Claim the PLIC interrupt

### pllic\_release()

Usage	<code>void pllic_release(u32 pllic, u32 target, u32 gateway)</code>
Include	<b>driver/pllic.h</b>
Parameters	[IN] <code>pllic</code> PLIC register structure [IN] <code>target</code> HART number [IN] <code>gateway</code> interrupt type
Description	Release the PLIC interrupt.

## SPI API Calls

## spi\_applyConfig()

Usage	<code>void spi_applyConfig(Spi_Reg *reg, Spi_Config *config)</code>
Include	<b>driver/spi.h</b>
Parameters	[IN] <code>reg</code> struct of the SPI register [IN] <code>config</code> struct of the SPI configuration
Description	Applies the SPI configuration to to a register for initial configuration.

## spi\_cmdAvailability()

Usage	<code>spi_cmdAvailability(Spi_Reg *reg)</code>
Include	<b>driver/spi.h</b>
Parameters	[IN] <code>reg</code> struct of the SPI register
Description	Read the SPI command buffer.

## spi\_deselect()

Usage	<code>void spi_select(Spi_Reg *reg, uint32_t slaveId)</code>
Include	<b>driver/spi.h</b>
Parameters	[IN] <code>reg</code> struct of the SPI register [IN] <code>slaveId</code> ID for the slave
Description	De-asserts the SPI select (SS) pin.

## spi\_read()

Usage	<code>uint8_t spi_write(Spi_Reg *reg)</code>
Include	<b>driver/spi.h</b>
Parameters	[IN] <code>reg</code> struct of the SPI register
Returns	[OUT] <code>reg</code> One byte of data
Description	Receives one byte from the SPI slave.

## spi\_read32()

Usage	<code>uint32_t spi_write(Spi_Reg *reg)</code>
Include	<b>driver/spi.h</b>
Parameters	[IN] <code>reg</code> struct of the SPI register
Returns	[OUT] <code>reg</code> Data (up to 16 bits)
Description	Receives up to 16 bits of data from the SPI slave.

## spi\_rspOccupancy()

Usage	<code>spi_rspOccupancy(Spi_Reg *reg)</code>
Include	<b>driver/spi.h</b>
Parameters	[IN] <code>reg</code> struct of the SPI register
Description	Read the occupancy buffer.

## spi\_select()

Usage	<code>void spi_select(Spi_Reg *reg, uint32_t slaveId)</code>
Include	<b>driver/spi.h</b>
Parameters	[IN] <code>reg</code> struct of the SPI register [IN] <code>slaveId</code> ID for the slave
Description	Asserts the SPI select (SS) pin.



### spi\_write()

Usage	<code>void spi_write(Spi_Reg *reg, uint8_t data)</code>
Include	<b>driver/spi.h</b>
Parameters	[IN] <code>reg</code> struct of the SPI register [IN] <code>data</code> 8 bits of data to send out
Description	Transfers one byte to the SPI slave.

### spi\_write32()

Usage	<code>void spi_write(Spi_Reg *reg, uint32_t data)</code>
Include	<b>driver/spi.h</b>
Parameters	[IN] <code>reg</code> struct of the SPI register [IN] <code>data</code> up to 16 bits of data to send out
Description	Transfers up to 16 bits to the SPI slave.

### spi\_writeRead()

Usage	<code>uint8_t spi_writeRead(Spi_Reg *reg, uint8_t data)</code>
Include	<b>driver/spi.h</b>
Parameters	[IN] <code>reg</code> struct of the SPI register [IN] <code>data</code> 8 bits of data to send out
Returns	[OUT] <code>reg</code> one byte of data
Description	Transfers one byte to the SPI slave and receives one byte from the SPI slave.

