Application Report

SPMA040A–January 2012–Revised November 2012

Using SYS/BIOS With Stellaris® ARM® Cortex™-M3 Microcontrollers

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Stellaris® Microcontrollers

ABSTRACT

This document provides a brief overview of the Texas Instruments' SYS/BIOS Real-Time Operating System (RTOS) and outlines how to implement SYS/BIOS on the Stellaris® ARM® Cortex™-M3 family of microcontrollers. In addition to setting up and running an example project provided within the SYS/BIOS software package, this document outlines the process of creating a new SYS/BIOS project with the Code Composer Studio™ v4.2 (CCS) integrated development environment (IDE). As a final step, this document outlines the integration of the StellarisWare® Application Programming Interfaces (APIs) into a SYS/BIOS project.

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1 Introduction

SYS/BIOS is a real-time operating system (RTOS) kernel created by Texas Instruments (TI) that is intended to be used in embedded applications on a variety of the TI microprocessors and microcontrollers including the Stellaris Cortex-M3 family of devices. Several key benefits of the SYS/BIOS RTOS include:

- Scheduling
- Pre-emptive, deterministic multi-tasking
- Configuration tools
- Memory management
- Hardware abstraction for cross-platform applications

SYS/BIOS is included in the installation of Code Composer Studio (CCS), so creating a new project is fairly straightforward. The configuration of the kernel is abstracted from the hardware by the SYS/BIOS configuration tool called XGConf, which is based on the open-source XDCTools. This tool is a graphical user interface (GUI) that allows for quick and easy manipulation of the RTOS components such as tasks, interrupts, and semaphores. This GUI is incorporated into CCS and automatically generates the required initialization code for configuring the SYS/BIOS kernel.

The remainder of this document describes the SYS/BIOS kernel in detail and the process of implementing a SYS/BIOS-based project on a Stellaris ARM Cortex-M3 microcontroller. More detailed information about the SYS/BIOS RTOS can be found in documents listed in Section 7, *References*.

2 Overview of SYS/BIOS

SYS/BIOS is an RTOS kernel designed by Texas Instruments to run on a variety of TI microcontrollers. SYS/BIOS provides the following features:

- Preemptive, priority-based scheduler
- Memory allocation and stack management
- I/O services

The preemptive, priority-based scheduler ensures that the highest priority thread that is ready to run is executed by the system. This configuration ensures that time-sensitive computations are handled with a minimum amount of latency. The SYS/BIOS kernel can be optimized for custom projects in order to improve the code size of the final application. Detailed timing and size benchmark information can be found on the SYS/BIOS Wiki page located on the Texas Instruments Embedded Processor Wiki.

An advantage of using SYS/BIOS is the application portability between TI digital signal processors (DSPs), ARM-based microcontrollers, and MSP430 microcontrollers. The abstraction accomplished by the RTOS allows for code to be ported between the various product families with little to no modification required.

This overview is based on SYS/BIOS version 6.32.02.39. Different versions of SYS/BIOS may contain slightly different features.

2.1 Configuration Tools

The configuration of the SYS/BIOS kernel is saved in the *.cfg file in the project. This file defines the basic parameters for modules used in the system as well as any statically-defined instances of modules.

The configuration file can be modified using one of two methods:

- Graphically (using the XGCONF configuration utility)
- Textually (using the XDCScript editor or other text editor)

After a project is loaded into CCS, open the *.cfg file by right-clicking the file in the project and selecting Open with > XGCONF as shown in Figure 1. For instructions on opening a SYS/BIOS project in CCS, see Section 4, *Running an Existing SYS/BIOS Project*.

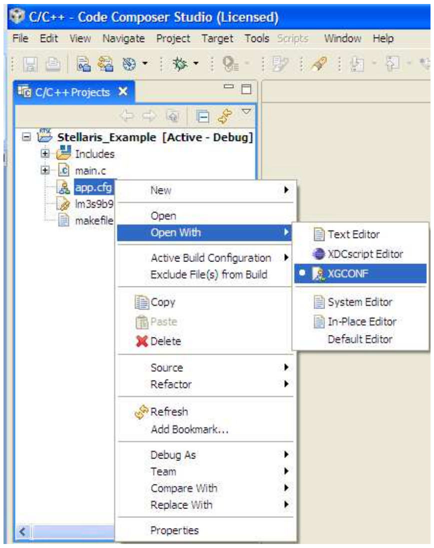


Figure 1. Opening the .cfg File

Figure 2 shows the System Overview tab of the configuration tool that appears after the file opens.

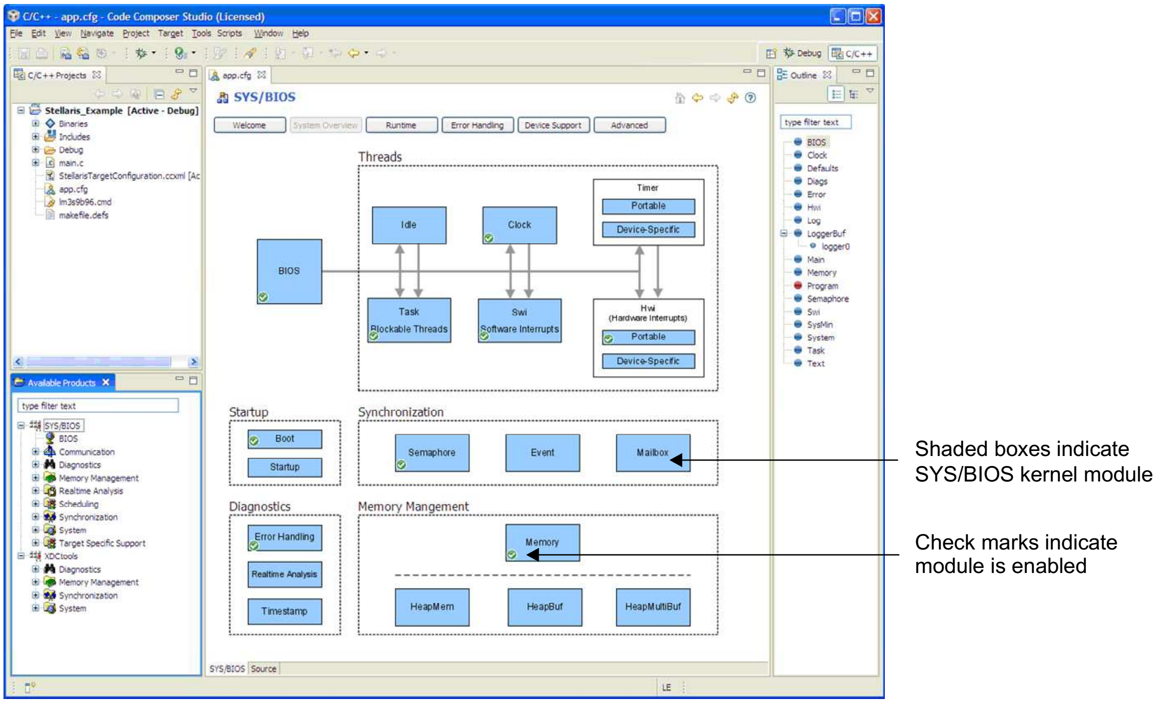


Figure 2. Configuration Tool Overview

Each of the shaded blocks on the screen corresponds to a module within the SYS/BIOS kernel. The check mark in the lower left hand corner of the shaded box indicates that the module is enabled in the current configuration. There are two methods for enabling and disabling the use of modules within a system:

- Right-click the shaded box in the GUI

  OR
- Right-click the module in the Available Products list on the left side of the screen

Figure 3 shows the two methods for adding and removing modules in a SYS/BIOS project.

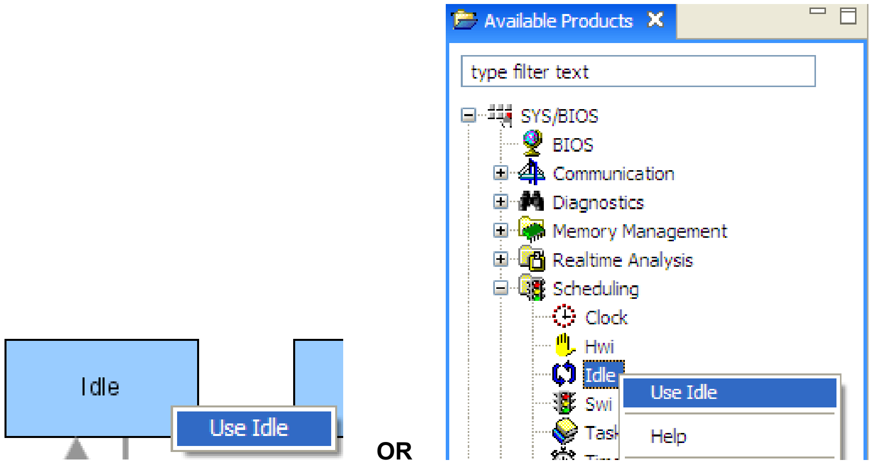


Figure 3. Adding and Removing Modules

Instances of enabled modules can be removed from or added statically to a program using two methods:

- Right-click the shaded box in the GUI

  OR

- Right-click the item in the outline

Figure 4 shows the two methods for creating a new task within a program. Note that instances of modules can be created and configured dynamically at run-time using calls to the SYS/BIOS application programming interfaces (APIs).

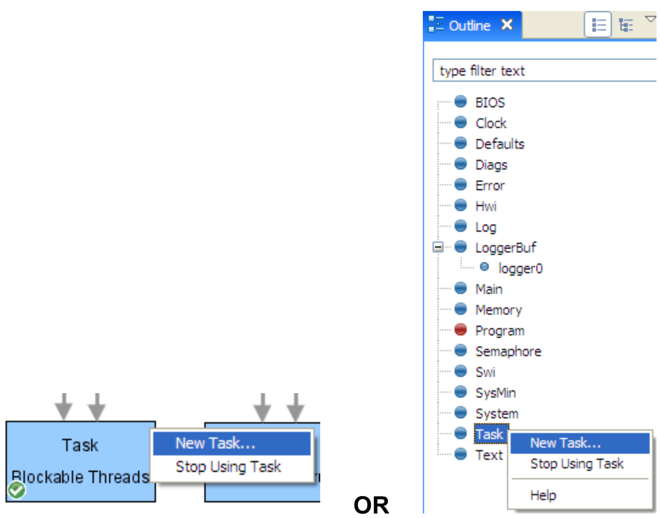


Figure 4. Creating New Module Instances

Double-clicking the shaded box or clicking the item in the outline opens a window with the available options for the module.

Figure 5 shows the options window that appears when the task module is selected. This window controls the global task options. The options for individual tasks are modified by clicking the specific task in the outline.

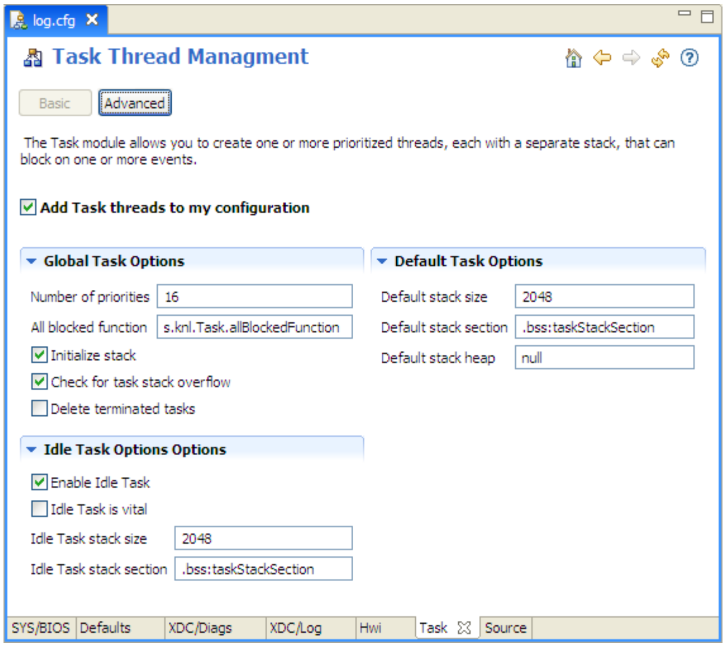


Figure 5. Edit Module Options

In addition to the graphical configuration utility, a text-based editor can be used to configure the RTOS. At the bottom of the window shown in Figure 5 is a *Source* tab. This tab displays the text version of the configuration file. When a module is selected, the relevant code is highlighted, as shown in Figure 6. Clicking an item in the outline changes the sections of code that are highlighted.

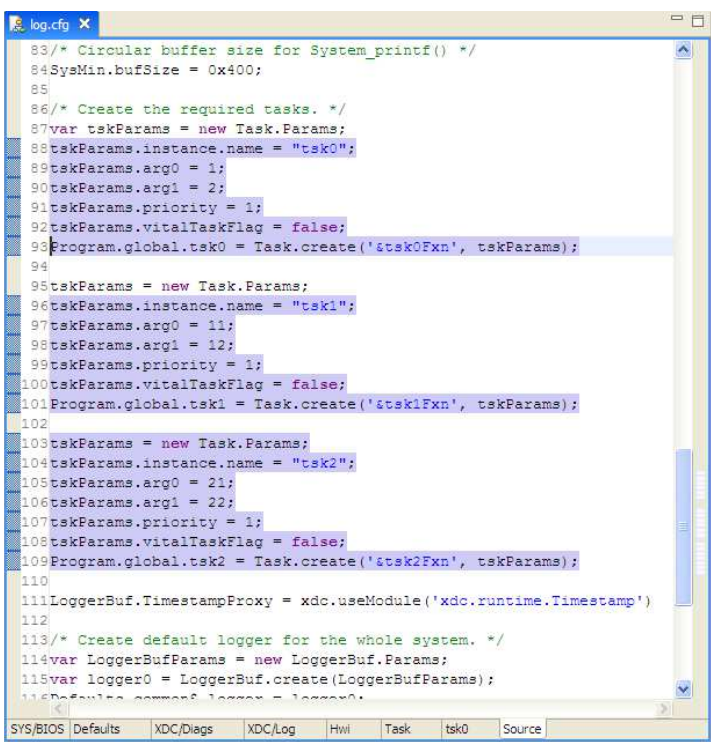


Figure 6. Text-Based Editor

The text-based editor can be opened outside of the GUI editor by right-clicking the .cfg file in the project and selecting either Open With > XDCScript Editor or Open With > Text Editor.

A detailed description of the available parameters is found in the API Reference in the SYS/BIOS section of the Help Contents found in the Help > Help Contents menu of Code Composer Studio.

2.2 Threads and Priority Levels

Within SYS/BIOS, the term *thread* refers to a set of instructions that can be executed by the CPU after the required registers have been properly initialized. The four types of threads available in SYS/BIOS are:

- Hardware interrupt (HWI)
- Software interrupt (SWI)
- Task
- Idle

There are two types of priority levels in a SYS/BIOS system:

- Implicit priority levels—defined by thread type
- Explicit priority levels—defined by the programmer

The implicit priority levels for the four main thread types are shown in Figure 7.

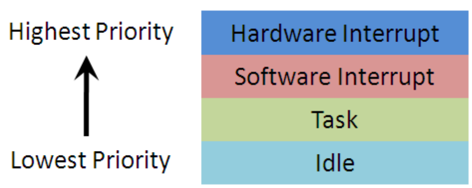


Figure 7. Implicit Thread Priority Levels

Hardware interrupts have the highest implicit priority level in the system followed by software interrupts, tasks, and finally idle tasks, which have the lowest implicit priority level.

The individual HWIs, SWIs, and tasks can be assigned explicit priority levels that are secondary to the implicit priority levels. On Stellaris devices, the maximum number of hardware interrupt priorities is 8, the maximum number of software interrupt priorities is 32, and the maximum number of task priorities is 32. The priority levels assigned to HWIs in a SYS/BIOS-based program changes based on the hardware for which the code is compiled to run. On Stellaris devices, the highest priority HWI has a value of 0 and the lowest value depends on the number of priority levels defined for HWIs. SWIs and tasks inherit the SYS/BIOS default priority levels such that the lowest priority has a value of 0. The highest priority level value for SWIs and tasks depends upon the number of software interrupt priority levels and task priority levels that are implemented.

