dsPIC®
LANGUAGE TOOLS
GETTING STARTED

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Table of Contents

NOTES:

Preface

NOTICE TO CUSTOMERS

All documentation becomes dated, and this manual is no exception. Microchip tools and documentation are constantly evolving to meet customer needs, so some actual dialogs and/or tool descriptions may differ from those in this document. Please refer to our web site (www.microchip.com) to obtain the latest documentation available.

Documents are identified with a "DS" number. This number is located on the bottom of each page, in front of the page number. The numbering convention for the DS number is "DSXXXXXA", where "XXXXX" is the document number and "A" is the revision level of the document.

For the most up-to-date information on development tools, see the MPLAB® IDE on-line help. Select the Help menu, and then Topics to open a list of available on-line help files.

INTRODUCTION

This chapter contains general information that will be useful to know before using the dsPIC Language Tools. Items discussed in this chapter include:

- About This Guide
- Recommended Reading
- The Microchip Web Site
- Development Systems Customer Change Notification Service
- Customer Support

ABOUT THIS GUIDE

Document Layout

This document describes how to use dsPIC® Language Tools as development tools to emulate and debug firmware on a target board. The manual layout is as follows:

- **Chapter 1: Installation and Overview** – How to install the dsPIC language tools on your PC and how they work.
- **Chapter 2: Tutorial 1 – Creating a Project** – How to set up a project using dsPIC tools.
- **Chapter 3: Tutorial 2 – Real-Time Interrupt** – How to create a dsPIC application using a real-time interrupt.
- **Chapter 4: Tutorial 3 – Mixed C and Assembly Files** – How to create a dsPIC application using a combination of C and assembly code files.

Conventions Used in this Guide

This manual uses the following documentation conventions:

DOCUMENTATION CONVENTIONS

<table>
<tr><th>Description</th><th>Represents</th><th>Examples</th></tr>
<tr><td colspan="3">Arial font:</td></tr>
<tr><td rowspan="2">Italic characters</td><td>Referenced books</td><td>MPLAB® IDE User’s Guide</td></tr>
<tr><td>Emphasized text</td><td>...is the only compiler...</td></tr>
<tr><td rowspan="3">Initial caps</td><td>A window</td><td>the Output window</td></tr>
<tr><td>A dialog</td><td>the Settings dialog</td></tr>
<tr><td>A menu selection</td><td>select Enable Programmer</td></tr>
<tr><td>Quotes</td><td>A field name in a window or dialog</td><td>“Save project before build”</td></tr>
<tr><td>Underlined, italic text with right angle bracket</td><td>A menu path</td><td><u>File>Save</u></td></tr>
<tr><td rowspan="2">Bold characters</td><td>A dialog button</td><td>Click OK</td></tr>
<tr><td>A tab</td><td>Click the Power tab</td></tr>
<tr><td>‘bnnnn</td><td>A binary number where n is a digit</td><td>‘b00100, ‘b10</td></tr>
<tr><td>Text in angle brackets < ></td><td>A key on the keyboard</td><td>Press <Enter>, <F1></td></tr>
<tr><td colspan="3">Courier font:</td></tr>
<tr><td rowspan="6">Plain Courier</td><td>Sample source code</td><td><code>#define START</code></td></tr>
<tr><td>Filenames</td><td><code>autoexec.bat</code></td></tr>
<tr><td>File paths</td><td><code>c:\mcc18\h</code></td></tr>
<tr><td>Keywords</td><td><code>_asm, _endasm, static</code></td></tr>
<tr><td>Command-line options</td><td><code>-Opa+, -Opa-</code></td></tr>
<tr><td>Bit values</td><td><code>0, 1</code></td></tr>
<tr><td>Italic Courier</td><td>A variable argument</td><td><code>file.o</code>, where <code>file</code> can be any valid filename</td></tr>
<tr><td><code>0xnnnn</code></td><td>A hexadecimal number where <code>n</code> is a hexadecimal digit</td><td><code>0xFFFF</code>, <code>0x007A</code></td></tr>
<tr><td>Square brackets [ ]</td><td>Optional arguments</td><td><code>mcc18 [options] file [options]</code></td></tr>
<tr><td>Curly brackets and pipe character: { | }</td><td>Choice of mutually exclusive arguments; an OR selection</td><td><code>errorlevel {0|1}</code></td></tr>
<tr><td rowspan="2">Ellipses...</td><td>Replaces repeated text</td><td><code>var_name [, var_name...]</code></td></tr>
<tr><td>Represents code supplied by user</td><td><code>void main (void)
{ ...
}</code></td></tr>
</table>

RECOMMENDED READING

This user's guide describes how to use dsPIC Language Tools. Other useful documents are listed below. The following Microchip documents are available and recommended as supplemental reference resources.

README Files

For the latest information on Microchip tools, read the associated README files (ASCII text files) included with the software.

MPLAB® ASM30, MPLAB LINK30 and Utilities User's Guide (DS51317)

A guide to using the dsPIC DSC assembler, MPLAB ASM30, dsPIC DSC linker, MPLAB LINK30 and various dsPIC DSC utilities, including MPLAB LIB30 archiver/librarian.

MPLAB® C30 C Compiler User's Guide (DS51284)

A guide to using the dsPIC DSC C compiler. MPLAB LINK30 is used with this tool.

dsPIC® Language Tools Libraries (DS51456)

DSP, dsPIC peripheral and standard (including math) libraries, as well as MPLAB C30 built-in functions, for use with dsPIC language tools.

GNU HTML Documentation

This documentation is provided on the language tool CD-ROM. It describes the standard GNU development tools, upon which MPLAB C30 is based.

dsPIC30F Data Sheet General Purpose and Sensor Families (DS70083)

Data sheet for dsPIC30F digital signal controller (DSC). Gives an overview of the device and its architecture. Details memory organization, DSP operation and peripheral functionality. Includes electrical characteristics.

dsPIC30F Family Reference Manual (DS70046)

Family reference guide explains the operation of the dsPIC30F MCU family architecture and peripheral modules.

dsPIC30F Programmer's Reference Manual (DS70030)

Programmer's guide to dsPIC30F devices. Includes the programmer's model and instruction set.

C Standards Information

American National Standard for Information Systems – *Programming Language – C*. American National Standards Institute (ANSI), 11 West 42nd. Street, New York, New York, 10036.

This standard specifies the form and establishes the interpretation of programs expressed in the programming language C. Its purpose is to promote portability, reliability, maintainability and efficient execution of C language programs on a variety of computing systems.

C Reference Manuals

Harbison, Samuel P., and Steele, Guy L., *C A Reference Manual*, Fourth Edition, Prentice-Hall, Englewood Cliffs, N.J. 07632.

Kernighan, Brian W., and Ritchie, Dennis M., *The C Programming Language*, Second Edition. Prentice Hall, Englewood Cliffs, N.J. 07632.

Kochan, Steven G., *Programming In ANSI C*, Revised Edition. Hayden Books, Indianapolis, Indiana 46268.

Plauger, P.J., *The Standard C Library*, Prentice-Hall, Englewood Cliffs, N.J. 07632.

Van Sickle, Ted., *Programming Microcontrollers in C*, First Edition. LLH Technology Publishing, Eagle Rock, Virginia 24085.

THE MICROCHIP WEB SITE

Microchip provides online support via our WWW site at www.microchip.com. This web site is used as a means to make files and information easily available to customers. Accessible by using your favorite Internet browser, the web site contains the following information:

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

DEVELOPMENT SYSTEMS CUSTOMER CHANGE NOTIFICATION SERVICE

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

To register, access the Microchip web site at www.microchip.com, click on Customer Change Notification and follow the registration instructions.

The Development Systems product group categories are:

- **Compilers** – The latest information on Microchip C compilers and other language tools. These include the MPLAB C17, MPLAB C18 and MPLAB C30 C compilers; MPASM™ and MPLAB ASM30 assemblers; MPLINK™ and MPLAB LINK30 object linkers; and MPLIB™ and MPLAB LIB30 object librarians.
- **Emulators** – The latest information on Microchip in-circuit emulators.This includes the MPLAB ICE 2000 and MPLAB ICE 4000.
- **In-Circuit Debuggers** – The latest information on the Microchip in-circuit debugger, MPLAB ICD 2.
- **MPLAB IDE** – The latest information on Microchip MPLAB IDE, the Windows® Integrated Development Environment for development systems tools. This list is focused on the MPLAB IDE, MPLAB SIM simulator, MPLAB IDE Project Manager and general editing and debugging features.
- **Programmers** – The latest information on Microchip programmers. These include the MPLAB PM3 and PRO MATE® II device programmers and the PICSTART® Plus development programmer.