### spi\_writeRead32()

Usage	<code>uint8_t spi_writeRead(Spi_Reg *reg, uint32_t data)</code>
Include	<b>driver/spi.h</b>
Parameters	[IN] <code>reg</code> struct of the SPI register [IN] <code>data</code> up to 16 bits of data to send out
Returns	[OUT] <code>reg</code> Up to 16 bits of data
Description	Transfers up to 16 bits of data to the SPI slave and receives up to 16 bits of data from the SPI slave.

## SPI Flash Memory API Calls

### spiFlash\_f2m\_()

Usage	<code>void spiFlash_f2m_(Spi_Reg * spi, u32 flashAddress, u32 memoryAddress, u32 size)</code>
Include	<b>driver/spiFlash.h</b>
Parameters	[IN] <code>spi</code> reg struct of the SPI register [IN] <code>flashAddress</code> flash device address [IN] <code>memoryAddress</code> memory address [IN] <code>size</code> programming address size
Description	Copy data from the flash device to memory.

## spiFlash\_f2m()

Usage	<code>void spiFlash_f2m(Spi_Reg * spi, u32 cs, u32 flashAddress, u32 memoryAddress, u32 size)</code>
Include	<b>driver/spiFlash.h</b>
Parameters	[IN] <code>spi</code> reg struct of the SPI register [IN] <code>cs</code> chip select [IN] <code>flashAddress</code> flash device address [IN] <code>memoryAddress</code> memory address
Description	Copy data from the flash device to memory with chip select control.

## spiFlash\_f2m\_withGpioCs()

Usage	<code>void spiFlash_f2m_withGpioCs(Spi_Reg * spi, Gpio_Reg *gpio, u32 cs, u32 flashAddress, u32 memoryAddress, u32 size)</code>
Include	<b>driver/spiFlash.h</b>
Parameters	[IN] <code>spi</code> reg struct of the SPI register [IN] <code>gpio</code> reg struct of the GPIO register [IN] <code>cs</code> chip select [IN] <code>flashAddress</code> flash device address [IN] <code>memoryAddress</code> memory address [IN] <code>size</code> programming address size
Description	Flash device from the SPI master with GPIO chip select.

## spiFlash\_deselect()

Usage	<code>void spiFlash_deselect(Spi_Reg *spi, u32 cs)</code>
Include	<b>driver/spiFlash.h</b>
Parameters	[IN] <code>spi</code> reg struct of the SPI register [IN] <code>cs</code> chip select
Description	De-asserts the SPI flash device from the master chip select.

## spiFlash\_deselect\_withGpioCs()

Usage	<code>void spiFlash_deselect_withGpioCs(Gpio_Reg *gpio, u32 cs)</code>
Include	<b>driver/spiFlash.h</b>
Parameters	[IN] <code>gpio</code> reg struct of the GPIO register [IN] <code>cs</code> chip select
Description	De-asserts the SPI flash device from the master with the GPIO chip select.

## spiFlash\_init\_()

Usage	<code>void spiFlash_init_(Spi_Reg * spi)</code>
Include	<b>driver/spiFlash.h</b>
Parameters	[IN] <code>spi</code> reg struct of the SPI register
Description	Initialize the SPI reg struct.

## spiFlash\_init()

Usage	<code>void spiFlash_init(Spi_Reg * spi, u32 cs)</code>
Include	<b>driver/spiFlash.h</b>
Parameters	[IN] <code>spi</code> reg struct of the SPI register [IN] <code>cs</code> chip select
Description	Initialize the SPI reg struct with chip select de-asserted.

### spiFlash\_init\_withGpioCs()

Usage	<code>void spiFlash_init_withGpioCs(Spi_Reg * spi, Gpio_Reg *gpio, u32 cs)</code>
Include	<b>driver/spiFlash.h</b>
Parameters	[IN] <code>spi</code> reg struct of the SPI register [IN] <code>gpio</code> reg struct of the GPIO register [IN] <code>cs</code> chip select
Description	Initialize the SPI reg struct with GPIO chip select de-asserted.