The preemptive, priority-based scheduler ensures that the highest priority thread that is ready to run is executed by the CPU. A number of threads can be ready to execute at any given time, but the thread with the highest priority executes first. In order to switch between threads, the context of the thread must be saved. This context includes the program counter, the stack, and any relevant register values. Specific stack functionality for each thread type is included in the following sections.

2.3 Hardware Interrupts

Programs without an RTOS typically have a low-priority infinite while loop that is interrupted by a high-priority interrupt service routine (ISR). This type of system allows for two priority levels in a foreground and background scheduling system. This configuration is not easily scalable and is often insufficient for complex systems that require multiple priority levels. A SYS/BIOS-based system introduces threading services that allow for these multiple priority levels and deterministic scheduling.

Figure 8 shows the relationship between a typical program and a program based on the SYS/BIOS RTOS.

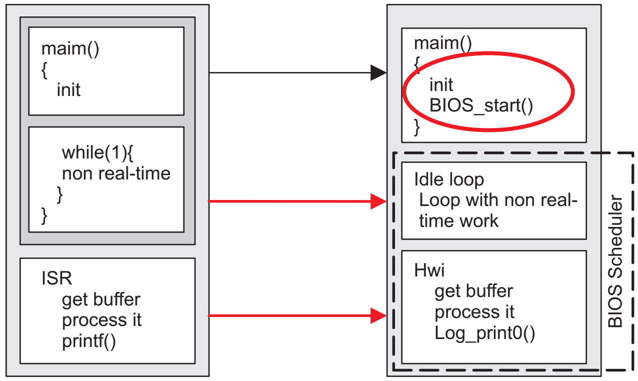


Figure 8. Foreground and Background Scheduling

The Idle loop runs as the lowest priority and is typically used for activating low-power modes, built-in self tests (BISTs), and user interface code. This loop is preempted by higher priority threads and resumes execution at the point where the loop was preempted as soon as the higher priority code completes execution. The hardware interrupt (HWI) replaces the functionality of the interrupt service routine (ISR). The SYS/BIOS scheduler is wrapped around the system to ensure that the highest priority thread is executed as soon as the thread is ready and that program execution is returned to the Idle loop when the HWI completes execution. The BIOS_start( ) function starts the scheduler after the main program initializes the required hardware and peripherals in the main Init( ) function.

An optional addition to a SYS/BIOS program which is enabled in the default configuration is the Interrupt Dispatcher. The Interrupt Dispatcher allows hardware interrupts to run properly with other threads because of its knowledge of the SYS/BIOS scheduler. Low priority threads are properly disabled when the higher priority tasks are executing. The dispatcher also enables several of the debugging features that allow the user to see when interrupts occur. The interrupt dispatcher is a piece of code that is common to all interrupts so the dispatcher can reduce the footprint size of the code. The Interrupt Dispatcher consists of three components:

- Interrupt vectors—the location of the dispatcher is patched into the interrupt vector table
- Dispatch table—contains parameters for the hardware interrupt
- Interrupt stack—saves the context when interrupts preempt each other

Following is an outline of the operation of the Interrupt Dispatcher. The steps in parentheses *( )* can be optimized out depending on the configuration of the system. Configured zero latency interrupts are never disabled by the dispatcher.

1. Globally disable all dispatcher managed interrupts, but not zero latency interrupts, for critical section protection
2. (Disable Task scheduler)
3. (Disable SWI scheduler)
4. Save interrupt return pointer
5. (Call configured HWI begin hook functions)
6. (Globally enable dispatcher managed interrupts, but not zero latency interrupts, if auto-interrupt-nesting support is enabled)
7. Call ISR function
8. (Globally disable dispatcher managed interrupts if auto-interrupt-nesting support is enabled)
9. (Call configured HWI end hook functions)
10. (Run the SWI scheduler which runs any SWIs that were posted by the ISR)
11. (Run Task scheduler, which manages Task pre-emption if required)
12. Return from ISR

Do not use the interrupt keyword when defining a hardware interrupt within a SYS/BIOS program since the Interrupt Dispatcher already handles the saving of the context.

The implementation of hardware interrupts depends on the specific device family. With respect to the Stellaris Cortex-M3 family of devices, the hardware interrupts can be configured to use the Nested Vector Interrupt Controller (NVIC). The NVIC allows the application to take advantage of the minimal interrupt latency built into the core, but the latency is not the default configuration of the SYS/BIOS kernel. The Zero-Latency-Interrupt feature of the SYS/BIOS system bypasses the SYS/BIOS interrupt dispatcher and, therefore, prohibits ISRs from using the SYS/BIOS services and APIs. Additional information about incorporating this type of interrupt structure can be found on the SYS/BIOS for Stellaris Devices Wiki page.

Find more detailed information about hardware interrupts in the SYS/BIOS API Reference in the SYS/BIOS section of the Help Contents found in the Help > Help Contents menu of Code Composer Studio.

2.4 Software Interrupts

Hardware interrupts are often used to service time-sensitive resources. However, once these data have been collected, the data can be passed to a less-restrictive thread for further processing. In SYS/BIOS, software interrupts (SWIs) are often used to process hardware interrupt data. They are preemptive and generally have a priority between 0–15. SWIs operate from a single stack which reduces the memory size of the overall application but prevents SWIs from blocking on semaphores, suspending themselves using a sleep function, or terminating themselves using an exit function. The size of the stack required for the SWIs is directly proportional to the number of priority levels that the system needs. The saving and restoring of the SWI context is automatically handled by the SYS/BIOS kernel. Figure 9 shows how SWIs fit into the SYS/BIOS architecture.

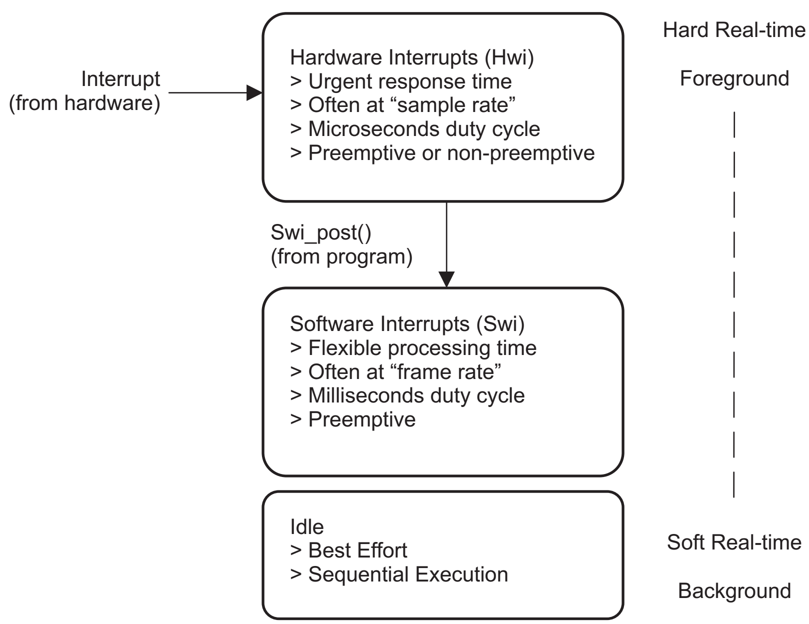


Figure 9. Hardware Versus Software Interrupts

SWIs are made ready to run when the Swi_Post( ) function is called, typically by a hardware interrupt. A SWI runs only once regardless of the number of times the SWI was posted prior to execution.

Figure 10 shows how a system with hardware and software interrupts enabled processes the two threads.

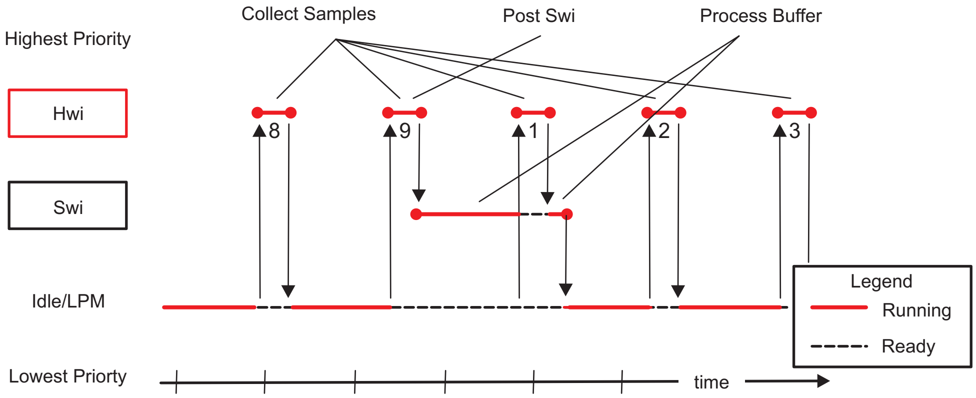


Figure 10. HWI and SWI Example

The HWI is used to collect samples in a periodic time frame and place them into a buffer. The SWI is then used to process one of the samples (for example, sample 9). The processing of this data takes longer than the time between samples. Using this configuration, the HWI is able to retrieve the new data while the SWI continues to process the previous sample. As soon as both the HWI and SWI are finished processing, the Idle thread regains control of the system.

SWIs of the same priority are processed in a first in first out (FIFO)-type system. Figure 11 shows an instance where this may occur and how the interrupts are processed.

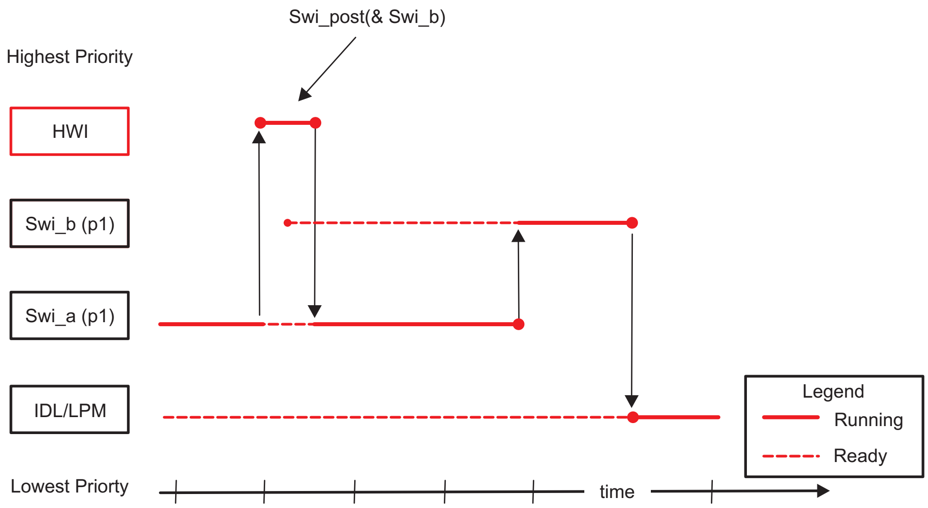


Figure 11. Same Priority SWIs

Swi_a and Swi_b are both set to the same priority level of 1. A HWI preempts the execution of Swi_a and during its process, posts a call to Swi_b. Since the SWIs are of equal priorities, Swi_a must complete executing its instructions before Swi_b can begin executing. As soon as both of the SWIs are done executing, program control is returned to the Idle thread.

Although SWIs only run once regardless of the number of times the SWIs were posted prior to execution, you can also determine how many times a SWI was posted. The Swi_inc( ) function returns the number of times the SWI was posted before the SWI ran. You can also schedule a SWI after the SWI has been called multiple times. The Swi_dec( ) function requires that the SWI is posted an explicit number of times before the SWI is scheduled. These and other functions are explained in further detail in the SYS/BIOS API Reference in the SYS/BIOS section of the Help Contents found in the Help > Help Contents menu of Code Composer Studio.

Find more detailed information about software interrupts in the Software Interrupt Run-Time API in the SYS/BIOS section of the Help Contents found in the Help > Help Contents menu of Code Composer Studio.

2.5 Tasks

The third SYS/BIOS thread type is a task. Unlike hardware and software interrupts, tasks can block and allow other tasks to execute. This requires that each instance of a task has its own stack in memory as opposed to the common stack model that is used by SWIs and HWIs. Therefore, tasks are more memory intensive than other thread types. Tasks can preempt and be preempted based on their priority, which can be changed dynamically. When tasks must wait for an event to occur or a resource to become available, they block themselves using some type of synchronization module, such as a semaphore.

Creating a new task in SYS/BIOS can be done one of two ways:

- Statically at compile time
- Dynamically during runtime

Two tasks can point to a single function as long as the function is re-entrant. Arguments to the function can be used to determine which task called the function.

The life cycle of a task consists of four states:

- **Ready**: a task is ready to be executed
  - If a task is statically created at startup, the task enters this state
  - If a task is dynamically created during runtime using the task_create( ) API, the task enters this state
  - The highest priority task that is ready to run is moved from the ready state to the running state
  - If a task in the ready state calls the task_delete( ) function, the task is moved to the terminated state
- **Running**: a task is the highest priority task ready to run
  - If a higher priority task preempts this task, the scheduler puts the task back into the ready state
  - If a task is running and is then blocked by a semaphore_pend( ) API call because the task is waiting for a resource of event, the status is changed to blocked
  - If the running task calls the task_yield( ) function, the task is moved to the ready state
  - If the task call the task_exit( ) function, the task is moved to the terminated state
- **Blocked**: a task is waiting for a resource or event and posted a semaphore_pend( ) API call
  - If a semaphore_post call is made, the task is moved back to the ready state
- **Terminated**: a task has completed execution
  - A task should not be terminated when the task is in the blocked state to ensure that program resources are properly released before the task is terminated

Figure 12 displays the four task states and how the tasks transition between them.

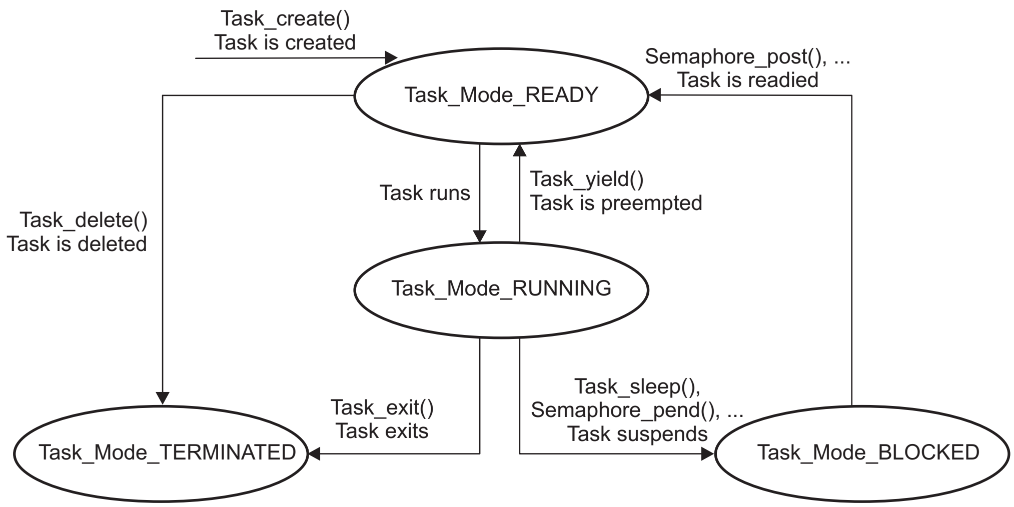


Figure 12. Task State Diagram

Find more information about the SYS/BIOS tasks in the *SYS/BIOS User's Manual* in the SYS/BIOS section of the Help Contents found in the Help > Help Contents menu of Code Composer Studio.

2.6 Synchronization Modules

The SYS/BIOS kernel provides several different modules for synchronizing tasks within the system. These include semaphores, gates, events, and mailboxes.

Semaphores are typically used to protect a hardware resource that is accessed by multiple tasks. Using a semaphore ensures that the task that is accessing the hardware resource completes its action before allowing another task to take control of the resource. An example of an application where a semaphore is useful is when multiple tasks need to write data to a UART interface. Interrupting a task when the task is in the middle of printing a message generates a jumbled message on the output terminal.