CUSTOMER SUPPORT

Users of Microchip products can receive assistance through several channels:

- Distributor or Representative
- Local Sales Office
- Field Application Engineer (FAE)
- Technical Support
- Development Systems Information Line

Customers should contact their distributor, representative or field application engineer (FAE) for support. Local sales offices are also available to help customers. A listing of sales offices and locations is included in the back of this document.

Technical support is available through the web site at: http://support.microchip.com

In addition, there is a Development Systems Information Line which lists the latest versions of Microchip's development systems software products. This line also provides information on how customers can receive currently available upgrade kits.

The Development Systems Information Line numbers are:

1-800-755-2345 – United States and most of Canada

1-480-792-7302 – Other International Locations

NOTES:

Chapter 1. Installation and Overview

1.1 INTRODUCTION

This document is intended to help use dsPIC30F software tools by providing a step-by-step guide to using MPLAB® C30 with the MPLAB Integrated Development Environment (IDE) v6.30 or later. MPLAB IDE should already be installed on the PC.

MPLAB IDE is provided on CD-ROM and is available from www.microchip.com at no charge. The project manager for MPLAB IDE and the MPLAB SIM simulator are both components of MPLAB IDE and, along with the built-in debugger, will be used extensively in this guide.

Items discussed in this chapter are:

- Installing MPLAB ASM30, MPLAB LINK30 and Language Tool Utilities
- Installing MPLAB C30
- Uninstalling MPLAB C30
- Tutorial Overview

1.2 INSTALLING MPLAB ASM30, MPLAB LINK30 AND LANGUAGE TOOL UTILITIES

MPLAB ASM30 and MPLAB LINK30 are provided free with MPLAB IDE. They are also included in the MPLAB C30 compiler installation. To ensure compatibility between all dsPIC30F tools, the versions of these tools provided with MPLAB C30 compiler should be used.

1.3 INSTALLING MPLAB C30

- When installing MPLAB C30 compiler as an update to a previous version, it may overwrite existing files on the PC. A backup should be made to retain files which may have been modified.
- Insert the CD-ROM into the PC and execute the installation MPLAB C30 vX.XX (where X.XX is the current version number) file. A series of dialogs will step through the installation process. The installation may take a few minutes as it searches for MPLAB IDE and other related files on the PC.
- To follow the examples in this guide, make sure that the check box for EXAMPLES is checked.

1.4 UNINSTALLING MPLAB C30

To uninstall MPLAB C30, open the folder where the compiler is installed and double-click on UNWISE.EXE.

Note:	When uninstalling an upgraded version of MPLAB C30, the entire installation will be removed. If files have been added to directories after the previous installation, these will not be removed.

1.5 TUTORIAL OVERVIEW

The following tutorials are intended to help an engineer familiar with the C programming language and embedded systems concepts get started using the MPLAB C30 compiler with MPLAB Integrated Development Environment (IDE). This document shows how to create and build projects, how to write code using features of dsPIC30F devices and how to verify and debug code written with MPLAB C30.

These tutorials assume that the MPLAB C30 compiler and MPLAB IDE v6.30 (or later) are installed. Please refer to the dsPIC® literature, such as the *dsPIC30F Data Sheet General Purpose and Sensor Families* (DS70083) and *dsPIC30F Programmer's Reference Manual* (DS70030) for information regarding processor-specific items such as the special function registers, instruction set and interrupt logic.

Tutorials presented in these chapters for using the MPLAB C30 compiler include:

- **Chapter 2** which demonstrates how to:
  - set up and build a project
  - run, step and set breakpoints in the example code
  - debug the code.
- **Chapter 3** which demonstrates how to:
  - use templates to create a source file
  - use a real-time interrupt in C
- **Chapter 4** which demonstrates how to:
  - use MPLAB C30 compiler with an assembly language DSP routine
  - pass parameters to and from an assembly language module

Chapter 2. Tutorial 1 - Creating A Project

2.1 INTRODUCTION

The simple source code in this tutorial is designed for an MPLAB IDE v6.xx project. It will use the MPLAB SIM simulator for the dsPIC30F6014 device. The tutorial assumes that the directory `c:\pic30_tools` is the MPLAB C30 compiler installation directory.

This tutorial consists of:

- Creating a File
- Using the Project Wizard
- Using the Project Window
- Setting Up Build Options
- Building the Project
- Troubleshooting Build Errors
- Debugging with the MPLAB SIM Simulator
- Generating a Map File
- Debugging at Assembly Code Level
- Exploring Further

2.2 CREATING A FILE

Start MPLAB IDE v6.30 (or later) and select *File>New* to bring up a new empty source file. The source code that should be typed in (or copied and pasted if viewing this electronically) to this new source file window is shown in **Example 2-1**.

EXAMPLE 2-1: MYFILE.C

```
#include "p30f6014.h"

int counter;            // for TRISB and PORTB declarations
int main (void)
{
   counter = 1;
   TRISB = 0;           // configure PORTB for output
   while(1)             // do forever
   {
      PORTB = counter; // send value of 'counter' out PORTB
      counter++;
   }
   return 0;
}
```

`TRISB` and `PORTB` are special function registers on the dsPIC30F6014 device. `PORTB` is a set of general purpose input/output pins. `TRISB` bits configure the `PORTB` pins as inputs (1) or outputs (0).

Use *File>Save As* to save this file with the file name `MyFile.c` in the `\examples` folder under the installation folder (usually `c:\pic30_tools\examples`).

2.3 USING THE PROJECT WIZARD

Select *Project>Project Wizard* to create a new project. The Welcome page will appear. Click **Next>** to continue.

1. At “Step One: Select a Device”, use the pull-down menu to select the dsPIC30F6014 device. Click **Next>** to continue.
2. At “Step Two: Select a language toolsuite”, choose “Microchip C30 Toolsuite” as the “Active Toolsuite”. Then click on each language tool in the toolsuite (under “Toolsuite Contents”) and check or set up its associated executable (Figure 2-1.)

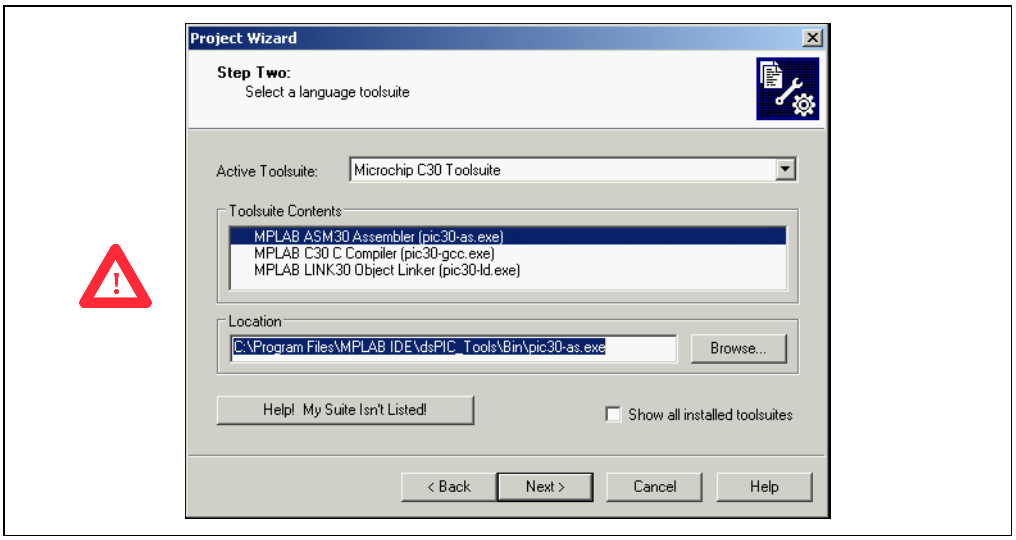
   MPLAB ASM30 Assembler should point to the assembler executable, `pic30-as.exe` under “Location”. If it does not, enter or browse to the executable location, which is by default:
   `C:\Program Files\MPLAB IDE\dsPIC_Tools\Bin\pic30-as.exe`

   MPLAB C30 C Compiler should point to the compiler executable, `pic30-gcc.exe` under “Location”. If it does not, enter or browse to the executable location, which is by default:
   `C:\pic30_tools\bin\pic30-gcc.exe`

   MPLAB LINK30 Object Linker should point to the linker executable, `pic30-ld.exe` under “Location”. If it does not, enter or browse to the executable location, which is by default:
   `C:\Program Files\MPLAB IDE\dsPIC_Tools\Bin\pic30-ld.exe`