### spiFlash\_read\_id\_()

Usage	<code>u8 spiFlash_read_id_(u32 spi)</code>
Include	<b>driver/spiFlash.h</b>
Parameters	[IN] <code>spi</code> reg struct of the SPI register
Returns	8-bit SPI flash ID
Description	Read the ID from the flash.

### spiFlash\_read\_id()

Usage	<code>u8 spiFlash_read_id(u32 spi, u32 cs)</code>
Include	<b>driver/spiFlash.h</b>
Parameters	[IN] <code>spi</code> reg struct of the SPI register [IN] <code>cs</code> chip select
Returns	8-bit SPI flash ID
Description	Read the ID from the flash with chip select.

### spiFlash\_select()

Usage	<code>void spiFlash_select(Spi_Reg *spi, u32 cs)</code>
Include	<b>driver/spiFlash.h</b>
Parameters	[IN] <code>spi</code> reg struct of the SPI register [IN] <code>cs</code> chip select
Description	Select the SPI flash device.

### spiFlash\_select\_withGpioCs()

Usage	<code>spiFlash_select_withGpioCs(Gpio_Reg *gpio, u32 cs)</code>
Include	<b>driver/spiFlash.h</b>
Parameters	[IN] <code>gpio</code> reg struct of the GPIO register [IN] <code>cs</code> chip select
Description	Select the SPI flash device with the GPIO chip select.

### spiFlash\_software\_reset()

Usage	<code>void spiFlash_software_reset(Spi_Reg * spi, u32 cs)</code>
Include	<b>driver/spiFlash.h</b>
Parameters	[IN] <code>spi</code> reg struct of the SPI register [IN] <code>cs</code> chip select
Description	Reset the SPI flash.

### spiFlash\_wake\_()

Usage	<code>void spiFlash_wake_(Spi_Reg * spi)</code>
Include	<b>driver/spiFlash.h</b>
Parameters	[IN] <code>spi</code> reg struct of the SPI register
Description	Release power down from the SPI master.

### spiFlash\_wake()

Usage	<code>void spiFlash_wake(Spi_Reg * spi, u32 cs)</code>
Include	<b>driver/spiFlash.h</b>
Parameters	[IN] <code>spi</code> reg struct of the SPI register [IN] <code>cs</code> chip select
Description	Release power down from the SPI master with chip select.

### spiFlash\_wake\_withGpioCs()

Usage	<code>void spiFlash_wake_withGpioCs(Spi_Reg * spi, Gpio_Reg *gpio, u32 cs)</code>
Include	<b>driver/spiFlash.h</b>
Parameters	[IN] <code>spi</code> reg struct of the SPI register [IN] <code>gpio</code> reg struct of the GPIO register [IN] <code>cs</code> chip select
Description	Release power down from the SPI master with the GPIO chip select.

## UART API Calls

### uart\_applyConfig()

Usage	<code>char uart_applyConfig(Uart_Reg *reg, Uart_Config *config)</code>
Include	<b>driver/uart.h</b>
Parameters	[IN] <code>reg</code> struct of the UART register [IN] <code>config</code> struct of the UART configuration
Description	Applies the UART configuration to a register for initial configuration.

### uart\_emptyInterruptEna()

Usage	<code>uart_emptyInterruptEna(u32 reg char ena)</code>
Include	<b>driver/uart.h</b>
Parameters	[IN] <code>reg</code> struct of the UART register [IN] <code>ena</code> Enable interrupt
Description	Enable the TX FIFO empty interrupt.

### uart\_NotemptyInterruptEna()

Usage	<code>uart_NotemptyInterruptEna(u32 reg char ena)</code>
Include	<b>driver/uart.h</b>
Parameters	[IN] <code>reg</code> struct of the UART register [IN] <code>ena</code> Enable interrupt
Description	Enable the RX FIFO not empty interrupt.

### uart\_read()

Usage	<code>char uart_read(Uart_Reg *reg)</code>
Include	<b>driver/uart.h</b>
Parameters	[IN] <code>reg</code> struct of the UART register
Returns	[OUT] <code>reg</code> character that is read
Description	Reads a character from the UART slave.