Gates are similar to semaphores but are typically used to protect shared sections of software as opposed to hardware resources. There are multiple types of pre-defined gates that can be used or user-defined gates can be created. For example, a gate would be used to protect the writing of a global variable to ensure that the variable is assigned a valid value by one task before another is allowed to access it.

Events are another specific implementation of a semaphore. They require that several conditions exist before a pending thread returns from a pend call. Note that only a single task can pend on an event at a time. In the case of the UART example mentioned above, the second task may want to ensure that the write buffer of the UART module is clear before the task begins writing data to the UART. The task would set up an event to check the UART write buffer before pending on the semaphore.

Mailboxes are used to pass data buffers between tasks. Events can be associated with mailboxes to allow for additional synchronization. Mailboxes can be used to ensure that the flow of incoming buffers does not exceed the ability of the system to process those buffers.

For the purpose of this document, only semaphores are covered in detail. Additional information about other synchronization modules can be found in the *SYS/BIOS User's Manual* in the SYS/BIOS section of the Help Contents found in the Help > Help Contents menu of Code Composer Studio.

Semaphores are used to protect resources that must complete a required operation within one task before switching control to another task. There are two types of semaphores in SYS/BIOS:

- Binary semaphores
- Counting semaphores

Binary semaphores are typically used for resources that are either in use or available. Counting semaphores allow a resource to be accessed by multiple tasks before restricting access to the resource. A count of zero is the lowest possible value for a semaphore and indicates that the resource is not available. Posting to a semaphore increments its count while pending on a semaphore decrements its count.

Calling semaphore_post(mySem) on a semaphore mySem with a count of one results in:

- A count of 2 on a counting semaphore
- A count of 1 on a binary semaphore

The following examples and figures show the operation of semaphores.

If a task is running and calls the Semaphore_pend( ) function (that is, decrements the count of the semaphore) on a semaphore with a count of 2, the task continues to run as show in Figure 13.

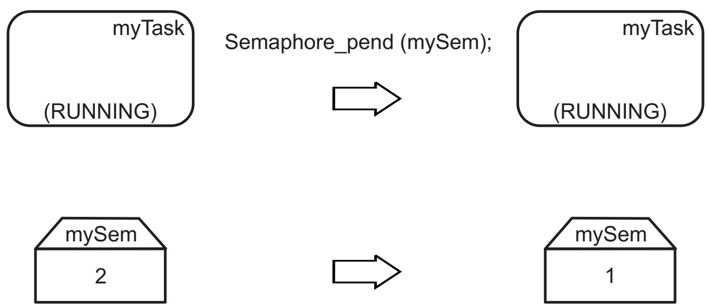


Figure 13. Task Continues to Run After Semaphore_Pend()

However, if a task is running and the task calls the Semaphore_pend( ) function on a semaphore with a count of 0, the task blocks as shown in Figure 14.

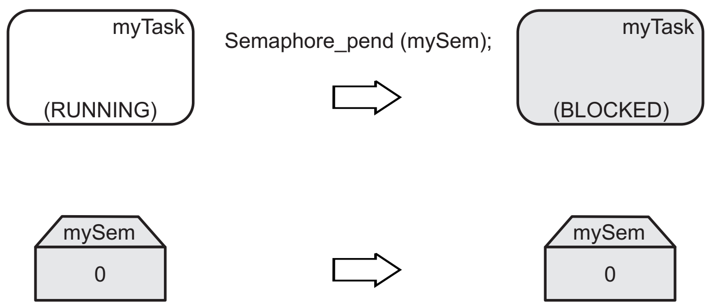


Figure 14. Blocking a Task With a Semaphore

To unblock the task, another task must call the semaphore_post( ) function to increment the count of the semaphore. In the example in Figure 15, the lower priority task posts the semaphore to indicate that the task no longer requires access to the restricted resource. The higher priority task is then switched from the blocked to the running state because the task was waiting for this resource to become available. As soon as the task starts running, the task pends on the semaphore to notify the program that the task is now using the resource controlled by the semaphore.

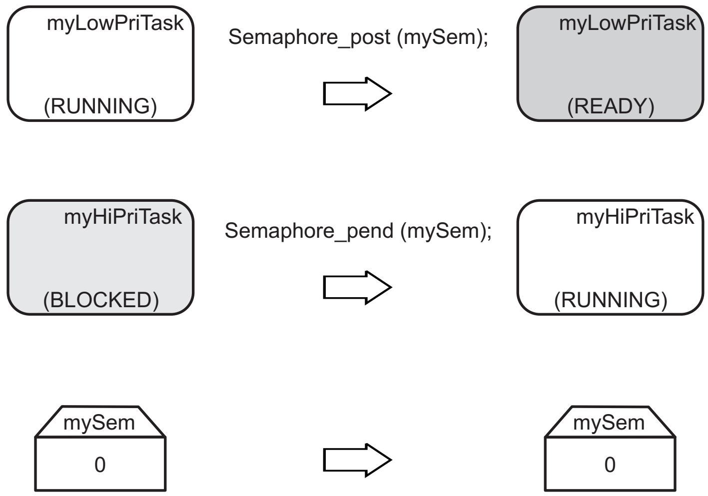


Figure 15. Unblocking a Task With a Semaphore

Note that in the SYS/BIOS kernel, the first task in the semaphore queue (not necessarily the higher priority task) is the first to unblock. This means that the first task that blocked is the first one that will be made ready to run when the semaphore is posted. Another important note is the fact that multiple tasks can block on the same semaphore (as Figure 16 illustrates), where both the high and medium priority tasks are waiting on the same semaphore. Since the medium priority task was the first to pend on the semaphore, the medium priority task is allowed to execute before the higher priority task. This type of priority inversion can be prevented with the use of a specific type of gate called a GateMutexPri.

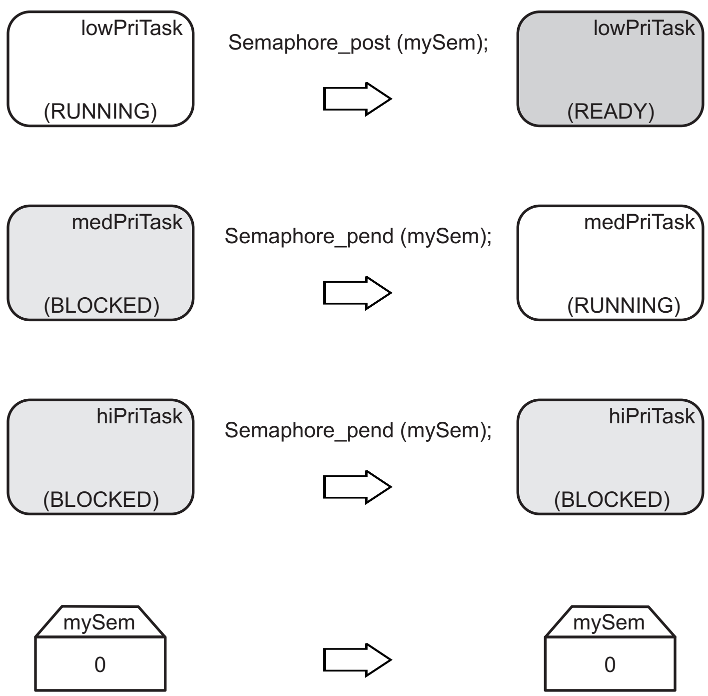


Figure 16. Unblocking a Task With a Semaphore When Multiple Tasks Are Blocked

Find more information about the SYS/BIOS semaphores in the *SYS/BIOS User's Manual* in the SYS/BIOS section of the Help Contents found in the Help > Help Contents menu of Code Composer Studio.

2.7 Timers and Clocks

Timers and clocks can be configured within SYS/BIOS to maintain portability between TI microcontrollers. When the SYS/BIOS timer module is used, the kernel manages the hardware timer peripherals on the device. Timer threads are run within the context of a HWI thread.

The SYS/BIOS clock module layers on top of the timer modules and manages the RTOS time base. The clock module allows functions to be fired as one-shot timers or periodically using the functionality and priority of a software interrupt (SWI). Clocks run at the same SWI priority so they cannot preempt each other.

In the case of the Stellaris Cortex-M3, the SysTick timer in the core can be used as the RTOS time base by adding the following lines into the configuration file:

```
var halTimer = xdc.useModule('ti.sysbios.hal.Timer');
halTimer.TimerProxy = xdc.useModule('ti.sysbios.family.arm.m3.Timer');
```

More information about using specific Cortex-M3 timers in a SYS/BIOS application can be found on the SYS/BIOS for Stellaris Devices Wiki page.

In addition to the timer and clock module, a timestamp module is provided as a component of the SYS/BIOS architecture. This module is useful for benchmarking applications that require precise timing measurements.

Find more information about the SYS/BIOS timers and clocks in the *SYS/BIOS User's Manual* in the SYS/BIOS section of the Help Contents found in the Help > Help Contents menu of Code Composer Studio.

2.8 Debugging Tools

The process of debugging a real time system requires additional real-time analysis tools because of the latency that is introduced into the system with a traditional debugger. SYS/BIOS provides several tools and features including:

- Asserts
- Logging in application and RTOS
- Real-time analysis

Asserts check for common user mistakes such as calling an API with an invalid argument or from an unsupported context. Logging prints important events in both the application and the RTOS to a terminal for debugging timing issues in a system. Real-time analysis streams debugging data to the host without stopping the processor.

An important feature to note about the SYS/BIOS debugging tools is that the log and trace information is formatted on the host computer so that the application processor can continue to execute code with minimal to no interference.

To access the SYS/BIOS real-time analysis (RTA) tools, make sure CCS is in the debug perspective. Then, navigate to the Tools > RTA menu option to see the available RTA tools. Figure 17 displays the available RTA tools.

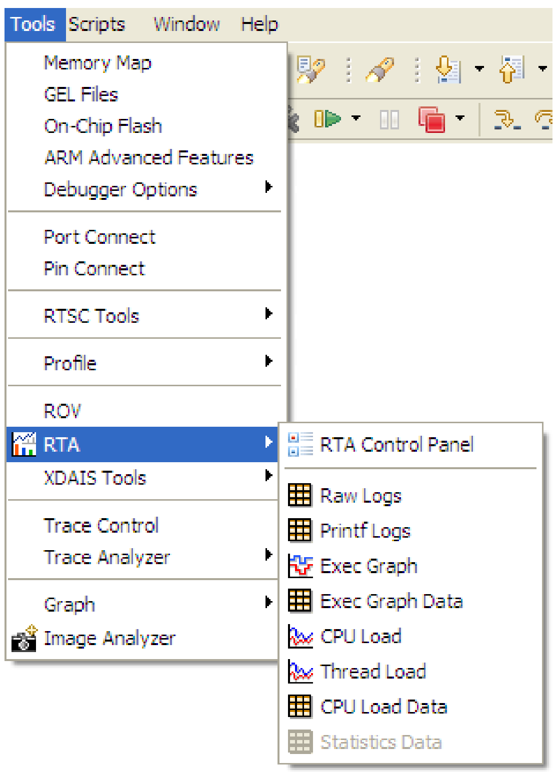


Figure 17. Real-Time Analysis Tools

In addition to the RTA tools, the Runtime Object Viewer (ROV) can analyze a SYS/BIOS system. This tool contains a list of the modules used in the program and displays detailed information about the selected module. For example, if the task module is selected, the mode, arguments, stack size, and other attributes of each of the tasks are updated when the program is paused or a breakpoint is encountered.

Find more information about the SYS/BIOS debugging tools in the *SYS/BIOS User's Manual* in the SYS/BIOS section of the Help Contents found in the Help > Help Contents menu of Code Composer Studio.

3 Downloading SYS/BIOS

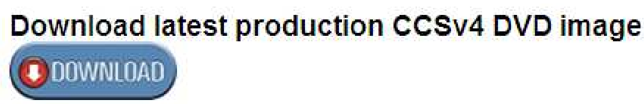
SYS/BIOS is provided as part of Texas Instruments' Code Composer Studio (CCS) Integrated Development Environment (IDE). SYS/BIOS can also be downloaded as a stand-alone component, but this download process is not explained in this document. For more information about the stand-alone component, visit the SYS/BIOS Wiki.

Download the latest version of CCS from the Texas Instruments Embedded Processors Wiki. Note that the code size limited version of CCS does not include SYS/BIOS, so you must download the full DVD versions.

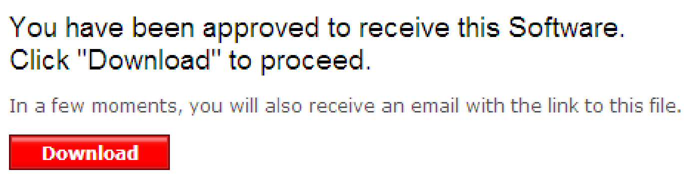
For the purpose of this document, CCS version 4.2.4.00033 was used. Different versions of CCS can be used but may contain slightly different features.

To download and install Code Composer Studio:

1. Go to http://processors.wiki.ti.com/index.php/Download_CCS
2. Click the **Download** button for the latest production CCSv4 DVD image

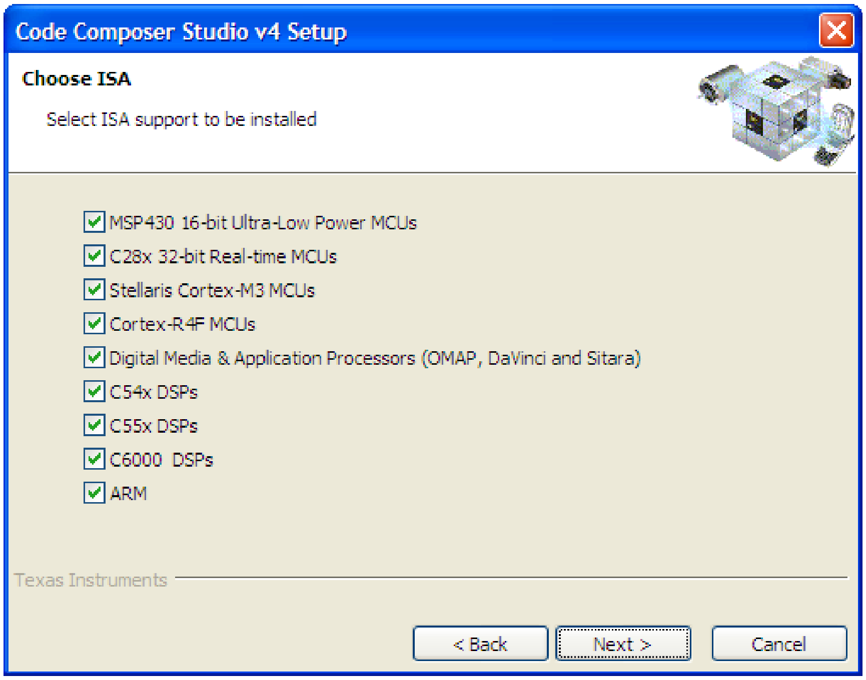


3. Click the **Download** button to download the .zip file.



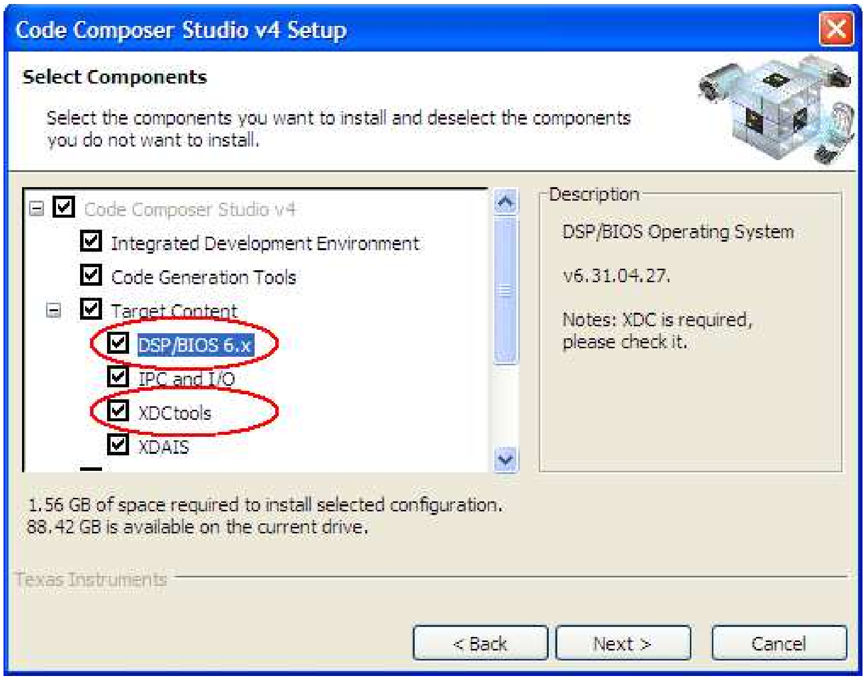
4. Save the .zip file.
5. Extract the .zip file.
6. Run setup_CCS_x.x.x.x.exe.
7. You can use the default installation settings or only install the required components for the Stellaris family of devices (Stellaris Cortex-M3 CPUs and ARM).