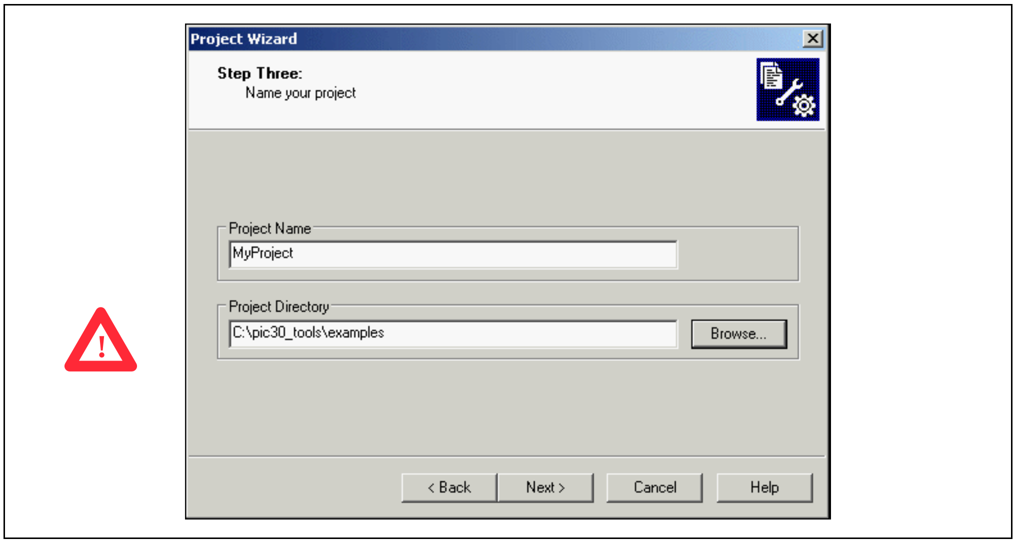
   Click **Next>** to continue.

FIGURE 2-1: PROJECT WIZARD - SELECT LANGUAGE TOOLSUITE



3. At “Step Three: Name your project”, enter the name of the project as `MyProject` and use **Browse** to go the `\examples` folder in the installation directory for MPLAB C30. Then click **Next>** to continue.

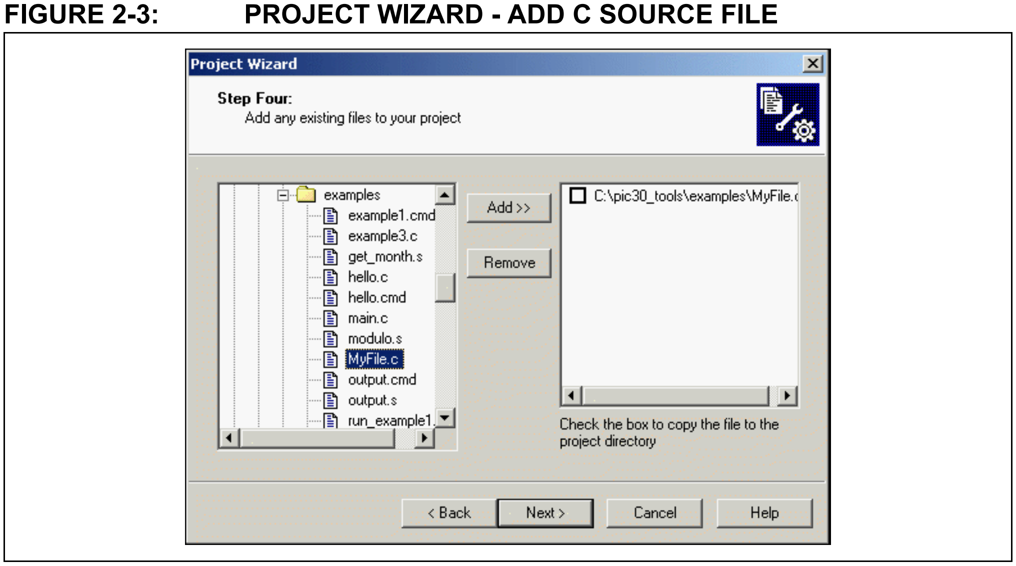
FIGURE 2-2: PROJECT WIZARD - PROJECT NAME AND DIRECTORY



4. At “Step Four: Add any existing files to your project”, two files will be added to the project.

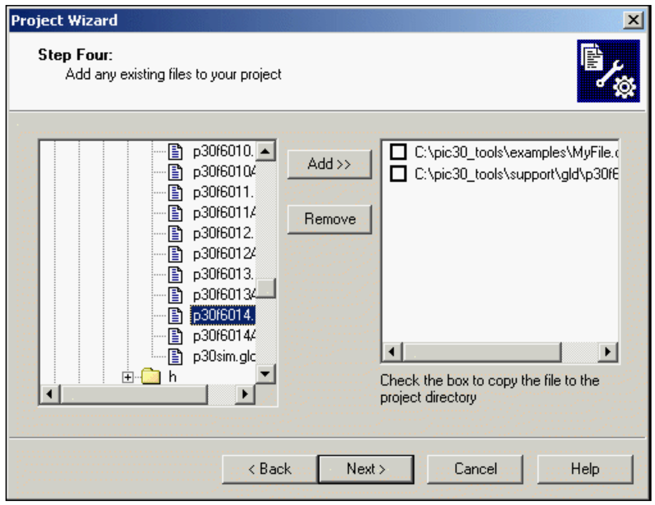
   First, select the source file created earlier, `MyFile.c`, in the `\examples` folder. Press **ADD>>** to add it to the list of files to be used for this project (on the right).

FIGURE 2-3: PROJECT WIZARD - ADD C SOURCE FILE



Second, a linker script file must be added to tell the linker about the memory organization of the dsPIC30F6014 device. Linker scripts are located in the `\support\gld` folder in the installation directory for MPLAB C30. Scroll down to the `p30f6014.gld` file, click on it to highlight, and click **ADD>>** to add the file to the project.

FIGURE 2-4: PROJECT WIZARD - ADD LINKER SCRIPT



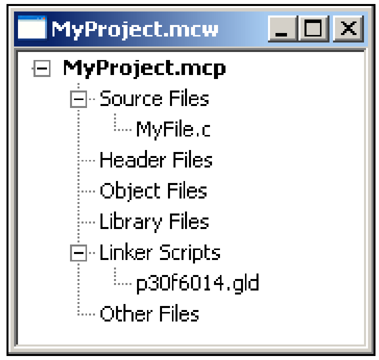
Select **Next>** to continue.

5. At the Summary screen, review the “Project Parameters” to verify that the device, toolsuite and project file location are correct. If you wish to change anything, use **Back** to return to a previous wizard dialog. Click **Finish** to create the new project and workspace.

2.4 USING THE PROJECT WINDOW

Locate the project window on the MPLAB IDE workspace. The file name of the workspace should appear in the top title bar of the project window, `MyProject.mcw`, with the file name as the top “node” in the project, `MyProject.mcp`.

FIGURE 2-5: PROJECT WINDOW



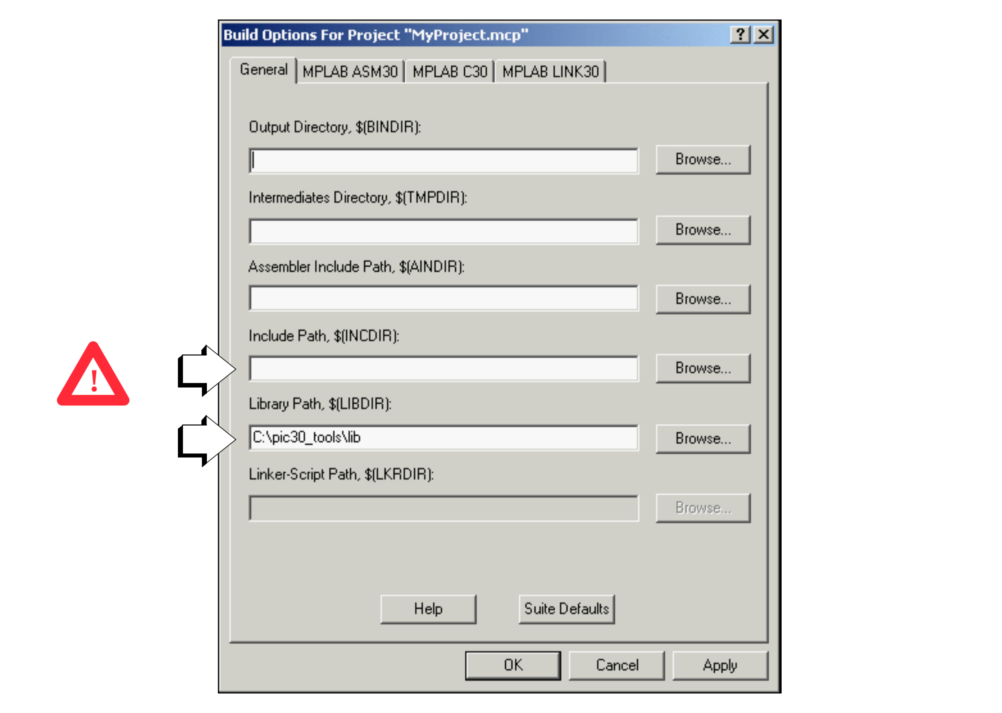
> **Note:** If an error was made, highlight a file name and press the Delete key or use the right mouse menu to delete a file. Place the cursor over “Source Files” or “Linker Scripts” and use the right mouse menu to add the proper files to the project.