### uart\_readOccupancy()

Usage	<code>uint32_t uart_readOccupancy(Uart_Reg *reg)</code>
Include	<b>driver/uart.h</b>
Parameters	[IN] <code>reg</code> struct of the UART register
Description	Read the number of bytes in the RX FIFO.

### uart\_status\_read()

Usage	<code>uart_status_read(u32 reg)</code>
Include	<b>driver/uart.h</b>
Parameters	[IN] <code>reg</code> struct of the UART register
Returns	[OUT] 32-bit status register from the UART
Description	Read the UART status.

## uart\_status\_write()

Usage	<code>uart_status_write(u32 reg)</code>
Include	<b>driver/uart.h</b>
Parameters	[IN] <code>reg</code> struct of the UART register [IN] <code>data</code> input data for the UART status.
Returns	[OUT] 32-bit status register from the UART
Description	Write the UART status.

## uart\_write()

Usage	<code>void uart_write(Uart_Reg *reg, char data)</code>
Include	<b>driver/uart.h</b>
Parameters	[IN] <code>reg</code> struct of the UART register [IN] <code>data</code> write a character
Description	Write a character to the UART.

## uart\_writeHex()

Usage	<code>void uart_writeHex(u32 reg, int value)</code>
Include	<b>driver/uart.h</b>
Parameters	[IN] <code>reg</code> struct of the UART register [IN] <code>value</code> number to send as UART character
Description	Convert a number to a character and send it to the UART in hexadecimal.

## uart\_writeStr()

Usage	<code>void uart_writeStr(Uart_Reg *reg, char* str)</code>
Include	<b>driver/uart.h</b>
Parameters	[IN] <code>reg</code> struct of the UART register [IN] <code>str</code> string to write
Description	Write a string to the UART TX.

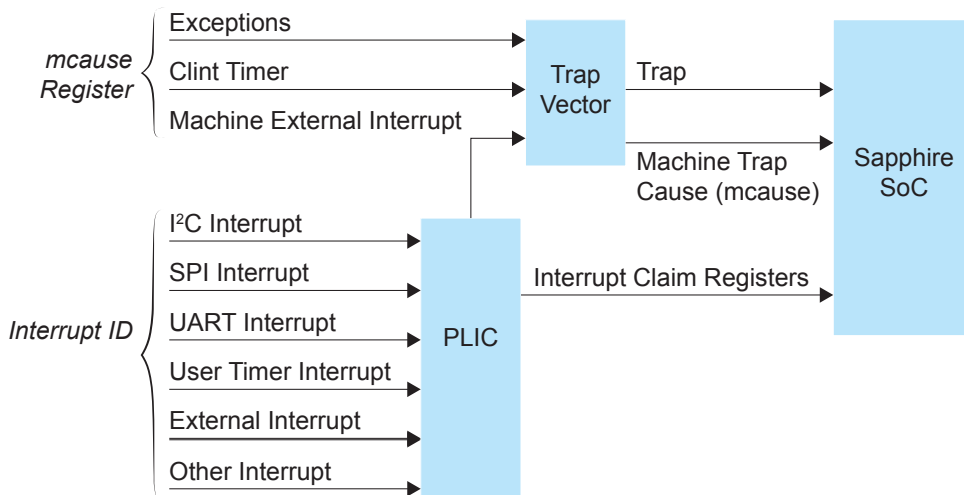
## uart\_writeAvailability()

Usage	<code>uart_writeAvailability(Uart_Reg *reg)</code>
Include	<b>driver/uart.h</b>
Parameters	[IN] <code>reg</code> struct of the UART register
Description	UART read/write FIFO.

## Handling Interrupts

There are two kinds of interrupts, trap vectors and PLIC interrupts, and you handle them using different methods.