   Note: This screen lists the CCS packages that are not yet installed, so the screen may look different.


Code Composer Studio v4 Setup
Choose ISA
Select ISA support to be installed
MSP430 16-bit Ultra-Low Power MCUs
C28x 32-bit Real-time MCUs
Stellaris Cortex-M3 MCUs
Cortex-R4F MCUs
Digital Media & Application Processors (OMAP, DaVinci and Sitara)
C54x DSPs
C55x DSPs
C6000 DSPs
ARM
Texas Instruments
< Back
Next >
Cancel

8. Click **Next**.

9. Make sure that the DSP/BIOS 6.x and XDCtools boxes are checked on the next installer window.



10. Click **Next** and CCS installs to the selected directory.
11. Click **Finish** when the installer completes.

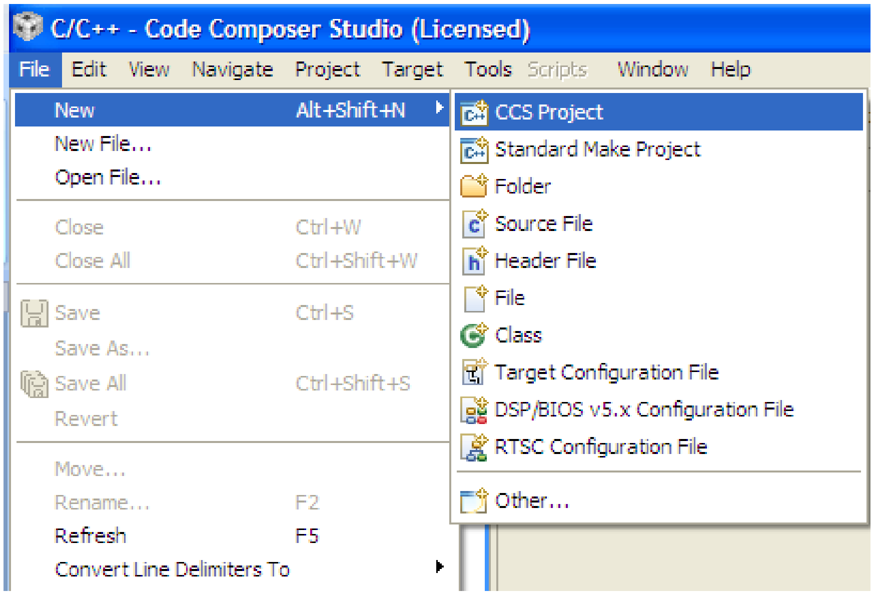
4 Running an Existing SYS/BIOS Project

The SYS/BOIS software package comes with several examples programs that showcase the features and capabilities of the kernel. The following steps outline the process of opening one of these examples and running the example on a target device.

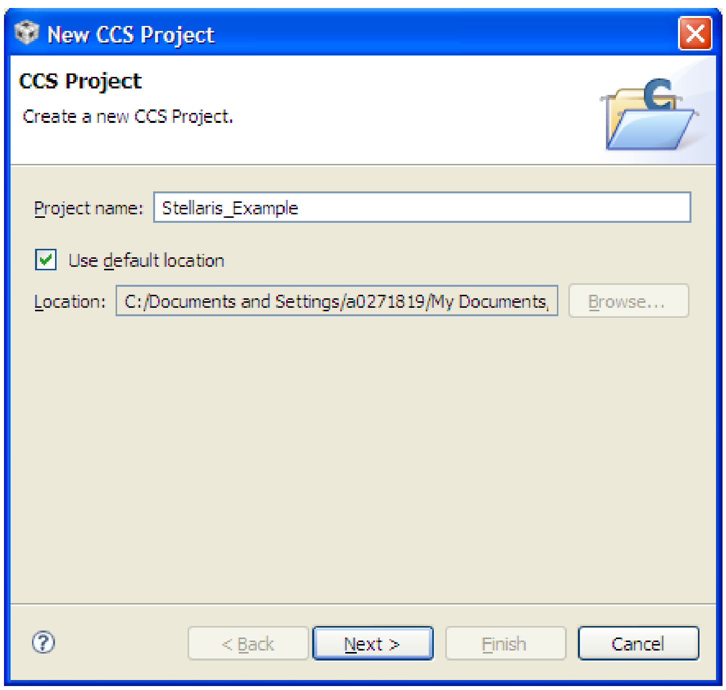
For the purpose of the example project, the Stellaris DK-LM3S9B96 development board is used. However, any of the Stellaris Cortex-M3 devices can be substituted and used as the platform for this example.

1. Launch CCS from Start > All Programs > Texas Instruments > Code Composer Studio v4.2.x > Code Composer Studio v4.
2. Make sure that the C/C++ perspective is selected in CCS.

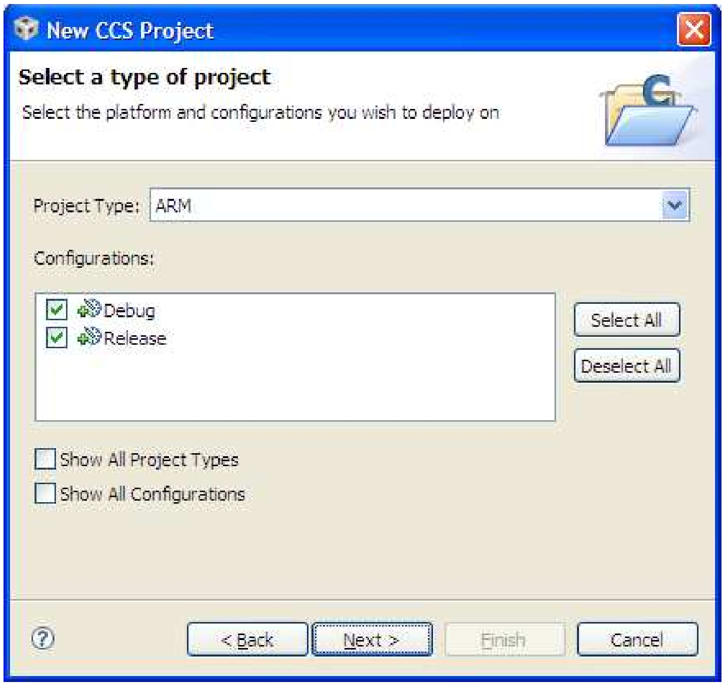
3. Select File > New > CCS Project.



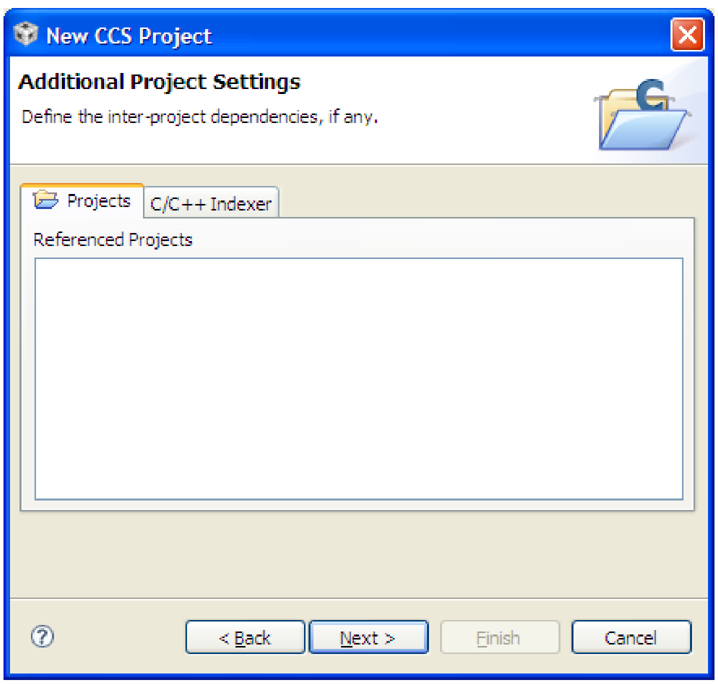
4. Type a name for the project in the Project name: field.



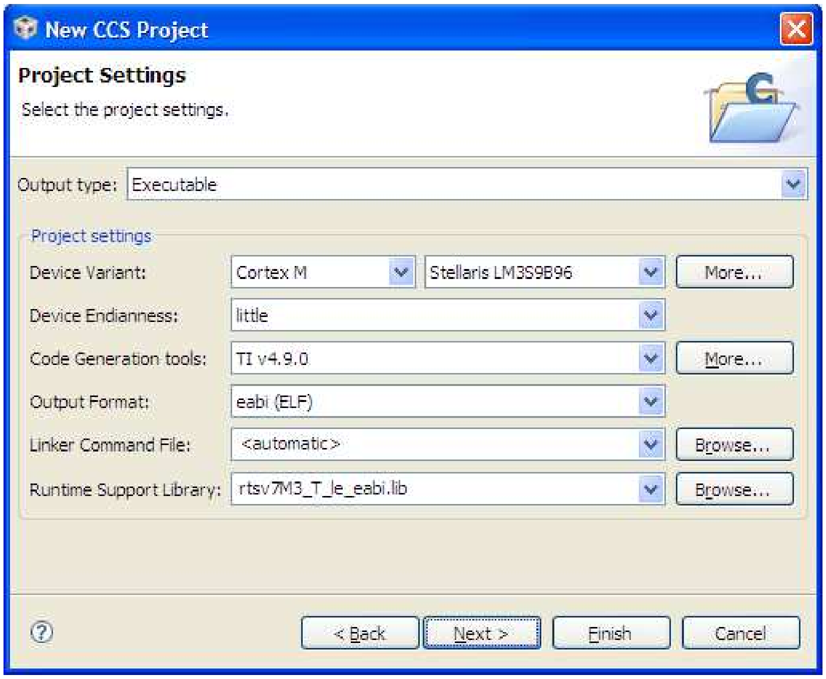
5. Click **Next**. Confirm that the ARM option is selected in the Project Type: drop-down menu.



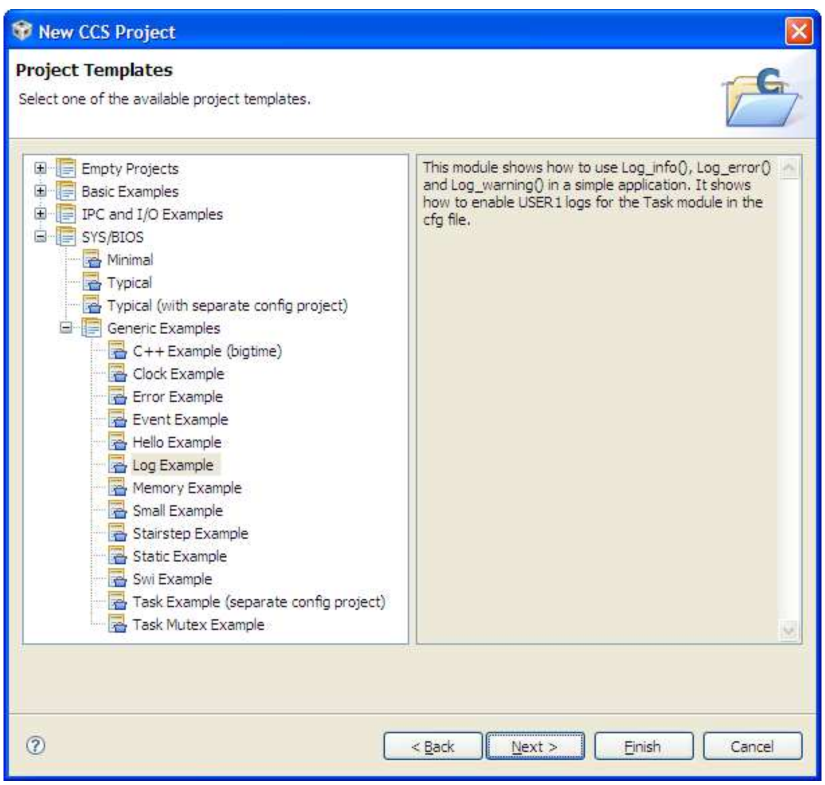
6. Click **Next**. In this case, there will not be any referenced projects, so leave all project boxes unchecked if any appear in the Referenced Projects field.



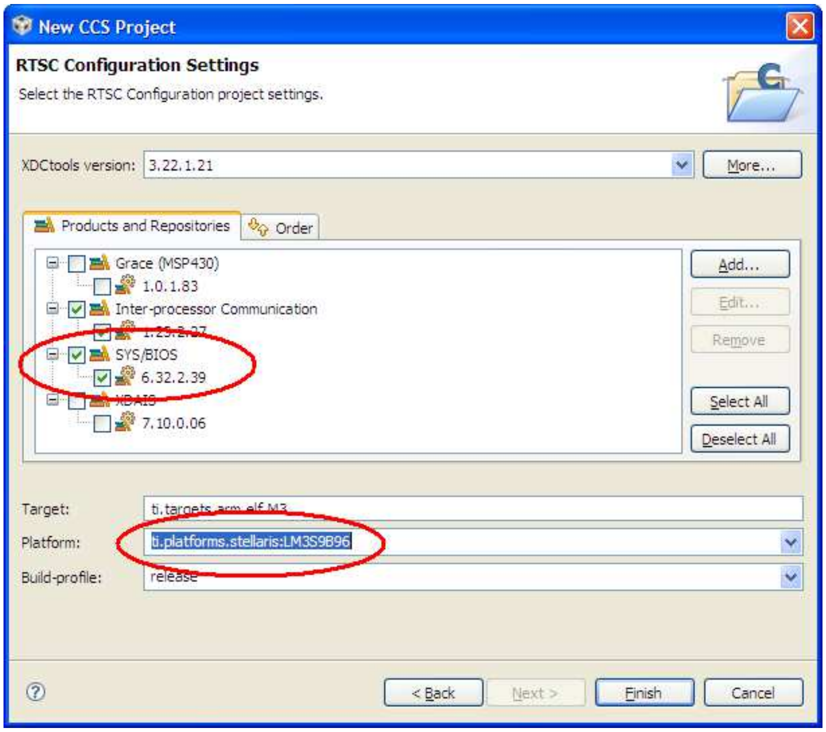
7. Click **Next**. Select Cortex M from the left Device Variant: drop-down menu. Select the Stellaris device you are using from the drop-down menu to the right of the Cortex M selection.



8. Click **Next**. Under the SYS/BIOS folder, select Generic Examples. Clicking each of the examples displays an explanation of the example in the right-hand window. Select the Log Example.



9. Click **Next**. Make sure that the SYS/BIOS box is checked in the main window. Also, select the appropriate platform from the Platform: drop-down menu.



10. Click **Finish**.

11. After the project is loaded, the project can be built and debugged. (See Section 5.3, *Building and Debugging a Project*.) The log example showcases the features of the Raw Logs and Printf Logs Real-Time Analysis (RTA) Tools. (See Section 2.8, *Debugging Tools*.)