2.5 SETTING UP BUILD OPTIONS

The dsPIC30F tools are almost ready to be invoked to build the project. However, the project and tool build options need to be checked.

1. Select *Project>Build Options* and click on “Project” to display the Build Options dialog for the entire project.
2. Click the **General** tab. In this tutorial, you do not need to fill in a path for “Include Path”, but you may need to for your own, future projects. The “Library path” should be the `\lib` directory of the MPLAB C30 installation directory.

FIGURE 2-6: BUILD OPTIONS DIALOG

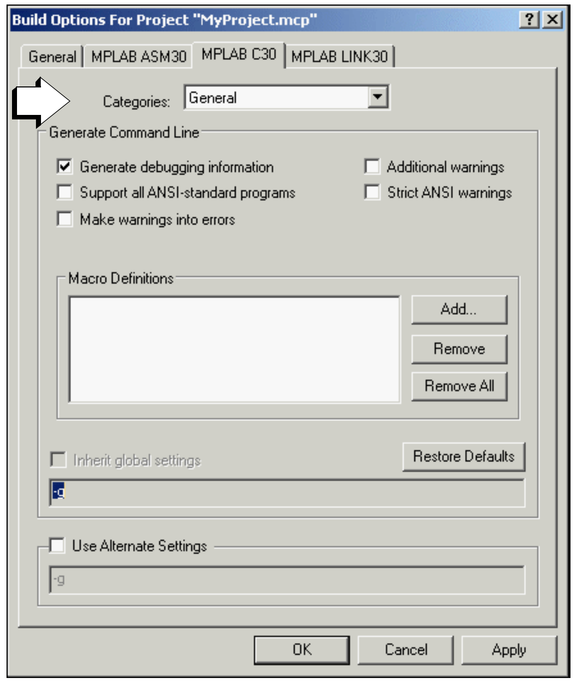


The various command-line options that are passed to the dsPIC tools can be set on the tool-specific tabs.

3. Click the **MPLAB C30** tab. There are three dialogs of options for MPLAB C30: General, Memory Model and Optimizations. These are selected in the "Categories" pull-down list and will change the items on the dialog accordingly.

   For this example, you will keep the default command-line options for MPLAB C30.

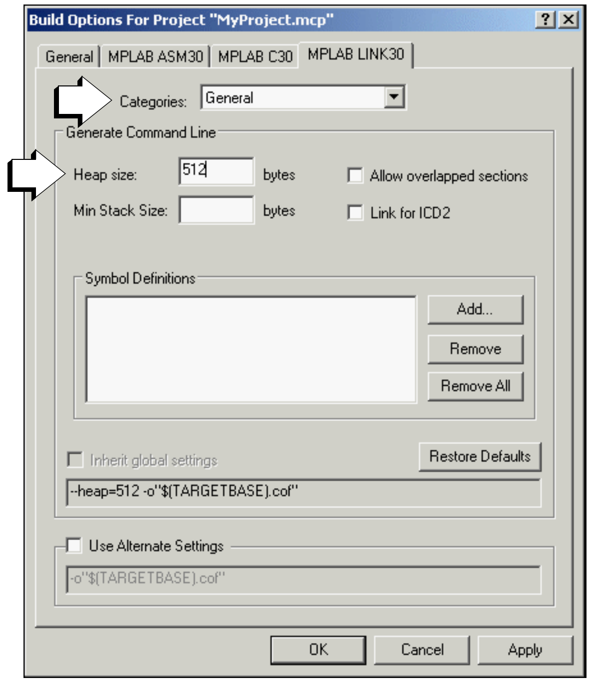
FIGURE 2-7: COMPILER BUILD OPTIONS - GENERAL



4. Click the **MPLAB LINK30** tab. There are three dialogs of options for MPLAB LINK30: General, Diagnostics and Symbols & Output. These are selected in the "Categories" pull-down list and will change the items on the dialog accordingly.

   MPLAB LINK30 needs to have a heap entered on its General category in order to run Tutorial 3 later in this guide. Enter 512 as the Heap size.

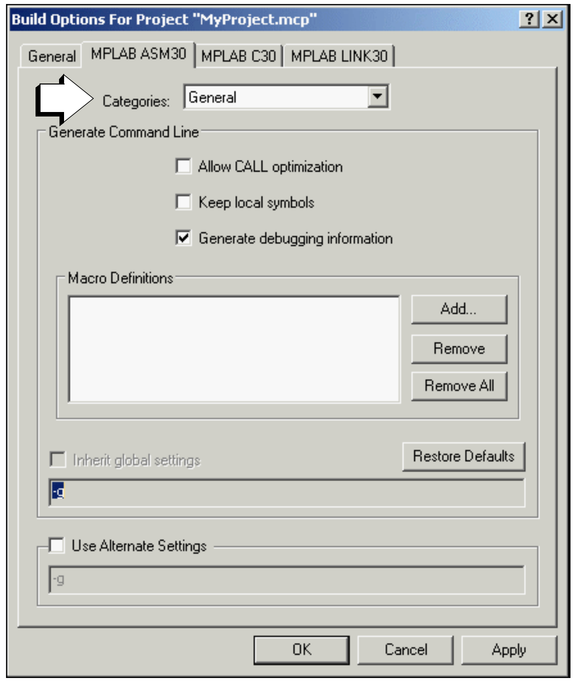
FIGURE 2-8: LINKER BUILD OPTIONS - GENERAL



5. Click the **MPLAB ASM30** tab. There are two dialogs of options for MPLAB ASM30: General and Diagnostics. These are selected in the “Categories” pull-down list and will change the items on the dialog accordingly.

   For this example, you will keep the default command-line options for MPLAB ASM30.

FIGURE 2-9: ASSEMBLER BUILD OPTIONS - GENERAL

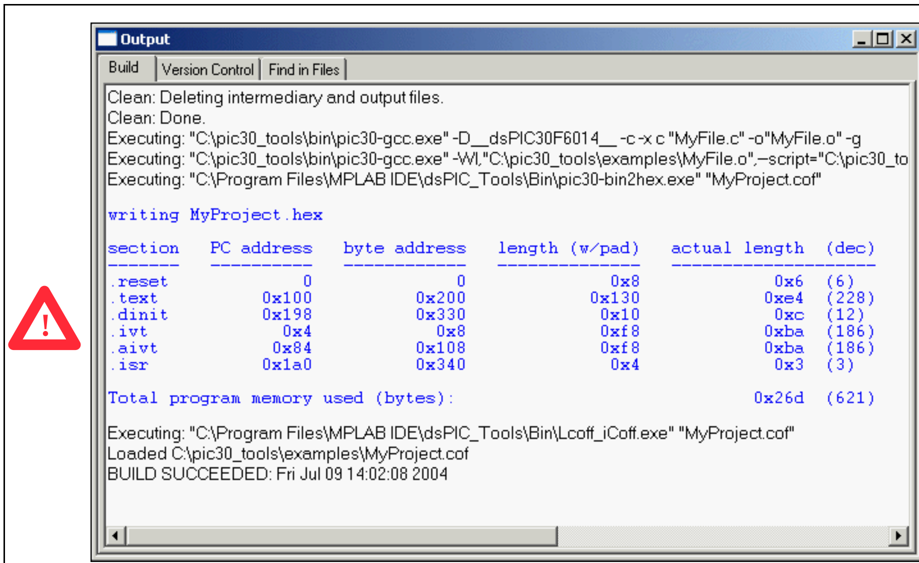


2.6 BUILDING THE PROJECT

Select *Project>Build All* to compile, assemble and link the project. If there are any error or warning messages, they will appear in the output window.

For this tutorial, the output window should display no errors and should show a message stating the project "`BUILD SUCCEEDED`." If there were any errors, check to see that the content of the source file matches the text of `myfile.c` displayed in **Example 2-1**.