Figure 18: Types of Interrupts

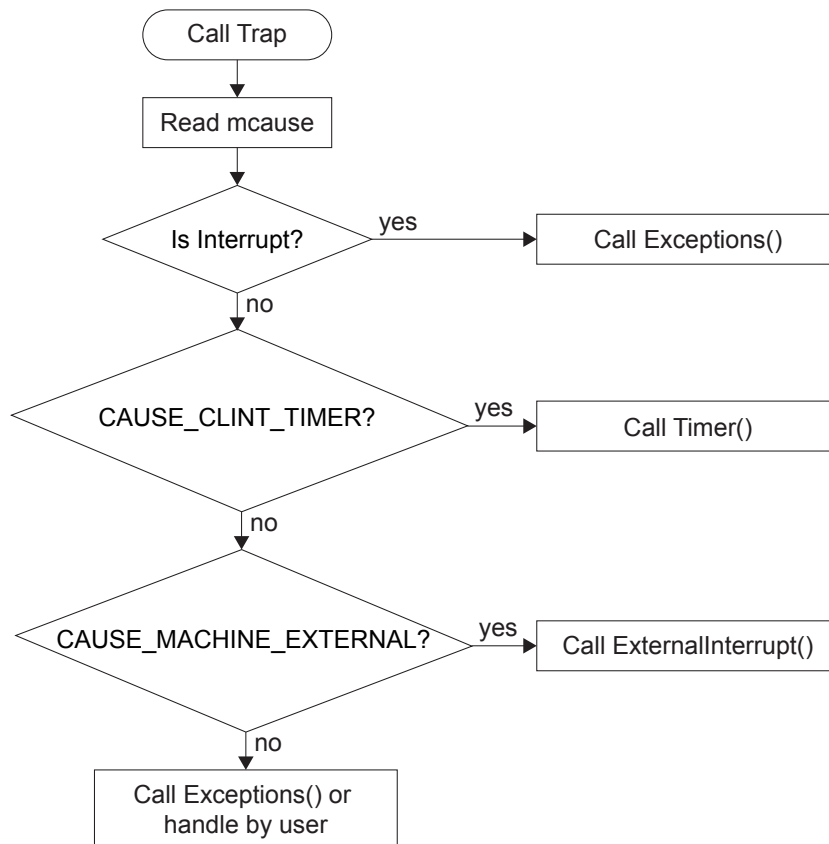


## Trap Vectors

Trap vectors trap interrupts or exceptions from the system. Read the Machine Cause Register (`mcause`) to identify which type of interrupt or exception the system is generating. Refer to "Machine Cause Register (`mcause`): 0x342" in the data sheet for your SoC for a list of the exceptions and interrupts used for trap vectors. The following flow chart explains how to handle trap vectors.

For `CAUSE_MACHINE_EXTERNAL`, it will call the subroutine to process the PLIC level interrupts.

Figure 19: Handling Trap Vectors



## PLIC Interrupts

The PLIC collects external interrupts and is also used for `CAUSE_MACHINE_EXTERNAL` cases. Read the interrupt claim registers (PLIC claim) to identify the source of the external interrupt. Refer to **Address Map** on page 43 for a list of the interrupt IDs.