5 Creating a Sample SYS/BIOS Project

Creating a new SYS/BIOS project is easily done with the use of the provided project templates. There are three types of templates:

- Minimal
- Typical
- Typical with a separate configuration project

The minimal template is used for applications that use only statically defined objects. Dynamic memory allocation is disabled to improve the code size and performance of the system. The template opens with a single task function consisting of several printf ( ) statements and a call to the Task_sleep( ) function.

The typical template is a common starting place for most SYS/BIOS applications. Unlike the minimal template, the typical template enables dynamic memory allocation which allows tasks to be created at runtime instead of statically defined at compile time. In fact, the example project opens with a call to the Task_create ( ) function in order to define the single default task.

The typical template with a separate configuration template creates a typical project in addition to a second project that contains the configuration file for the first project. Multiple projects can now reference the single configuration project for their SYS/BIOS settings thereby reducing build times and allowing several developers to use a uniform configuration.

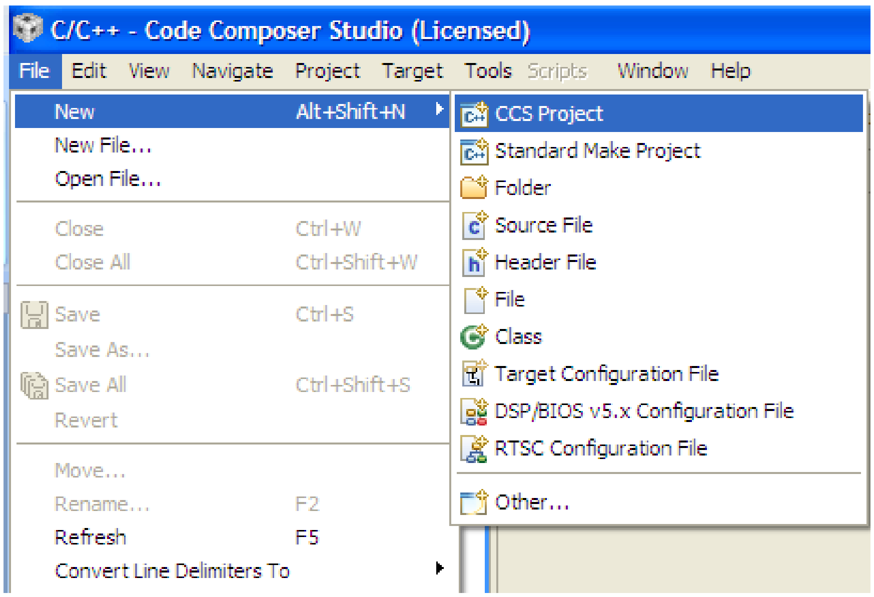
For the purpose of the example project listed below, the Stellaris DK-LM3S9B96 development board is used. However, any of the Stellaris Cortex-M3 devices can be substituted and used as the platform for this example.

5.1 Creating a New Project

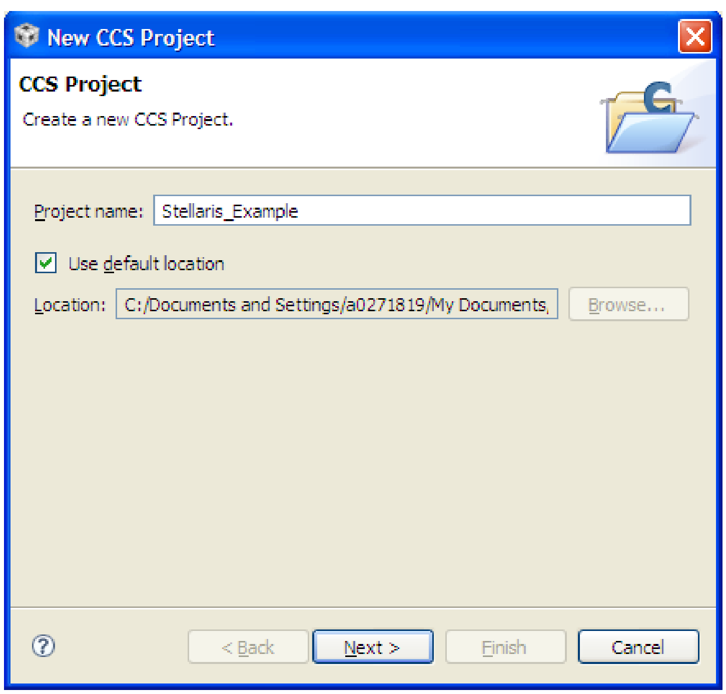
This section describes how to load a project template into the workspace.

1. Launch CCS from Start > All Programs > Texas Instruments > Code Composer Studio v4.2.x > Code Composer Studio v4.
2. Make sure that the C/C++ perspective is selected in CCS.

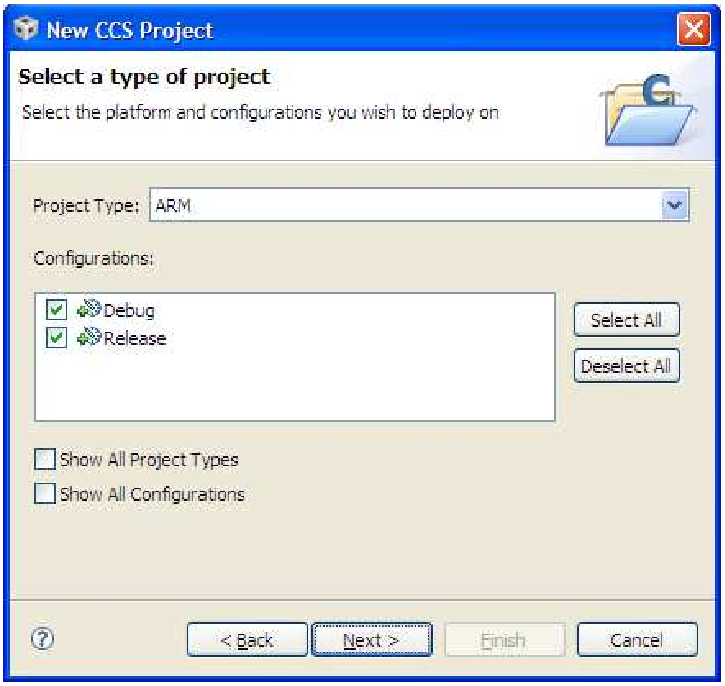
3. Select File > New > CCS Project.



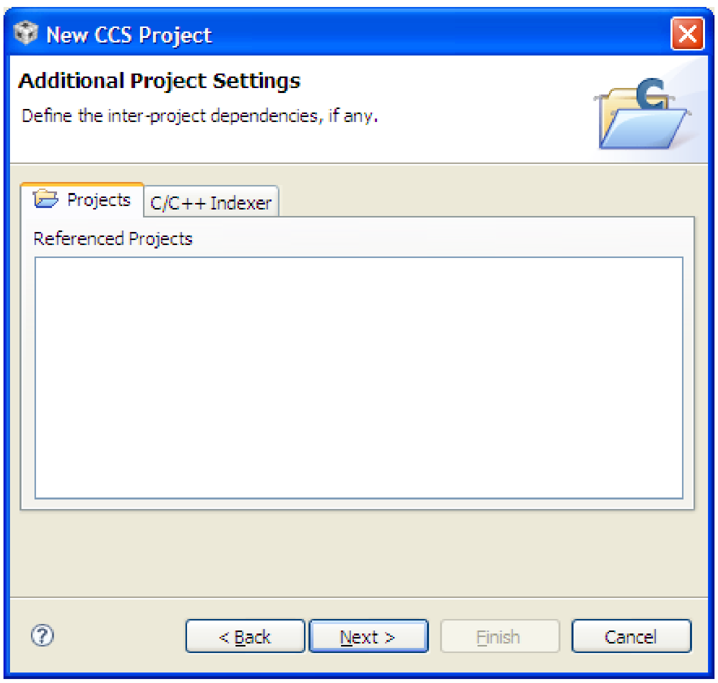
4. Type a name for the project in the Project name: field.



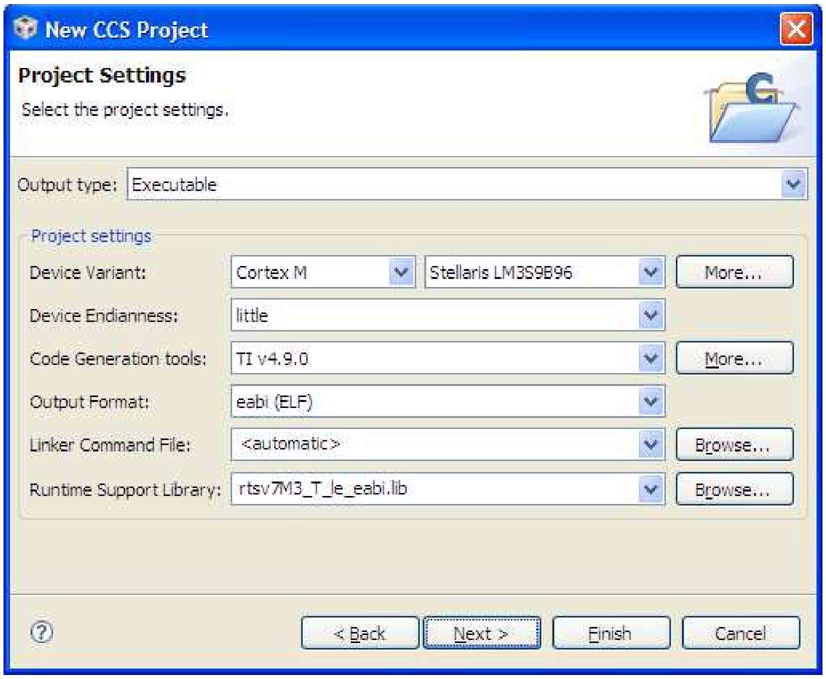
5. Click **Next**. Confirm that the ARM option is selected in the Project Type: drop-down menu.



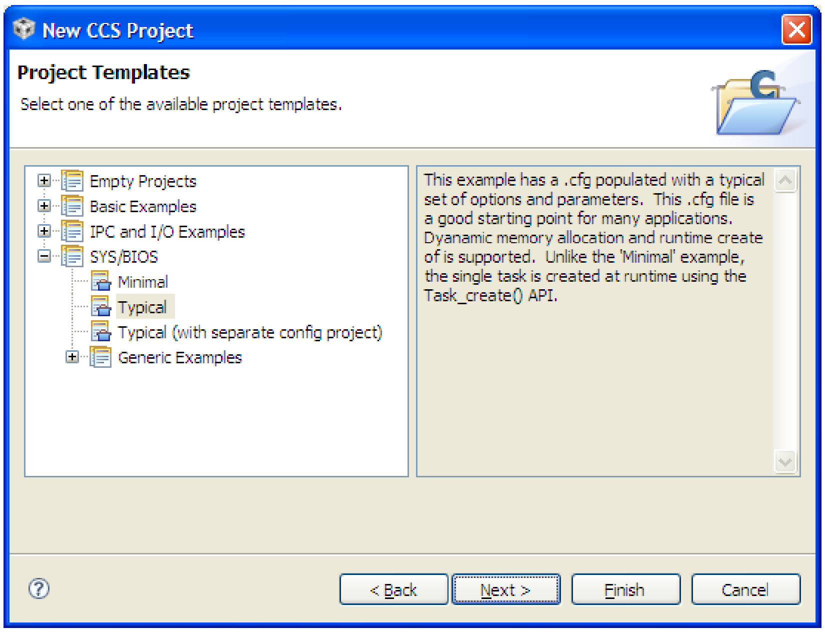
6. Click **Next**. In this case, there will not be any referenced projects, so leave all project boxes unchecked if any appear in the Referenced Projects field.



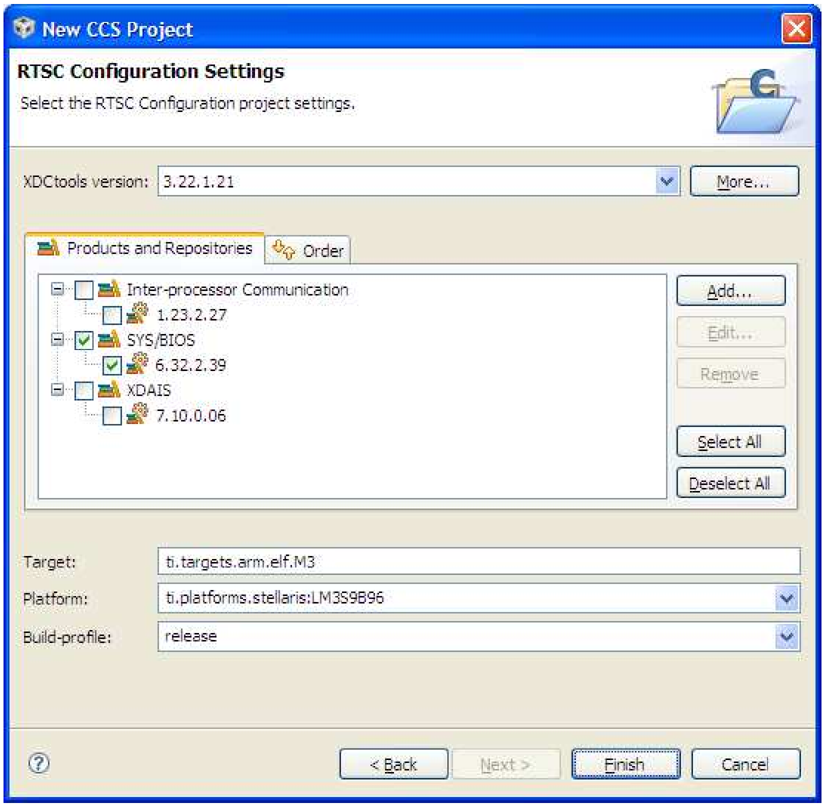
7. Click **Next**. Select Cortex M from the left Device Variant: drop-down menu. Select the Stellaris device you are using from the drop-down menu to the right of the Cortex M selection.



8. Click **Next**. Under the SYS/BIOS folder, select the new project type you would like to use (minimal, typical, or typical with a separate config project). These options are explained earlier in this section (see Section 5, *Creating a Sample SYS/BIOS Project*). Choose Typical for this example project.



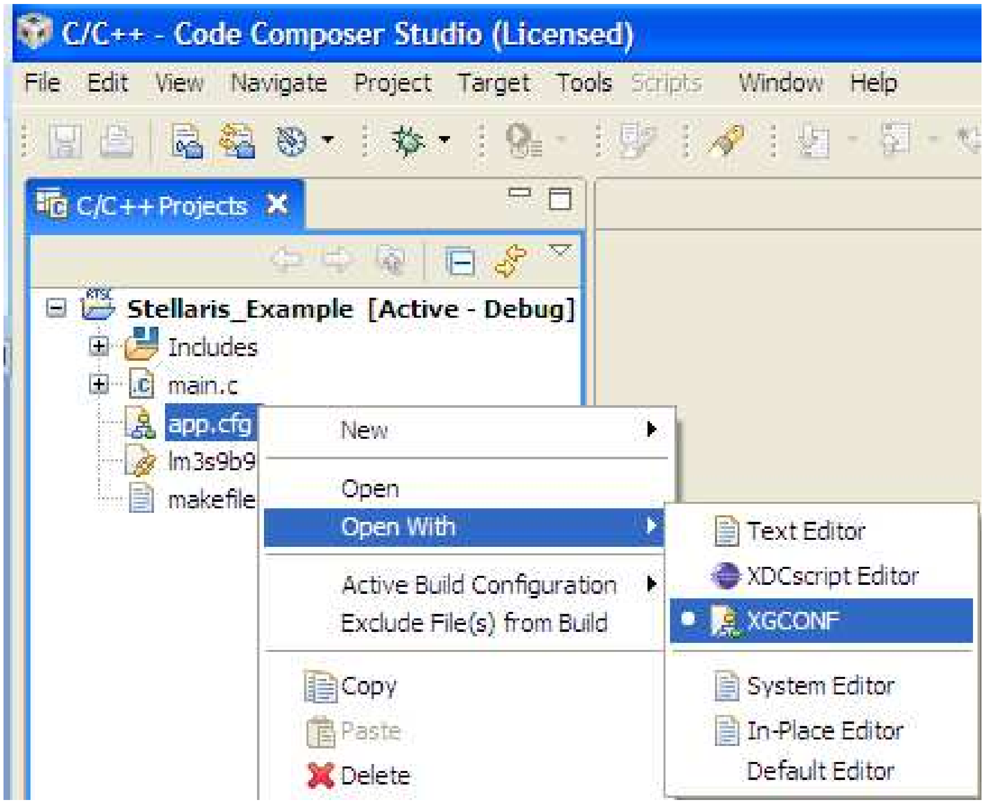
9. Click **Next**. Select the appropriate platform from the Platform: drop-down menu.