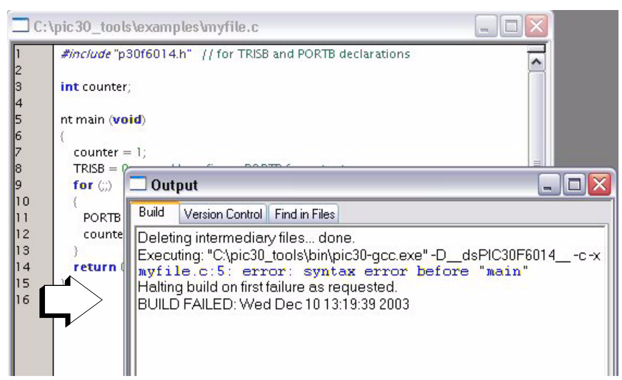
FIGURE 2-10: BUILD OUTPUT WINDOW



2.7 TROUBLESHOOTING BUILD ERRORS

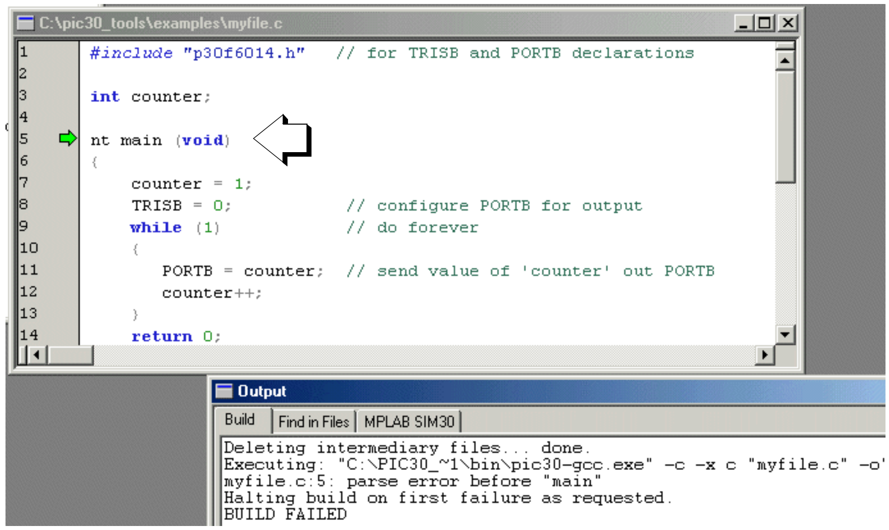
If errors were reported after building the project, double click on the line with the error message to go directly to the source code line that caused the error. If the example was typed in, the most common errors are misspellings, missing semicolons or unmatched braces. In the following screen, a typo was made. In this example, the letter "`i`" was accidentally omitted in the "`int`" declaration of `main()`. The error message will appear in the output window.

FIGURE 2-11: BUILD ERROR



After double clicking on the third line in the output window above, the desktop looks like this:

FIGURE 2-12: DOUBLE CLICK TO GO TO SOURCE



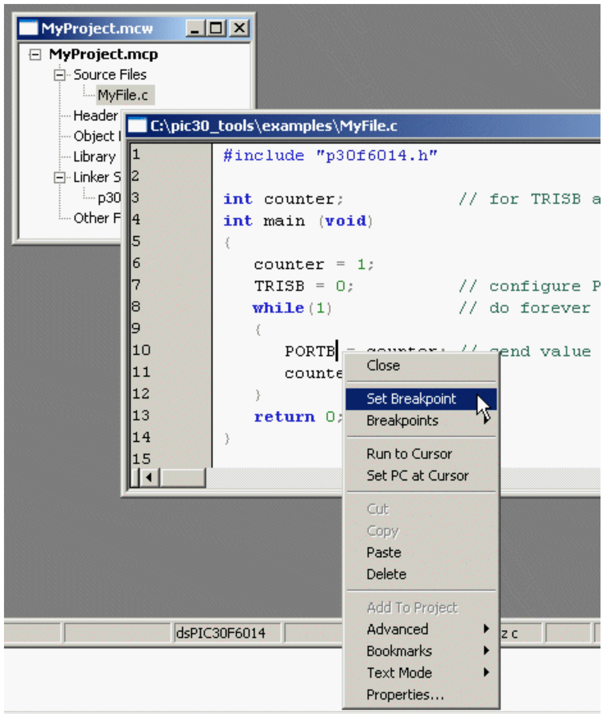
The offending typo "`nt`" is in black text rather than blue – a good indication that something is wrong, since key words are shown in blue color fonts. Typing an "`i`" to make the "`nt`" the proper key word "`int`," results in the text turning blue. Selecting *Project>Project Build All* again produces a successful build.

2.8 DEBUGGING WITH THE MPLAB SIM SIMULATOR

To debug application code, you need the help of a debug tool. In this tutorial, we will use the MPLAB SIM simulator. In the simulator, breakpoints can be set in the source code and the value of variables can be observed with a watch window.

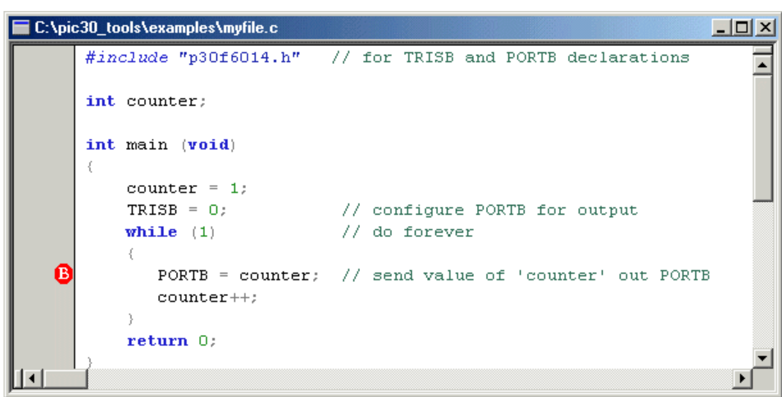
1. Select the MPLAB SIM simulator as the debugging tool by selecting *Debugger>Select Tool>MPLAB SIM*.
2. Open the source file by double-clicking on its name (`MyFile.c`) in the project tree of the Project window. In the source file, place the cursor over the line:
   `PORTB = counter;`
   Then click the right mouse button and select "Set Breakpoint".

FIGURE 2-13: SET BREAKPOINT



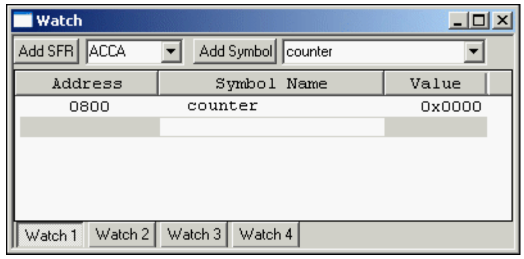
The red stop sign symbol in the margin along the left side of the source window indicates that the breakpoint has been set and is enabled.

FIGURE 2-14: BREAKPOINT IN SOURCE WINDOW



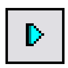
3. Select *View>Watch* to open a Watch window. Select `counter` from the pull-down expandable menu next to **Add Symbol** and then click **Add Symbol**.

FIGURE 2-15: ADD WATCH VARIABLE



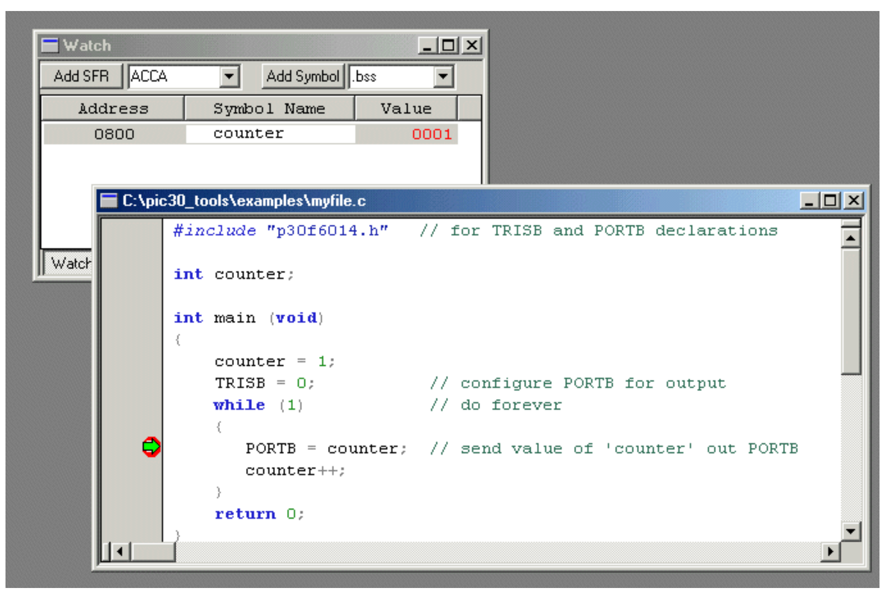
> **Note:** There are three ways to enter Watch variables: (1) in the method described above, a variable can be picked from a list, (2) the symbol's name can be typed directly in the Symbol Name column in the Watch window or (3) the variable's name can be highlighted in the source text and dragged to the Watch window.