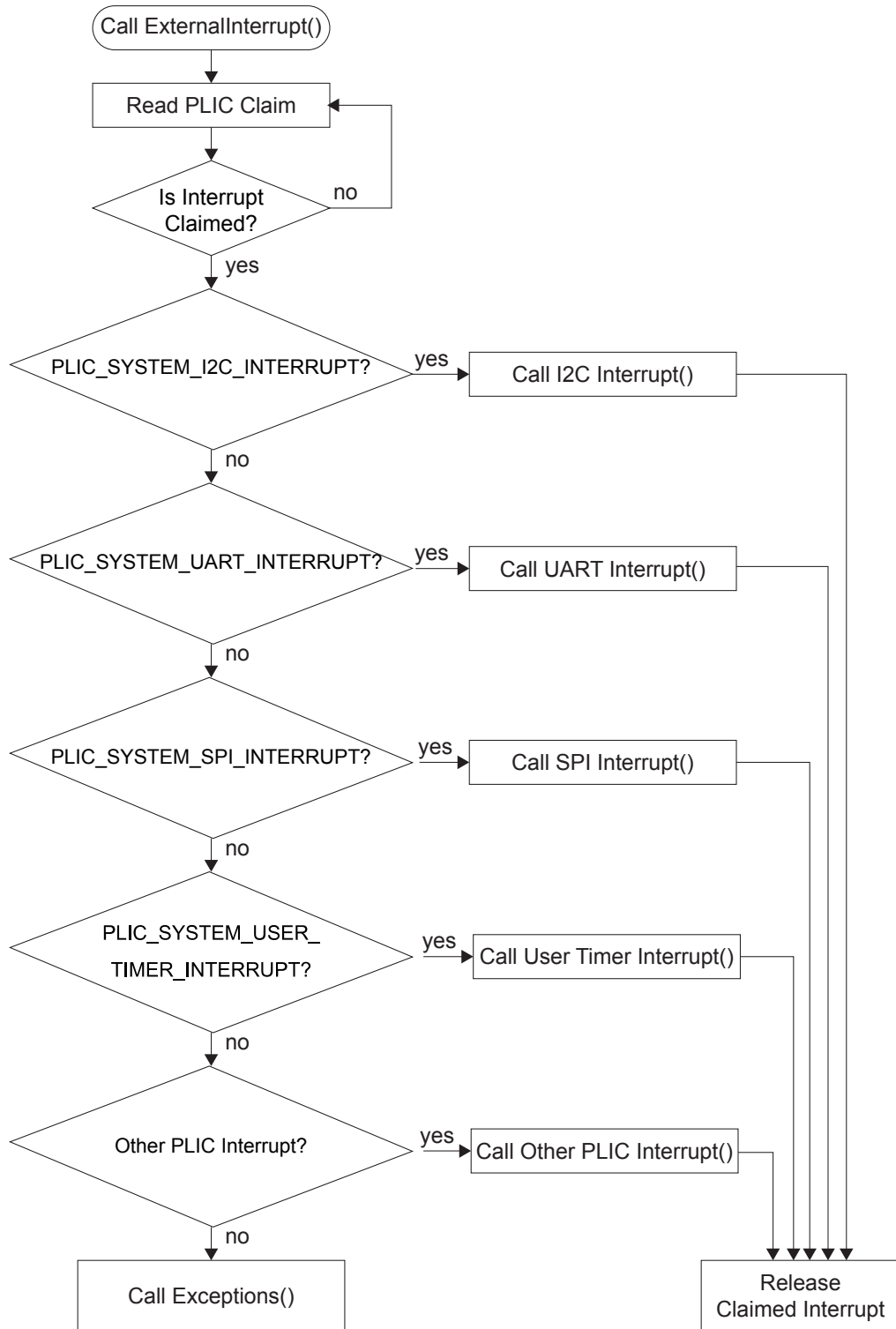


**Note:** For the Sapphire SoC, the interrupt IDs are user configurable. Refer to the interrupt IDs that you set in the IP Manager for each peripheral. The Address Map shows the default values.

The following flow chart shows how the PLIC handles interrupts. The PLIC identifies the interrupt ID and processes the corresponding interrupts.



Figure 20: Handling PLIC Interrupts



## Appendix: Re-Generate the Memory Initialization Files Manually

With the Efinity software v2022.1 and higher, you do not need to re-generate these files manually. These instructions are for reference if you are using an earlier software version.

To re-generate the memory initialization files manually using the **binGen.py** helper script. You find this script in the <project>/**embedded\_sw**/**<SoC module>**/tool directory.