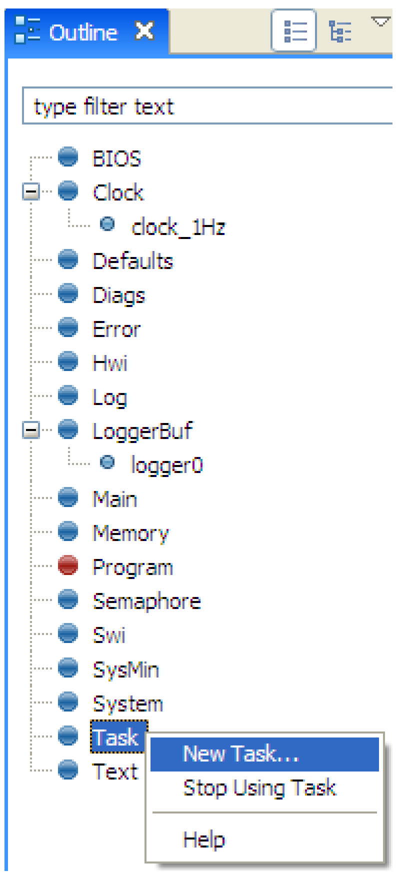
10. Click **Finish**.

11. Since we are using the StellarisWare library to access the GPIO peripheral, you must add driverlib to the project by following the steps provided in Section 5, *Creating a Sample SYS/BIOS Project*.

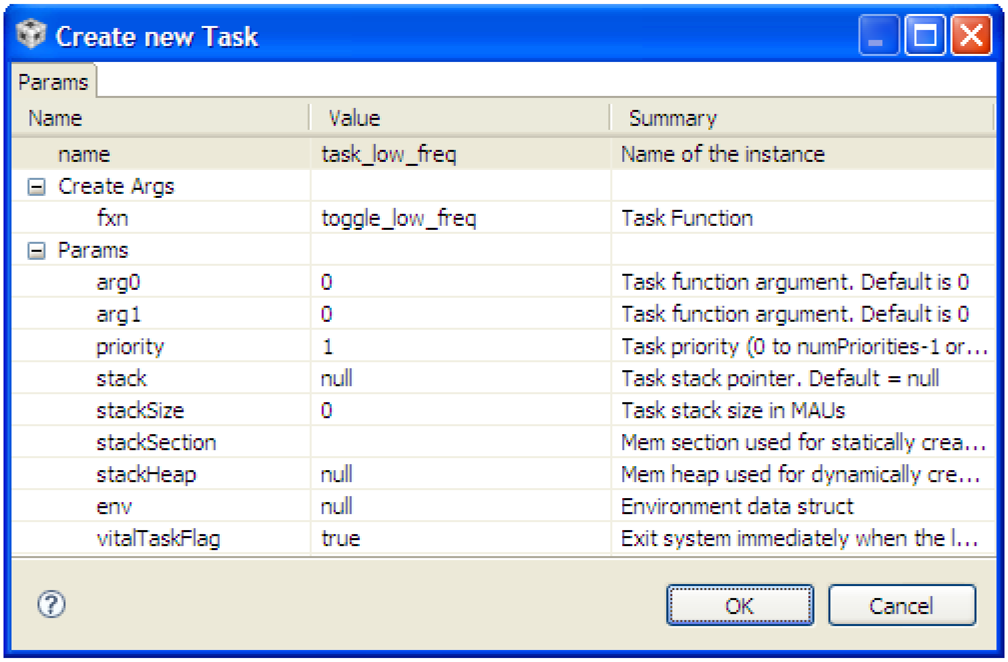
12. To begin editing the properties of the program, expand the project folder, right-click the app.cfg file, and select Open With > XGCONF. The main GUI editor opens. From here, the settings of the SYS/BIOS kernel can be modified. See Section 2.1, *Configuration Tools*, for more information about configuring the system.



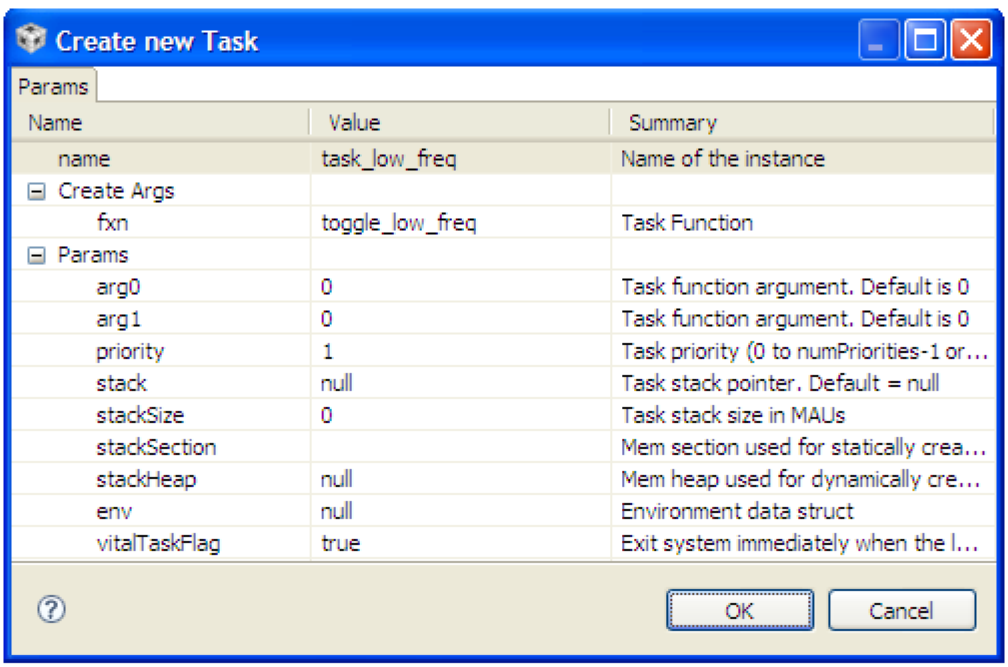
13. Create a new task by right-clicking Task and selecting New Task.



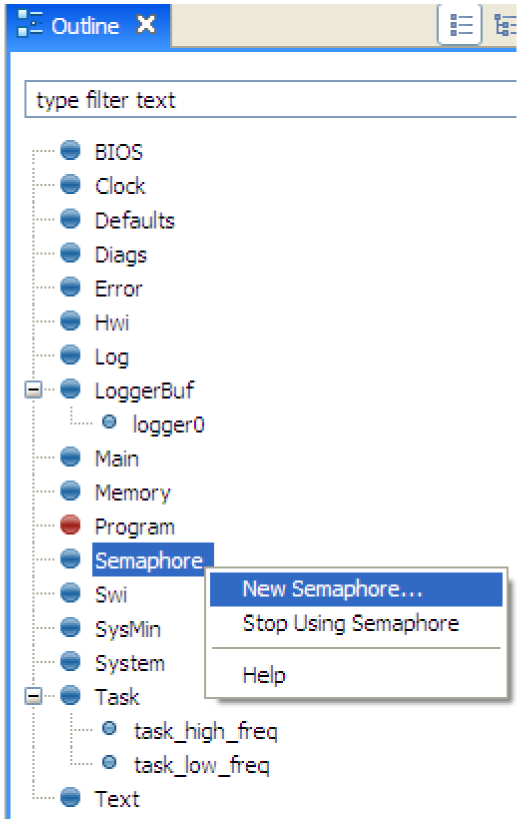
14. Edit the fields of the new task instance as shown. Click **OK**.



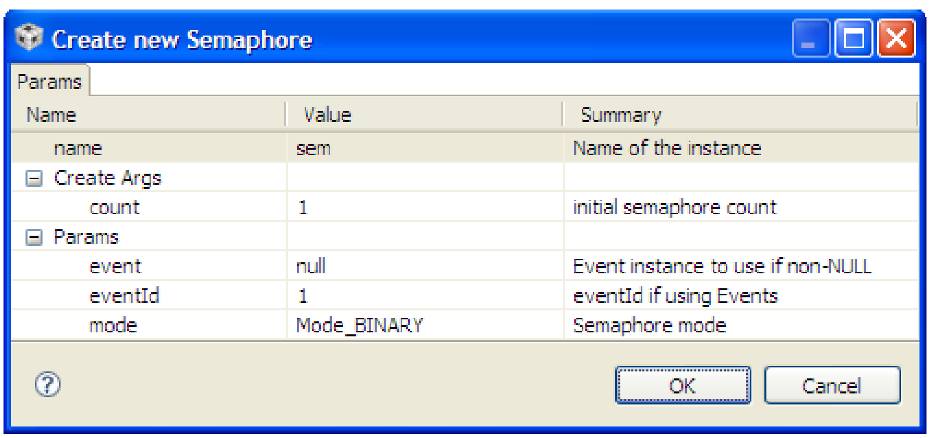
15. Add a second task instance by following the same method. Click **OK**.



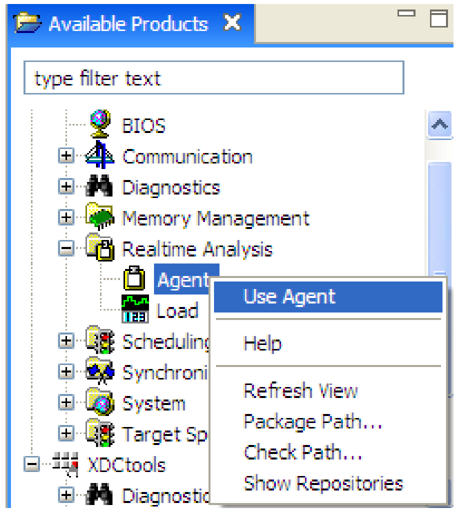
16. Create a new semaphore by right-clicking Semaphore and selecting New Semaphore.



17. Edit the fields of the new semaphore instance as shown. Click **OK.**



18. Add the Agent module to enable the real-time analysis tools for debugging.



19. Modify the main.c file to look like the following text.

```
/*
* ======== main.c ========
*/

#include <xdc/std.h>

#include <xdc/runtime/Error.h>
#include <xdc/runtime/System.h>
#include <xdc/runtime/Log.h>

#include <ti/sysbios/BIOS.h>
#include <ti/sysbios/knl/Task.h>
#include <ti/sysbios/knl/Semaphore.h>

#include "inc/hw_types.h"
#include "inc/hw_memmap.h"
#include "inc/lm3s9b96.h"
#include "driverlib/sysctl.h"
#include "driverlib/gpio.h"

extern Semaphore_Handle sem;

/*
* ======== Task Functions ========
*/

Void toggle_low_freq()
{
    while(1){
        Log_info0("toggle_low_freq() enter");

        //Pend on the semaphore
        Log_info0("toggle_low_freq() pend sem");
        Semaphore_pend(sem, BIOS_WAIT_FOREVER);

        //Set the value of the GPIO pin low
        Log_info0("toggle_low_freq() pin low");
        GPIOPinWrite(GPIO_PORTA_BASE, GPIO_PIN_6, 0);

        //Sleep
        Log_info0("toggle_low_freq() sleep");
        Task_sleep(10);
```

```
        //Post to the semaphore
        Log_info0("toggle_low_freq() post sem");
        Semaphore_post(sem);

        //Sleep
        Log_info0("toggle_low_freq() sleep");
        Task_sleep(10);

        Log_info0("toggle_low_freq() exit");
    }
}

Void toggle_high_freq()
{
    while(1){
        Log_info0("toggle_high_freq() enter");

        //Pend on the semaphore
        Log_info0("toggle_high_freq() pend sem");
        Semaphore_pend(sem, BIOS_WAIT_FOREVER);

        //Set the value of the GPIO pin low
        Log_info0("toggle_high_freq() pin low");
        GPIOPinWrite(GPIO_PORTA_BASE, GPIO_PIN_6, 0);

        //Sleep
        Log_info0("toggle_high_freq() sleep");
        Task_sleep(1);

        //Set the value of the GPIO pin high
        Log_info0("toggle_high_freq() pin high");
        GPIOPinWrite(GPIO_PORTA_BASE, GPIO_PIN_6, GPIO_PIN_6);

        //Post to the semaphore
        Log_info0("toggle_high_freq() post sem");
        Semaphore_post(sem);

        //Sleep
        Log_info0("toggle_high_freq() sleep");
        Task_sleep(1);

        Log_info0("toggle_high_freq() exit");
    }
}

/*
* ======== main ========
*/

Void main()
{
    Log_info0("enter main()");

    //Enable and configure the GPIO peripheral
    SysCtlPeripheralEnable(SYSCTL_PERIPH_GPIOA);
    GPIOPinTypeGPIOOutput(GPIO_PORTA_BASE, GPIO_PIN_6);

    //Initialize GPIO pin PA6 to a value of 0
    GPIOPinWrite(GPIO_PORTA_BASE, GPIO_PIN_6, 0);

    //Start the BIOS scheduler
    BIOS_start(); /* enable interrupts and start SYS/BIOS */
}
```

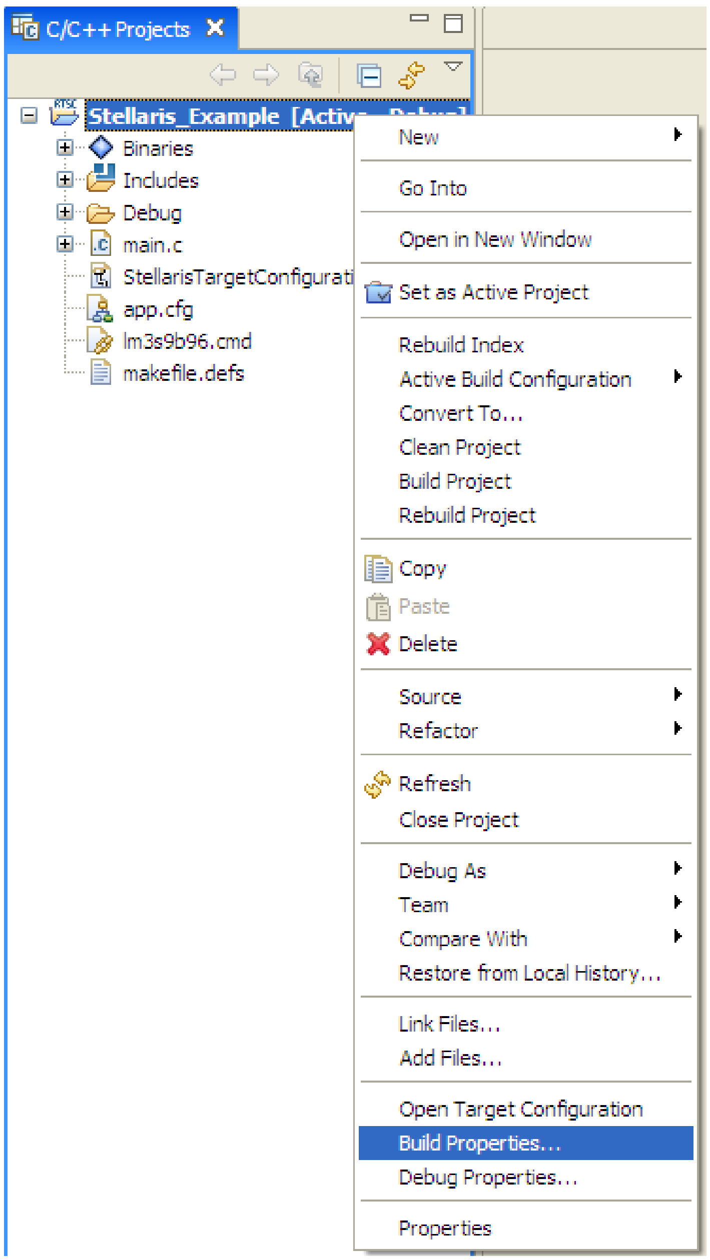
20. Save the project using File > Save All from the menu.