4. Press **Run** on the toolbar to run the program.

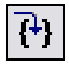


The program should halt just before the statement at the breakpoint is executed. The green arrow in the left margin of the source window points to the next statement to be executed. The Watch window should show `counter` with a value of '`1`'. The value of '`1`' will be shown in red, indicating that this variable has changed.

FIGURE 2-16: RUN TO BREAKPOINT

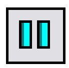


5. Press **Run** again to continue the program. Execution will continue in the `while` loop until it halts again at the line with the breakpoint. The Watch window should show `counter` with a value of ‘`2`’.
6. To step through the source code one statement at a time, use **Step Into** on the toolbar.

   As each statement executes, the green arrow in the margin of the source window moves to the next statement to be executed.
7. Place the cursor on the line with the breakpoint, and use the right mouse button menu to select “Remove Breakpoint”. Now press the Run button. The “Running...” message should appear on the lower left of the Status bar, and next to it, a moving bar will indicate that the program is running. The Step icon to the right of the Run Icon will be grayed out. If the Debugger menu is pulled down, the Step options will also be grayed out. While in the Run mode, these operations are disabled.

   To interrupt a running program, use **Halt** on the toolbar.

   Once the program has stopped (halted), the step icons are no longer grayed out.

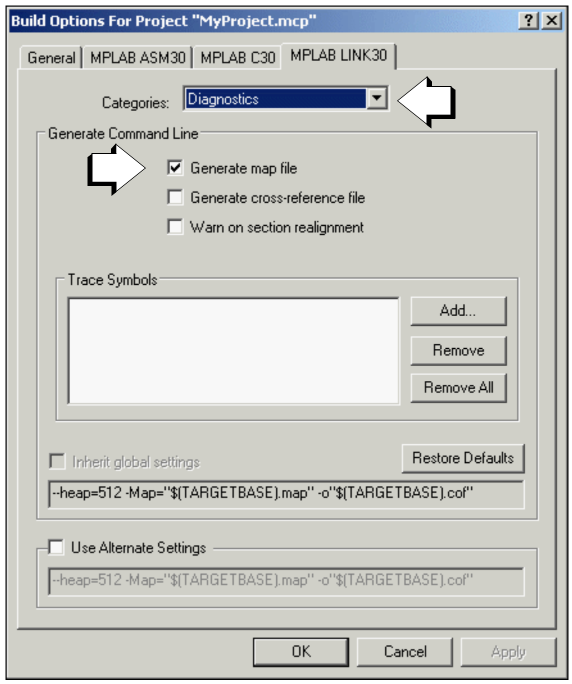
Note:	There are two basic modes while debugging: Halt or Run. Most debugging operations are done in Halt mode. In Run mode, most debug functions are not operational. Registers cannot be inspected or changed and a project cannot be rebuilt. Functions that try to access the memory or internal registers of the running target will not be available in Run mode.

2.9 GENERATING A MAP FILE

A map file provides additional information that may be useful in debugging, such as details of memory allocation. This file can be generated by setting the appropriate linker build option.

1. Select *Project>Build Options>Project*, and then click the **MPLAB LINK30** tab.
2. Select Diagnostics from "Categories" and then click on the checkbox for "Generate map file".
3. Click **OK** to save the option.
4. Rebuild the project (*Project>Build All*) to generate the map file.

FIGURE 2-17: GENERATE MAP FILE



The map file (`MyProject.map`) is present in the project directory and may be opened by selecting *File>Open*, and then browsing to the project directory. Select Files of Type "All files(*.)" in order to see the map file. This excerpt from the `MyProject.map` file shows the program and data memory area usage after `MyProject.C` was compiled.

EXAMPLE 2-2: MAP FILE EXCERPT

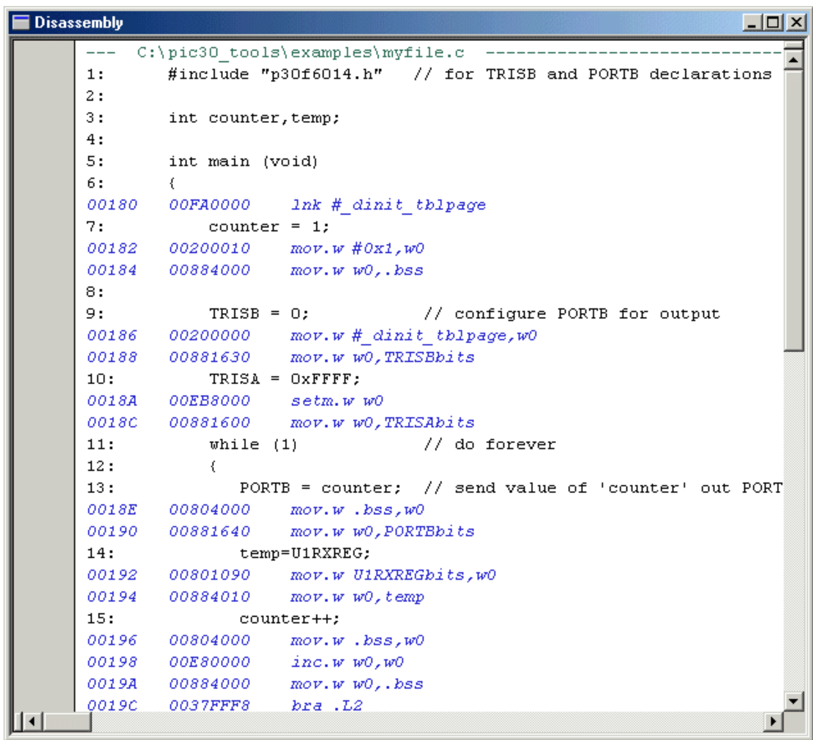
```
Program Memory Usage

section   address   length (PC units)     length (bytes)    (dec)
-------   -------   -----------------     --------------------
.reset          0                 0x4                0x6    (6)
.ivt          0x4                0x7c               0xba    (186)
.aivt        0x84                0x7c               0xba    (186)
.text       0x100                0xa0               0xf0    (240)
.dinit      0x1a0                 0x8                0xc    (12)

     Total program memory used (bytes):            0x276    (630)   <1%

Data Memory Usage

section   address      alignment gaps      total length     (dec)
-------   -------      --------------      --------------------
.bss        0x800                   0              0x4      (4)

     Total data memory used (bytes):                0x4     (4)   <1%
```

2.10 DEBUGGING AT ASSEMBLY CODE LEVEL

So far all debugging has been done from the C source file, using functions and variables as defined in the C code. For embedded systems programming, it may be necessary to dig down deeper into the assembly code level. MPLAB IDE provides tools to do both, and shows the correlation between the C code and the generated machine code.

1. Select the MPLAB IDE *View>Disassembly Listing* window to see the source code interspersed with the generated machine and assembly code. This is useful when debugging mixed C and assembly code, and when it is necessary to see the machine code generated from the C source code.

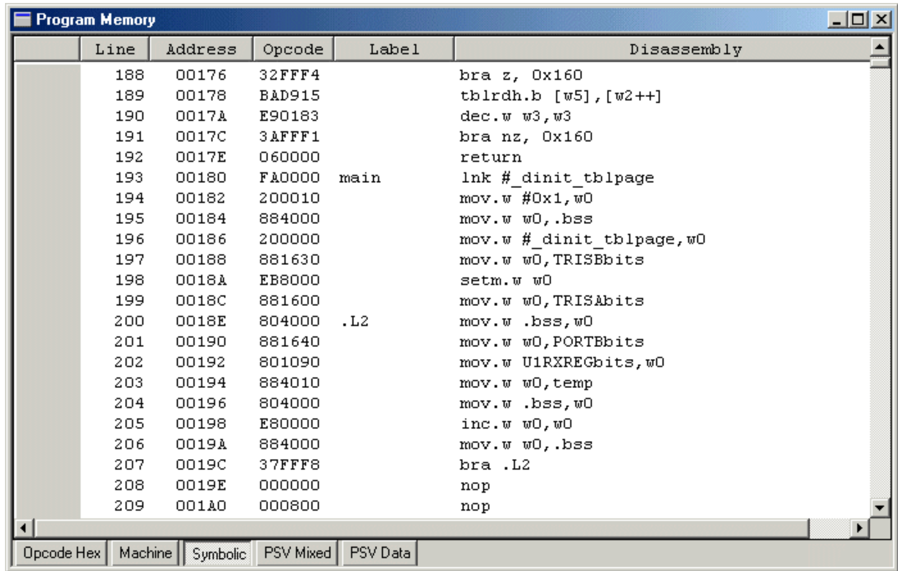
FIGURE 2-18: DISASSEMBLY WINDOW



The C source code is shown with the line number from the source code file shown on the left column. The generated machine hex code and the corresponding disassembled instructions are shown with the address in the left column. For the machine code instructions, the left column is the address of the instruction in program memory, followed by the hexadecimal bytes for the instruction and then the dsPIC30F disassembled instruction.