### Windows:

Open a command prompt and type these commands:

```
{EFINITY_HOME}/bin/setup.bat  
python3 binGen.py -b bootloader.bin -s <RAM size> -f <FPU>
```

### Linux:

Open a terminal and type these commands:

```
source ${EFINITY_HOME}/bin/setup.sh  
python3 binGen.py -b bootloader.bin -s <RAM size> -f <FPU>
```

where:

- <RAM size> is the on-chip RAM size you want to use.
- <FPU> indicates whether the floating-point unit is enabled for the SoC. 1: floating-point is enabled, 0: disabled.

This command generates the new memory initialization files. Copy these files into the same directory as your project **.xml** file, replacing the existing files.

Compile your design.

## Appendix: Import the Debug Configuration

With the Efinity software v2022.1 and higher, you do not need to import the debug configuration. These instructions are for reference if you are using an earlier software version.

To simplify the debugging steps, the Sapphire SoC includes debug configurations that you import. There are several configuration files, depending on which board you use.

Table 25: Debug Configurations

Debug Configuration	Use for
default	Debugging software on Trion® development boards.
default_ti	Debugging software on 钛金系列 development boards.
default_softTap	Debugging software on Trion or 钛金系列 development boards with the soft JTAG TAP interface. For example, you would need to use the soft TAP if you want to use the OpenOCD debugger and the Efinity® Debugger at the same time. (See <a href="#">Using a Soft JTAG Core for Example Designs</a> on page 58.)

To import a debug configuration and use it to launch a debug session:

1. Launch Eclipse by running the **run\_eclipse.bat** file (Windows) or **run\_eclipse.sh** (Linux).
2. Select a workspace (if you have not set one as a default).
3. Open the **axiDemo** project or select it under **C/C++ Projects**.
4. Right-click the **axiDemo** project name and choose **Import**.
5. In the Import dialog box, choose **Run/Debug > Launch Configurations**.
6. Click **Next**. The Import Launch Configurations dialog box opens.
7. Browse to the following directory and click **OK**:

Option	Description
Windows	<code>embedded_sw\&lt;SoC module&gt;\config</code>
Linux	<code>embedded_sw/&lt;SoC module&gt;/config_linux</code>

8. Check the box next to **config** (Windows) or **config\_linux** (Linux).
9. Click **Finish**.
10. Right-click the **axiDemo** project name and choose **Debug As > Debug Configurations**.
11. Enter `axiDemo` in the **Project** box.
12. Enter `build\axiDemo.elf` in the **C/C++ Application** box.
13. Windows only: you need to change the path to the **cpu0.yaml** file:
  - a. Click the **Debugger** tab.
  - b. In the **Config options** box, change `${workspace_loc}` to the full path to the **<SoC module>** directory.



**Note:** For the **cpu0.yaml** path, make sure to use `\\` as the directory separator because the first slash escapes the second one. For example, use:

```
c:\\Efinity\\2021.2\\project\\<project name>\\embedded_sw\\<SoC module>\\cpu0.yaml
```

14. Click **Debug**.



**Note:** If Eclipse prompts you to switch to the Debug Perspective, click **Switch**.

## Appendix: Copy a User Binary to the Flash Device (2 Terminals)

To boot from a flash device, you need to copy the binary to the device. These instructions describe how to use two command prompts or terminals to flash the user binary file.



**Note:** If you want to store the binary in the same flash device that holds the FPGA bitstream, refer to [Copy a User Binary to Flash \(Efinity Programmer\)](#) on page 41 instead.

You use two command prompts or terminals:

- The first terminal opens an OpenOCD connection to the SoC.
- The second connects to the first terminal to write to the flash.



**Important:** If you are using the OpenOCD debugger in Eclipse, terminate any debug processes before attempting to flash the memory.