5.2 Integrating StellarisWare Libraries

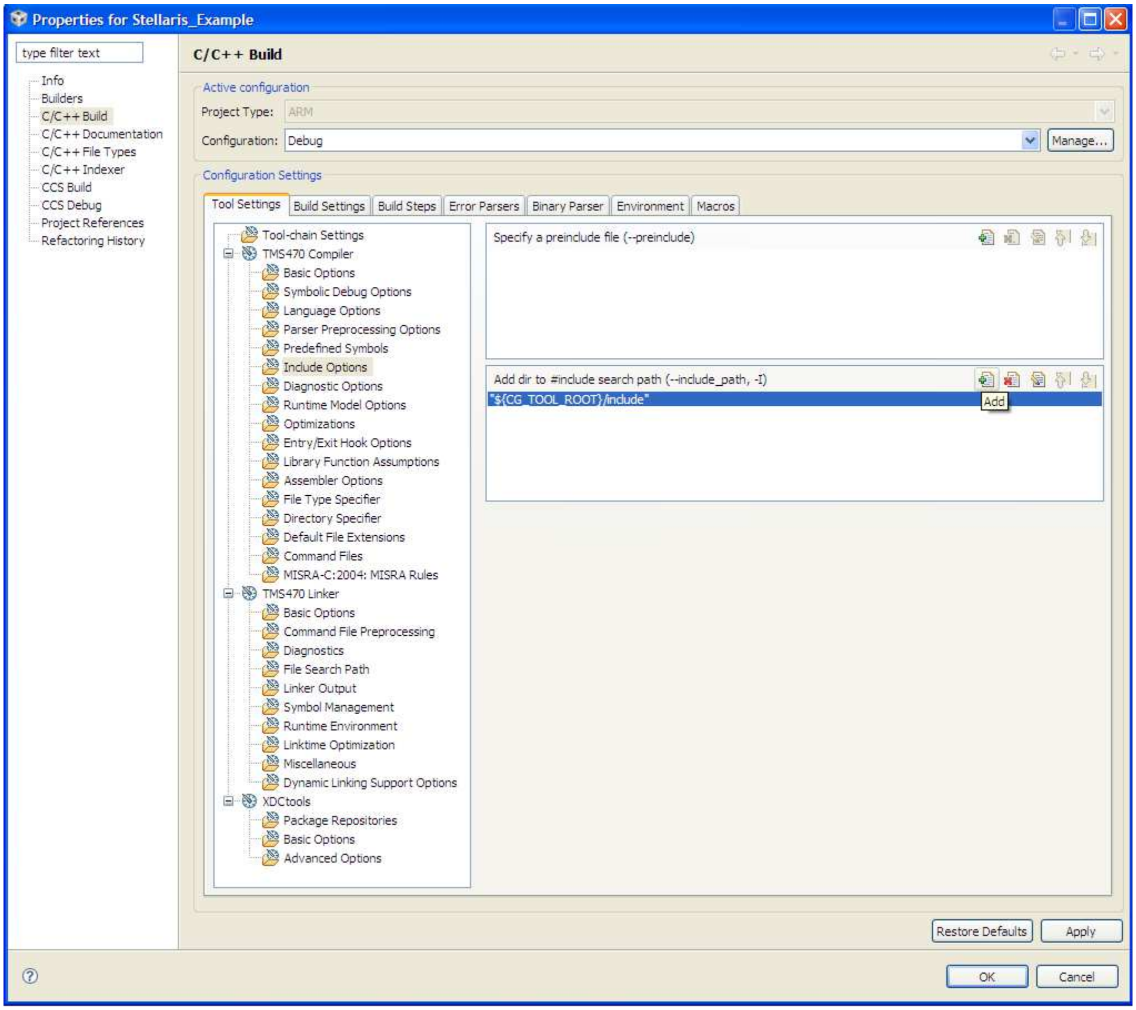
StellarisWare is a software package provided for use with Stellaris microcontrollers that enables the use of API functions located in the read-only memory (ROM) of most Stellaris devices. Note that not all StellarisWare functions are inherently thread-safe. In other words, having a higher-priority task call a function after the first task has started executing the function may cause unexpected failures in the system. To remedy these types of situations, those functions that are not thread-safe and are called from more than one context should be protected with the use of semaphores or gates.

The following steps outline the process of linking the driverlib API library into a SYS/BIOS project. The process should be repeated to incorporate the usblib (USB) and grlib (graphics) libraries. If your project does not include calls to the StellarisWare libraries, you can skip this section and go to Section 5.3, *Building and Debugging a Project*.

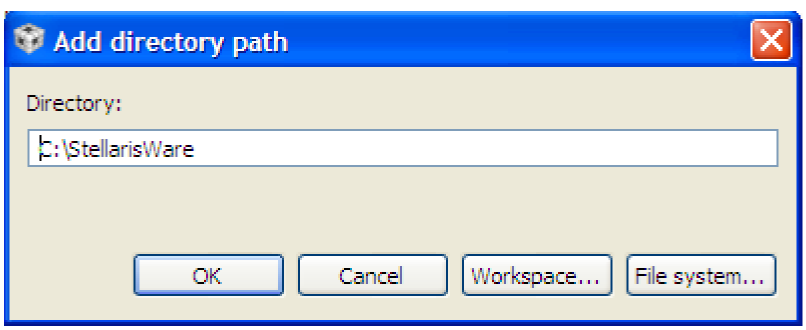
1. Right-click the name of your project and select Build Properties.



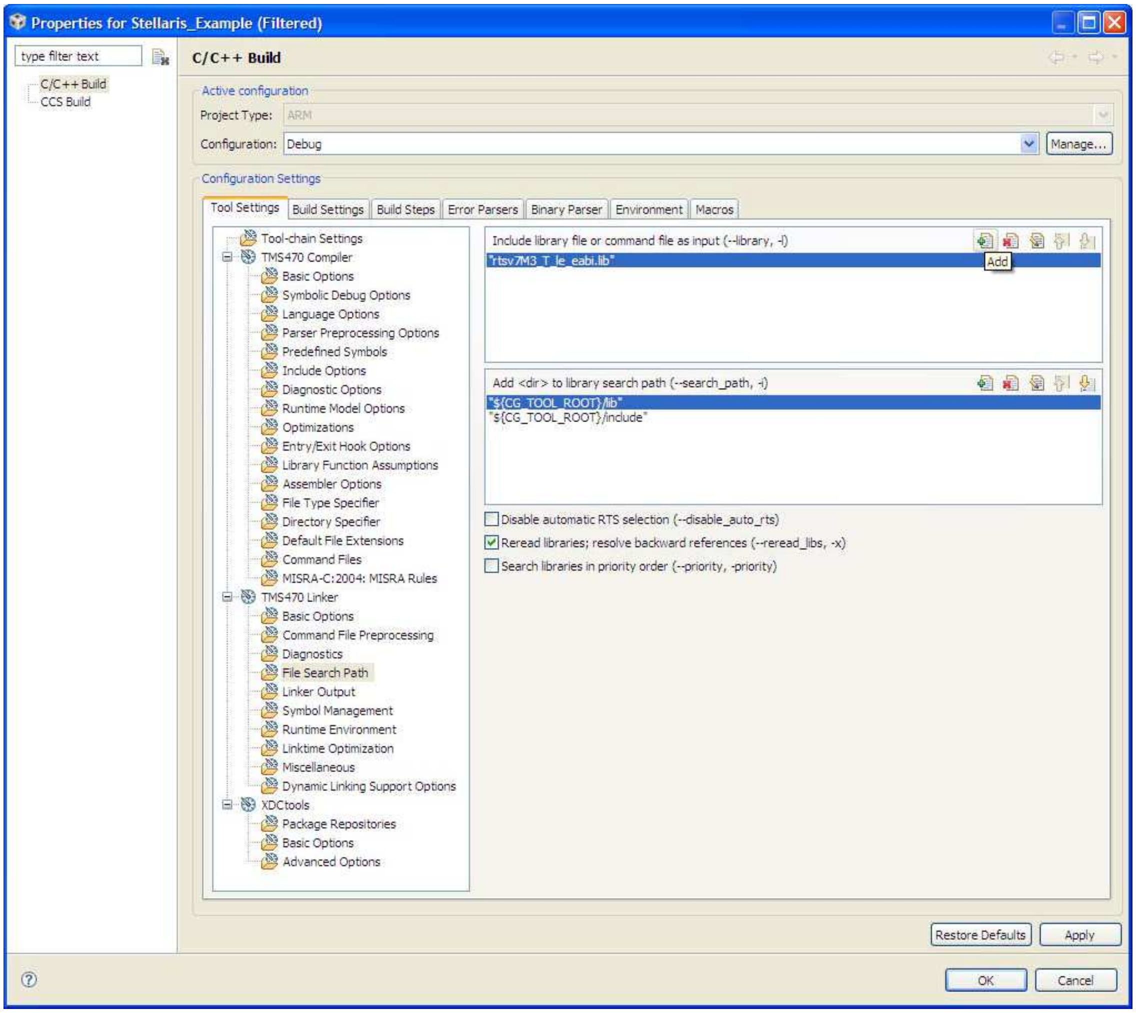
2. Click the *Include Options* folder under the TIMS470 Compiler folder in the folder tree on the Tool Settings tab. Click the **Add** button in the lower box that appears on the right-hand side of the screen.



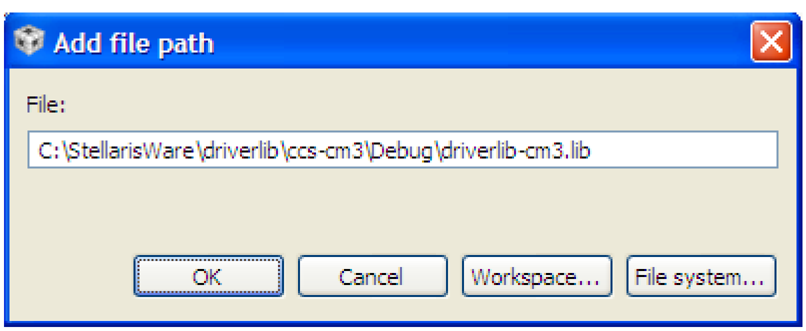
3. Type *C:\StellarisWare* into the Directory: field in the Add directory path dialog box. Click **OK**.



4. Click the *File Search Path* folder under the TMS470 Linker folder in the folder tree on the Tool Settings tab. Click the **Add** button in the upper box that appears on the right-hand side of the screen.



5. Type *C:\StellarisWare\driverlib\ccs-cm3\Debug\driverlib-cm3.lib* into the File: field in the Add file path dialog box.



6. Click **OK** in the Properties window.

7. In the main.c file, add the following include statements to the top of the code:

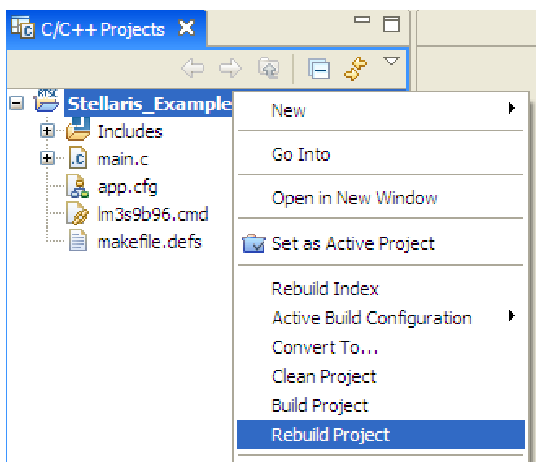
```
#include "inc/hw_types.h"
#include "driverlib/sysctl.h"
```

```
#include <xdc/std.h>

#include <xdc/runtime/Error.h>
#include <xdc/runtime/System.h>

#include <ti/sysbios/BIOS.h>

#include <ti/sysbios/knl/Task.h>

#include "inc/hw_types.h"
#include "driverlib/sysctl.h"
```

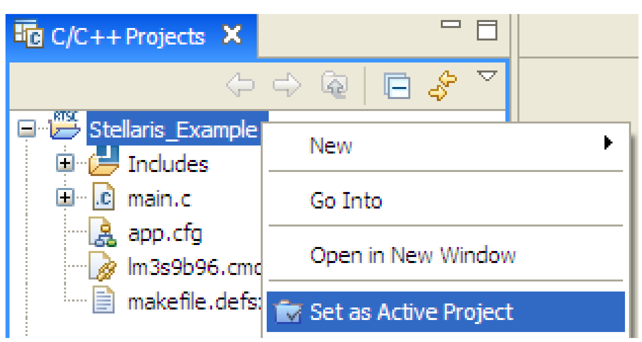
5.3 Building and Debugging a Project

This section outlines the steps required to build a project and launch the project in the debugger. This section also highlights several of the key SYS/BIOS diagnostic tools.

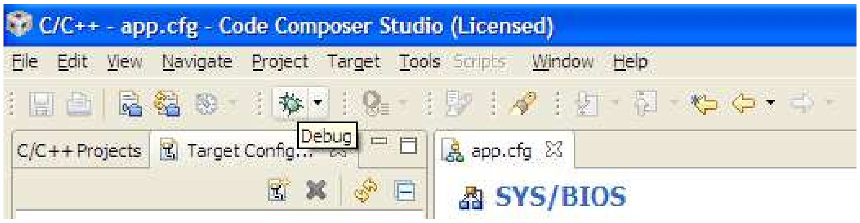
1. Build the project by right-clicking the project and selecting Rebuild Project.



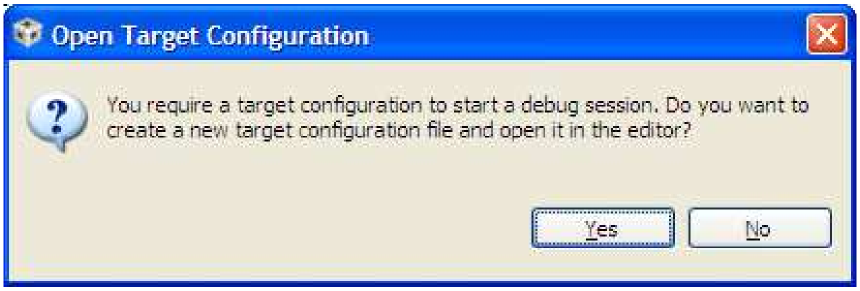
2. Connect the LM3S9B96 development kit to the PC.
3. Set the project as the Active Project.



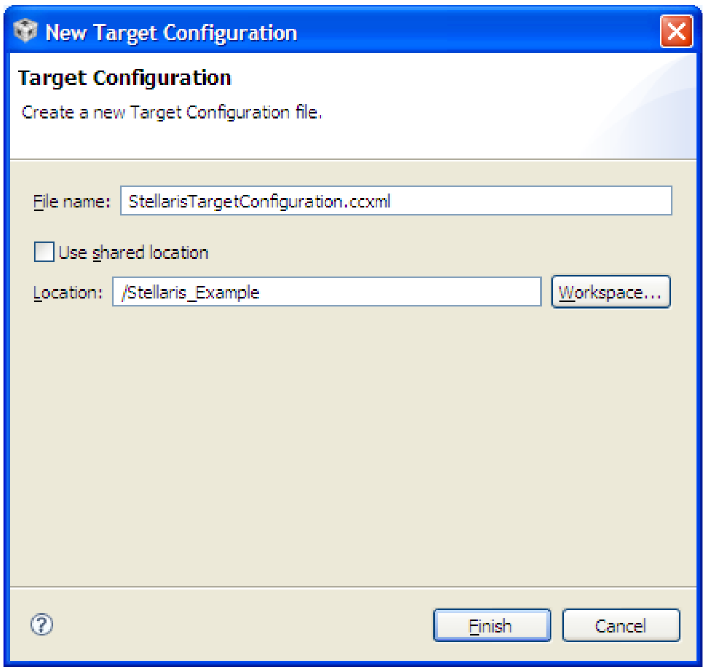
4. Click the green **Debug** button to load the code into the device and launch the debugger.