### Set Up Terminal 1

1. Open a Windows command prompt or Linux shell.
2. Change to **SDK\_Windows** or **SDK\_Ubuntu**.
3. Execute the **setup.bat** (Windows) or **setup.sh** (Linux) script.
4. Change to the directory that has the **cpu0.yaml** file.
5. Type the following commands to set up the OpenOCD server:

Windows:

```
openocd.exe -f bsp\efinix\EfxSapphireSoc\openocd\ftdi.cfg
-c "set CPU0_YAML cpu0.yaml"
-f bsp\efinix\EfxSapphireSoc\openocd\flash.cfg
```

Linux:

```
openocd -f bsp/efinix/EfxSapphireSoc/openocd/ftdi.cfg
-c "set CPU0_YAML cpu0.yaml"
-f bsp/efinix/EfxSapphireSoc/openocd/flash.cfg
```

The OpenOCD server connects and begins listening on port 4444.

### Set Up Terminal 2

1. Open a second command prompt or shell.
2. Enable telnet if it is not turned on. [Turn on telnet \(Windows\)](#)
3. Open a telnet local host on port 4444 with the command `telnet localhost 4444`.
4. In the OpenOCD shell or command prompt, use the following command to flash the user binary file:

```
flash write_image erase unlock <path>/<filename>.bin 0x380000
```

Where `<path>` is the full, absolute path to the **.bin** file.



**Note:** For Windows, use `\\` as the directory separators.

### Close Terminals

When you finish:

- Type `exit` in terminal 2 to close the telnet session.
- Type `Ctrl+C` in terminal 1 to close the OpenOCD session.



**Important:** OpenOCD cannot be running in Eclipse when you are using it in a terminal. If you try to run both at the same time, the application will crash or hang. Always close the terminals when you are done flashing the binary.

---

### Reset the FPGA

Press the reset button on your development board:

- Trion® T120 BGA324 Development Board—SW2
- 钛金系列 Ti60 F225 Development Board—SW3

# Revision History

Table 26: Revision History

Date	Version	Description
November 2022	4.2	Corrected boot sequence cases A and B. (DOC-932)
September 2022	4.1	Updates for the Ti180 M484 development board.
September 2022	4.0	Updated the instructions for debugging with OpenOCD. You now use launch scripts. Added information on the possible boot sequence scenarios. Enhanced the information on the address map. Added description for debugging with multiple cores. Added new SPI API functions. Added instructions on migrating from Ruby, Jade, and Opal to Sapphire. Updated IP Manager configuration options. Updated instructions on launching Eclipse. Updated Installing USB drivers topics.
June 2022	3.2	When finding the COM port in Windows, look for the first COM port listed under <b>Ports (COM &amp; LPT)</b> . (DOC-811) The VexRiscv core used in the Sapphire SoC has six pipeline stages.
March 2022	3.1	Fixed typo in Connect the FTDI Cable topic. (DOC-731)
December 2021	3.0	Updated the SDK version numbers. Updated the IP Manager Configuration Wizard description for new configuration options. Added instructions for using the Ti60 F225 Development Board and example design. Updated instructions for Eclipse global environment variables. Explained new Efinity Programmer feature for programming a flash device with a combined user bitstream and application binary. Updated register map. Updated the API Reference for new driver support.
October 2021	2.1	Corrected incomplete instructions for copying a user binary to flash. (DOC-576)
October 2021	2.0	IP Manager options changed for the updated Sapphire wizard. (DOC-544) Updated the address map. (DOC-544) Updated the example design description for the new features in the design. (DOC-544) New simulation instructions. (DOC-544) New instructions for changing the bootloader RAM size. (DOC-544) Changed the EfxApb3Example, EfxAxi4Example, and userInterruptDemo example descriptions. (DOC-544) Changed the TX pin number for the instructions on setting up a USB-to-UART module. (DOC-544) When using the Soft Debug Tap option, the IP Manager connects the pins for you. (DOC-544) Described the pins needed to connect an FTDI cable to the Trion® T120 BGA324 Development Board when using the Soft Debug Tap option. (DOC-544)
August 2021	1.1	Corrected typo in example design name in topics describing Eclipse and OpenOCD (EfxAxi4Example instead of EfxAxiExample). (DOC-517)
July 2021	1.0	Initial release.