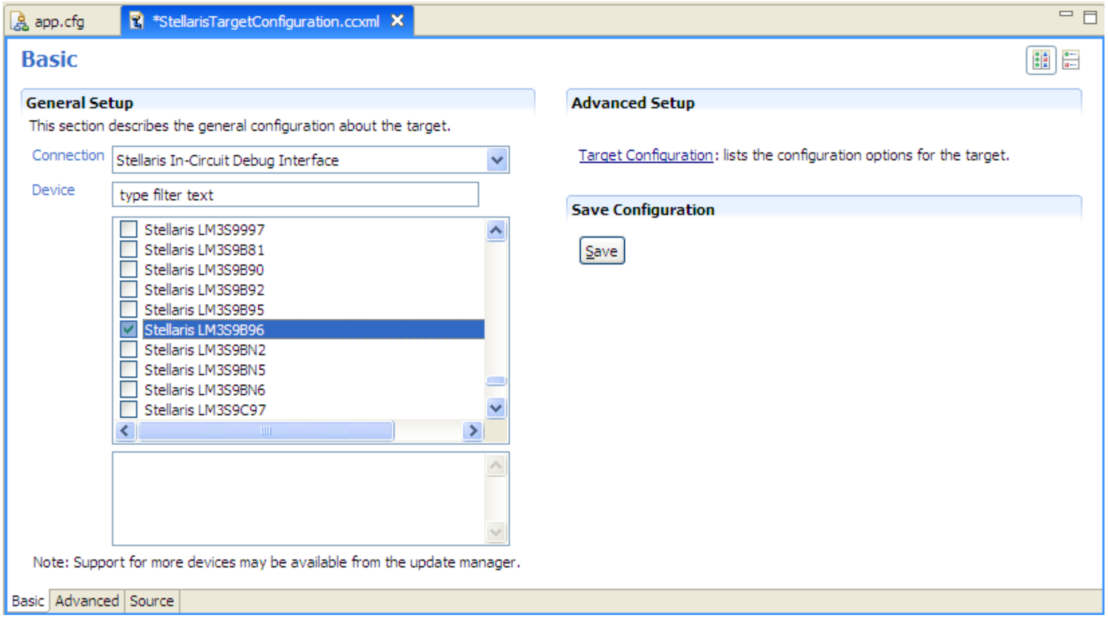
5. When the Open Target Configuration Dialog appears, click **Yes**.



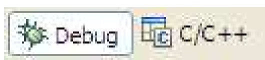
6. Type a name for the configuration file in the File name: text field.



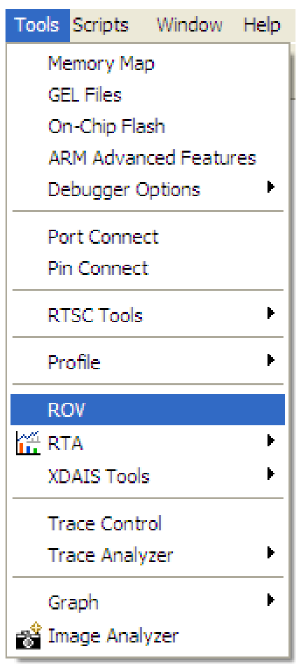
7. Select Stellaris In-Circuit Debug Interface in the Connection drop-down menu. Select your device from the Device window.



8. Click **Save**.
9. If the CCS Debug perspective does not launch automatically, change the perspective by clicking **Debug** in the top right-hand corner of the screen.



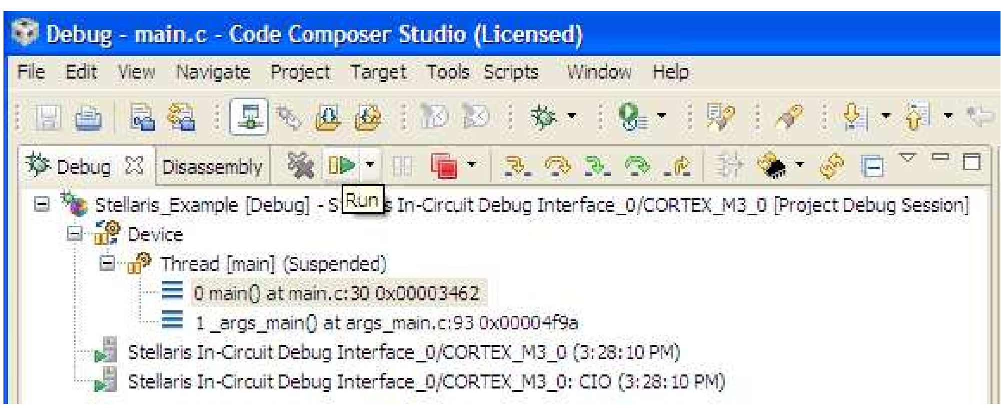
10. Go to Tools > ROV to open the Runtime Object Viewer. This tool provides information about the SYS/BIOS modules when the target is halted.



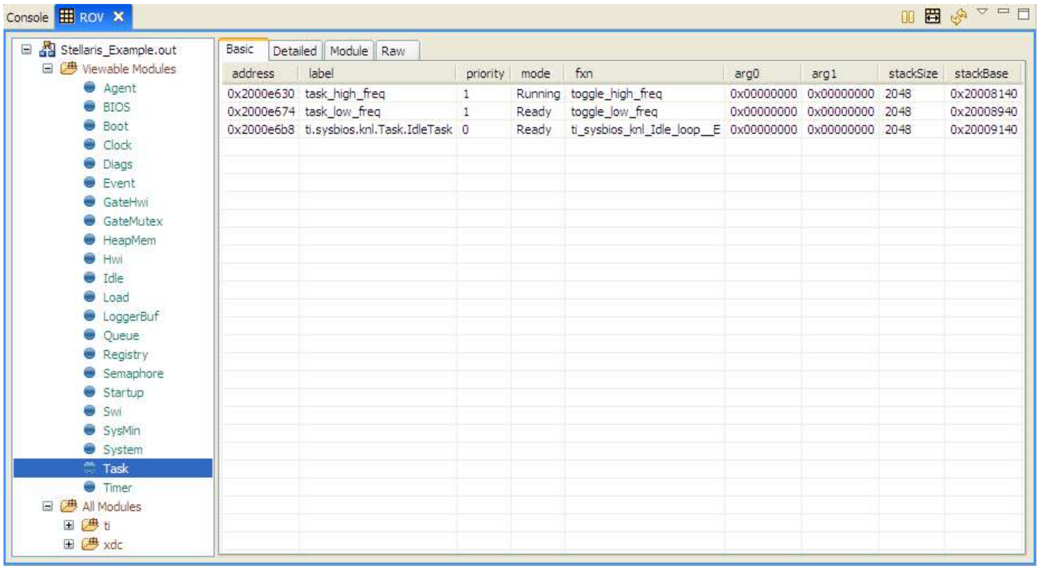
11. Set a breakpoint in each of the tasks as shown.

```
Void toggle_low_freq()
{
    while(1){
        Log_info0("toggle_low_freq() enter");

        //Pend on the semaphore
        Log_info0("toggle_low_freq() pend sem");
        Semaphore_pend(sem, BIOS_WAIT_FOREVER);

        //Set the value of the GPIO pin low
        Log_info0("toggle_low_freq() pin low");
        GPIO_PORTA_DATA_R &= !(GPIO_PIN_6);

        //Sleep
        Log_info0("toggle_low_freq() sleep");
        Task_sleep(10);

        //Post to the semaphore
        Log_info0("toggle_low_freq() post sem");
        Semaphore_post(sem);

        //Sleep
        Log_info0("toggle_low_freq() sleep");
        Task_sleep(10);

        Log_info0("toggle_low_freq() exit");
    }
}

Void toggle_high_freq()
{
    while(1){
        Log_info0("toggle_high_freq() enter");
```

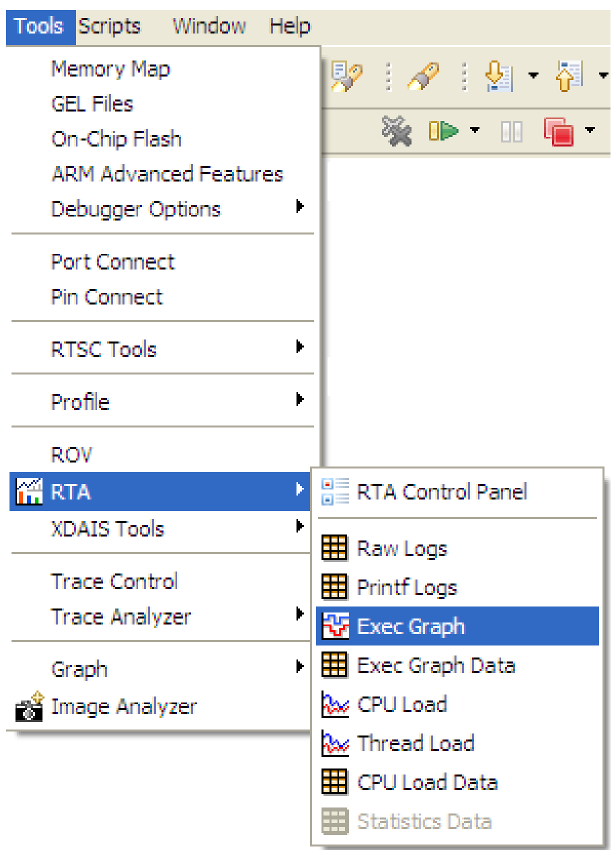
12. Run the debugger.



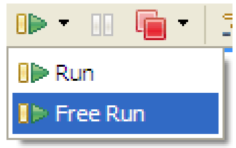
13. When the target halts at the first breakpoint, open the ROV tool and observe the task details. The state of each task is displayed along with other details about each task.



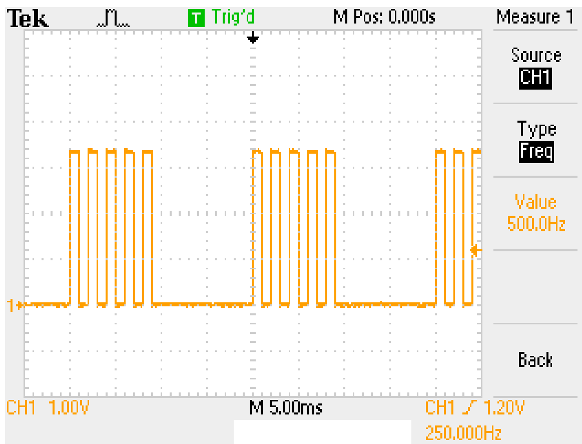
14. Explore the options available within the ROV Tool.
15. Go to Tools > RTA > Exec Graph to open one of the Real-Time Analysis Tools. The RTA tools provide diagnostic information about the system execution including logs, execution graphs, and load data.



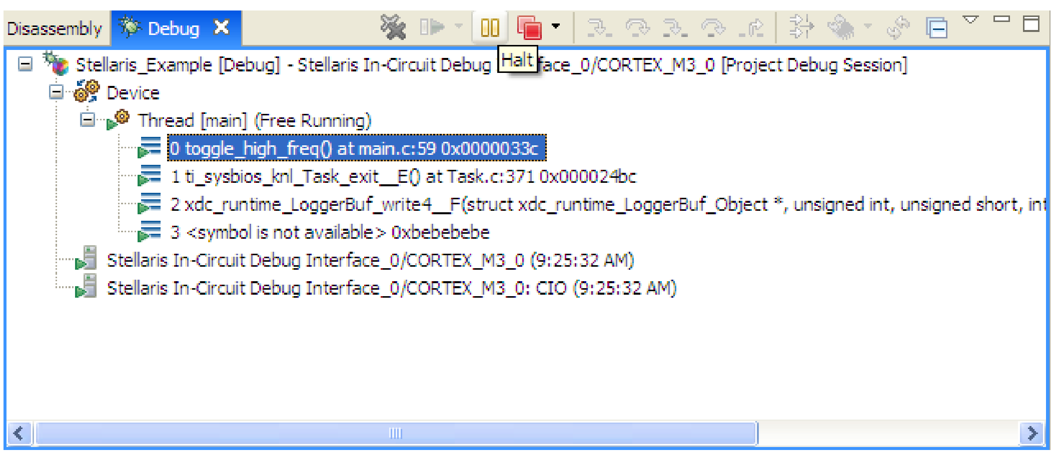
16. In order to bypass the breakpoints placed in the code for the ROV tool, Select Free Run from the drop-down option next to the Run button.



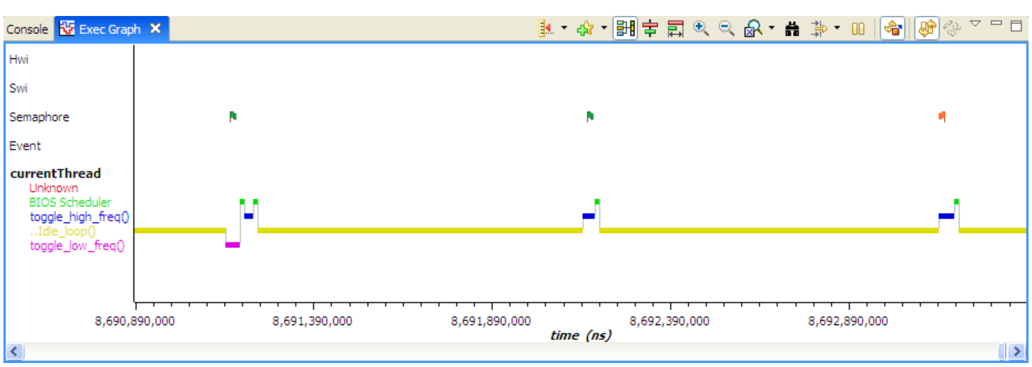
17. At this point, the following output should appear on GPIO pin PA6 of the development board. The high-frequency oscillations are created with the toggle_high_freq task while the lower frequency square wave envelope is created by the toggle_low_freq task.



18. Halt the target.



19. Observe the output in the Exec Graph window.



20. Explore the options available within the RTA Exec Graph Tool.

Find more information about the SYS/BIOS debugging tools in the *SYS/BIOS User's Manual* in the SYS/BIOS section of the Help Contents found in the Help > Help Contents menu of Code Composer Studio.

6 Conclusion

The SYS/BIOS kernel provides a basis for developing applications that require precise timing and instrumentation. The debugging features of the SYS/BIOS software package provide valuable insight into the execution state of the program at various stages of execution. The graphical configuration utility allows for quick and easy manipulation of the kernel settings and modules. Creating a project to run on Stellaris Cortex-M3 devices is a straight-forward process that is facilitated by the use of the provided SYS/BIOS project templates. Overall, SYS/BIOS provides a robust, portable structure for programming real-time applications.

7 References

The following related documents are available on the Stellaris web site at www.ti.com/stellaris:

- Stellaris LM3S9B96 Microcontroller Data Sheet (literature number SPMS182)
- StellarisWare Driver Library. Available for download at www.ti.com/tool/sw-drl.
- Stellaris® Peripheral Driver Library User's Guide, publication SW-DRL-UG (literature number SPMU019).
- StellarisWare software. Available for download at www.ti.com/tool/sw-lm3s

The Texas Instruments' Embedded Processors Wiki (processors.wiki.ti.com) contains the following SYS/BIOS resources:

- SYS/BIOS Overview
- SYS/BIOS Getting Started Guide
- SYS/BIOS Online Training
- SYS/BIOS for Stellaris Devices
- SYS/BIOS Getting Started Workshop

Additional resources are available on the web:

- SYS/BIOS E2E Forum
- Stellaris Sizing Benchmark
- Stellaris Timing Benchmark

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