2. Select *View>Program Memory* window to see only the machine and assembly code in program memory.

FIGURE 2-19: PROGRAM MEMORY WINDOW - SYMBOLIC



Line	Address	Opcode	Label	Disassembly
188	00176	32FFF4		bra z, 0x160
189	00178	BAD915		tblrdh.b [w5],[w2++]
190	0017A	E90183		dec.w w3,w3
191	0017C	3AFFF1		bra nz, 0x160
192	0017E	060000		return
193	00180	FA0000	main	lnk #_dinit_tblpage
194	00182	200010		mov.w #0x1,w0
195	00184	884000		mov.w w0,.bss
196	00186	200000		mov.w #_dinit_tblpage,w0
197	00188	881630		mov.w w0,TRISBbits
198	0018A	EB8000		setm.w w0
199	0018C	881600		mov.w w0,TRISAbits
200	0018E	804000	.L2	mov.w .bss,w0
201	00190	881640		mov.w w0,PORTBbits
202	00192	801090		mov.w U1RXREGbits,w0
203	00194	884010		mov.w w0,temp
204	00196	804000		mov.w .bss,w0
205	00198	E80000		inc.w w0,w0
206	0019A	884000		mov.w w0,.bss
207	0019C	37FFF8		bra .L2
208	0019E	000000		nop
209	001A0	000800		nop

By selecting the various tabs at the bottom of the Program Memory window, the code can be viewed with or without symbolic labels, as a raw hex dump, as mixed PSV code and data, or just as PSV data.

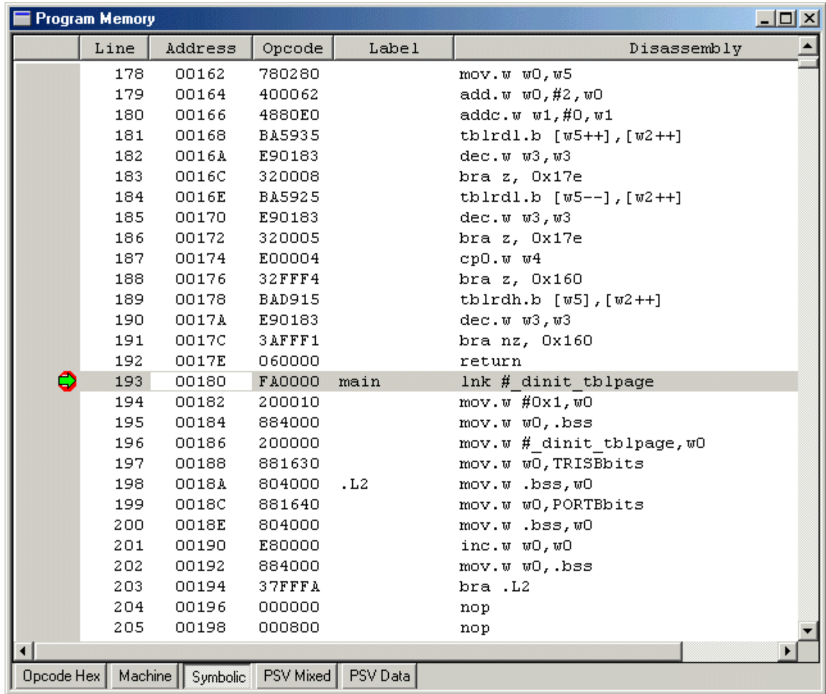
> **Note:** See the dsPIC device data sheet for more information about PSV data.

Breakpoints can be set, single-stepped, and all debug functions performed in any of the Source code, Disassembly and Program Memory windows.

3. Make sure the program is halted by pressing the Halt button. In the Program Memory window click on the Symbolic tab at the bottom to view the code tagged with symbols. Scroll down and click on the line with the label `main`, which corresponds to the `main()` function in the C file. Use the right mouse button to set a breakpoint on `main`. Press the Reset icon (or select to *Debugger>Reset* and select Processor Reset).

4. Now press Run. The program should halt at the breakpoint set at `main`.

FIGURE 2-20: BREAKPOINT IN PROGRAM MEMORY



5. Go back and look at the source file window (*File>Open*) and the Disassembly window (*View>Disassembly Listing*). The breakpoint should be seen in all three windows. The step function can now be used in any window to single step through C source lines or to single step through the machine code.

2.11 EXPLORING FURTHER

Go ahead and experiment with this example program. Things to explore include:

- Changing the value of `counter` by clicking on its value in the Watch window and typing in a new number.
- Assigning `counter` an initial value of one in its definition. Inspect the source code to see where `counter` is loaded with this value.

Chapter 3. Tutorial 2 - Real-Time Interrupt

3.1 INTRODUCTION

This next tutorial demonstrates real-time interrupt code implemented using the basic "template" file that comes with MPLAB® IDE software. Timer 1 on the dsPIC30F6104 will be used to generate a recurring interrupt to measure one-second intervals.

This tutorial consists of:

- Using Template Files
- Using the Template in a New Project
- Debugging with the MPLAB SIM Simulator
- Exploring Further

3.2 USING TEMPLATE FILES

Template files are source code files that can serve as a structure to build an application. They make it easy to start a project for an application since the C constructs and formats are provided in a simple file where details of an application can be added. The templates have example C statements for many common features of MPLAB C30 source code, including variables and constants, processor-specific include files, interrupt vectors and associated interrupt code, plus areas to insert application code.

The template has comments to help identify key constructs. In many cases macros are defined to make some things easier. In the simplest form, here is a "stripped-down" template without these comments and macros so its basic structure can be seen:

EXAMPLE 3-1: ELEMENTS OF A TEMPLATE FILE

```
#include "p30F6014.h"                           /* proc specific header */

#define CONSTANT1 10                            /* sample constant definition */

int array1[CONSTANT1] __attribute__((__space__(xmemory), __aligned__(32)));
                                                /* array with dsPIC30F attributes */
int array5[CONSTANT2];                          /* simple array */

int variable1 __attribute__((__space__(xmemory)));
                                                /* variable with attributes */
int variable3;                                  /* simple variable */

int main ( void )                               /* start of main application code */
  {
  /* Application code goes here */
  }

void __attribute__((__interrupt__(__save__(variable1,variable2)))) _INT0Interrupt(void)
                                                /* interrupt routine code */
  {
  /* Interrupt Service Routine code goes here  */
  }
```

This template code starts out with the `#include` statement to include the header file that has the processor-specific special function register definitions for this particular processor (dsPIC30F6014). Following this is a simple constant definition (`#define`) that can be modified and copied to make a list of constants for the application.

Two array definitions follow to show how to define an array with various attributes, specifying its section in memory, and how it is aligned in the memory architecture of the dsPIC device. The second array definition, `array5`, is a simple array.

Like arrays, variables can be assigned with attributes (`variable1`), or with no attributes (`variable3`).

A code fragment for `main()` follows. This is where code for the application can be placed. Following `main()` is the code framework for an interrupt.

Actual applications may use different interrupts, different attributes, and will be more complicated than this, but this template provides a simple place to start. Along with the appropriate linker file, the unmodified template can be added to a new project, and the project will build with no errors.

Templates are stored in a folder with the dsPIC tools installation directory named `\support\templates`, and are provided for both assembler and compiler source files in the corresponding `\asm` and `\c` folders.

Here is the full source code for the C template file for the dsPIC30F6014:

EXAMPLE 3-2: TEMP_6014.C TEMPLATE FILE

```
/**********************************************************************
 * This file is a basic template for creating C code for a dsPIC30F    *
 * device.  Copy this file into your project directory and modify or   *
 * add to it as needed.                                                *
 * Add the suitable linker script (e.g., p30f6014.gld) to the project. *
 *                                                                     *
 * If interrupts are not used, all code presented for that interrupt   *
 * can be removed or commented out with C-style comment declarations.  *
 *                                                                     *
 * For additional information about dsPIC architecture and language    *
 * tools, refer to the following documents:                            *
 *                                                                     *
 * MPLAB C30 Compiler User's Guide                       : C30.pdf     *
 * MPLAB C30 Compiler Reference Guide                    : R30.pdf     *
 * dsPIC 30F Assembler, Linker and Utilities User's Guide : ALU.pdf    *
 * dsPIC 30F 16-bit MCU Family Reference Manual          : DS70046     *
 * dsPIC 30F Sensor and General Purpose Family Data Sheet : DS70083    *
 * dsPIC 30F Programmer's Reference Manual               : DS70030     *
 *                                                                     *
 * Template file has been compiled with MPLAB C30 V 1.3.               *
 *                                                                     *
 **********************************************************************
 *                                                                     *
 *    Author:                                                          *
 *    Company:                                                         *
 *    Filename:       temp_6014.c                                      *
 *    Date:           08/20/2004                                       *
 *    File Version:   1.30                                             *
 *    Other Files Required: p30F6014.gld, libpic30.a                   *
 *    Tools Used: MPLAB GL  -> 6.60                                    *
 *                Compiler  -> 1.30                                    *
 *                Assembler -> 1.30                                    *
 *                Linker    -> 1.30                                    *
 *                                                                     *
 *    Devices Supported:                                               *
 *                dsPIC30F2011                                         *
 *                dsPIC30F3012                                         *
 *                dsPIC30F2012                                         *
 *                dsPIC30F3013                                         *
 *                dsPIC30F3014                                         *
 *                dsPIC30F5011                                         *
 *                dsPIC30F6011                                         *
 *                dsPIC30F6012                                         *
 *                dsPIC30F5013                                         *
 *                dsPIC30F6013                                         *
 *                dsPIC30F6014                                         *
 *                                                                     *
 **********************************************************************
```

```
 **********************************************************************
 *                                                                    *
 * Other Comments:                                                    *
 *                                                                    *
 * 1) C attributes, designated by the __attribute__ keyword, provide a *
 *    means to specify various characteristics of a variable or       *
 *    function, such as where a particular variable should be placed  *
 *    in memory, whether the variable should be aligned to a certain  *
 *    address boundary, whether a function is an Interrupt Service    *
 *    Routine (ISR), etc. If no special characteristics need to be    *
 *    specified for a variable or function, then attributes are not   *
 *    required. For more information about attributes, refer to the   *
 *    C30 User's Guide.                                               *
 *                                                                    *
 * 2) The __space__(xmemory) and __space__(ymemory) attributes        *
 *    are used to place a variable in X data space and Y data space,  *
 *    respectively. Variables accessed by dual-source DSP instructions *
 *    must be defined using these attributes.                         *
 *                                                                    *
 * 3) The aligned(k) attribute, used in variable definitions, is used  *
 *    to align a variable to the nearest higher 'k'-byte address      *
 *    boundary. 'k' must be substituted with a suitable constant      *
 *    number when the ModBuf_X(k) or ModBuf_Y(k) macro is invoked.    *
 *    In most cases, variables are aligned either to avoid potential  *
 *    misaligned memory accesses, or to configure a modulo buffer.    *
 *                                                                    *
 * 4) The __interrupt__ attribute is used to qualify a function as an  *
 *    interrupt service routine. An interrupt routine can be further  *
 *    configured to save certain variables on the stack, using the    *
 *    __save__(var-list) directive.                                   *
 *                                                                    *
 * 5) The __shadow__ attribute is used to set up any function to      *
 *    perform a fast context save using shadow registers.             *
 *                                                                    *
 * 6) Note the use of double-underscores (__) at the start and end of  *
 *    all the keywords mentioned above.                               *
 *                                                                    *
 **********************************************************************/

/* Include the appropriate header (.h) file, depending on device used */
/* Replace the path shown here with the header path in your system    */
/* Example (for dsPIC30F5013): #include "Your_path\p30F5013.h"        */

/* Alternatively, the header file may be inserted from the Project    */
/* window in the MPLAB IDE                                            */

#include "p30F6014.h"


/* Define constants here                          */

#define CONSTANT1 10
#define CONSTANT2 20


/* Define macros to simplify attribute declarations */

#define ModBuf_X(k) __attribute__((__space__(xmemory), __aligned__(k)))
#define ModBuf_Y(k) __attribute__((__space__(ymemory), __aligned__(k)))

/************* START OF GLOBAL DEFINITIONS **********/


/* Define arrays: array1[], array2[], etc.         */
/* with attributes, as given below                 */

/* either using the entire attribute               */
int array1[CONSTANT1] __attribute__((__space__(xmemory), __aligned__(32)));
int array2[CONSTANT1] __attribute__((__space__(ymemory), __aligned__(32)));

/* or using macros defined above                   */
int array3[CONSTANT1] ModBuf_X(32);
int array4[CONSTANT1] ModBuf_Y(32);
```

```
/* Define arrays without attributes                */

int array5[CONSTANT2];   /* array5 is NOT an aligned buffer */

/* ------------------------------------------------ */

/* Define global variables with attributes         */

int variable1 __attribute__((__space__(xmemory)));
int variable2 __attribute__((__space__(ymemory)));

/* Define global variables without attributes      */

int variable3;


/************** END OF GLOBAL DEFINITIONS ***********/


/************* START OF MAIN FUNCTION ***************/

int main ( void )
{

/* Code goes here                                  */

}
/****** START OF INTERRUPT SERVICE ROUTINES *********/

/* Replace the interrupt function names with the    */
/* appropriate names depending on interrupt source. */

/* The names of various interrupt functions for     */
/* each device are defined in the linker script.    */


/* Interrupt Service Routine 1                      */
/* No fast context save, and no variables stacked   */

void __attribute__((__interrupt__)) _ADCInterrupt(void)
{


/* Interrupt Service Routine code goes here         */

}


/* Interrupt Service Routine 2                      */
/* Fast context save (using push.s and pop.s)       */

void __attribute__((__interrupt__, __shadow__)) _T1Interrupt(void)
{

/* Interrupt Service Routine code goes here         */

}


/* Interrupt Service Routine 3: INT0Interrupt       */
/* Save and restore variables var1, var2, etc.      */

void __attribute__((__interrupt__(__save__(variable1,variable2)))) _INT0Interrupt(void)
{

/* Interrupt Service Routine code goes here         */

}

/********* END OF INTERRUPT SERVICE ROUTINES ********/
```

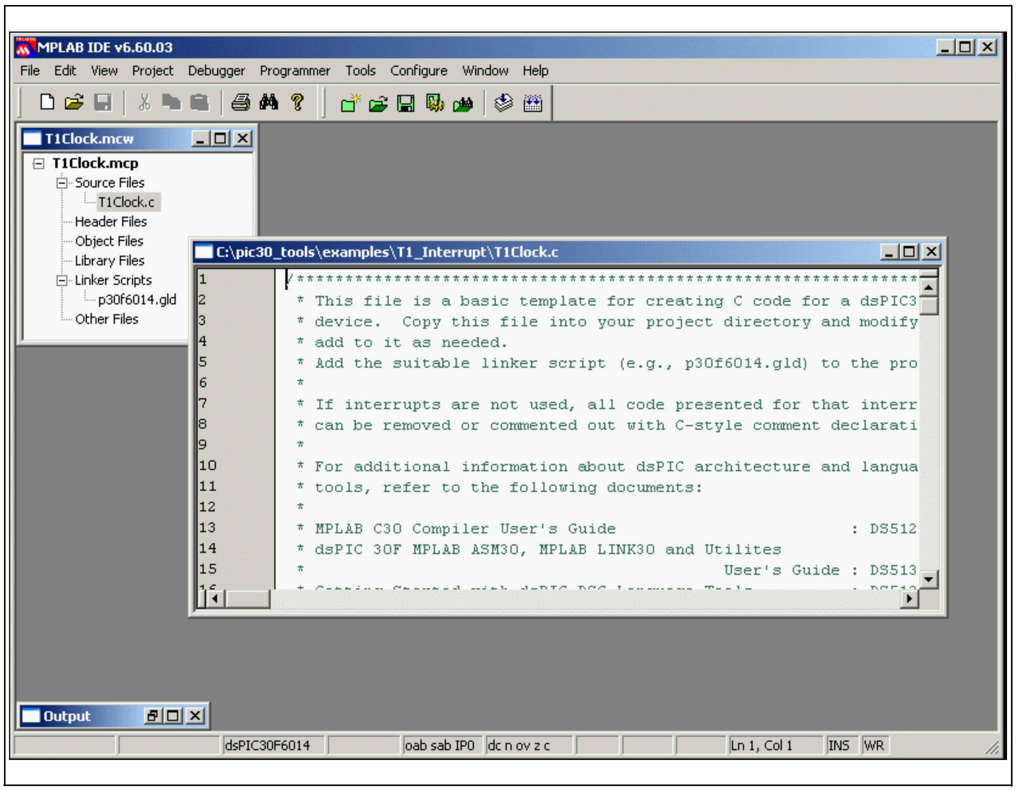
3.3 USING THE TEMPLATE IN A NEW PROJECT

For this tutorial, copy the template described above to a new project directory, following these steps. Go to Windows® Explorer for these folder/file operations.

1. Make a new folder named `\T1_Interrupt` in the `\Examples` directory under the MPLAB C30 installation directory.
2. Copy `C:\pic30_tools\support\templates\c\temp_6014.c` to the new `\T1_Interrupt` folder.
3. Rename the copied template file `temp_6014.c` in the `\T1_Interrupt` folder to `T1Clock.c`.
4. Return to MPLAB IDE.

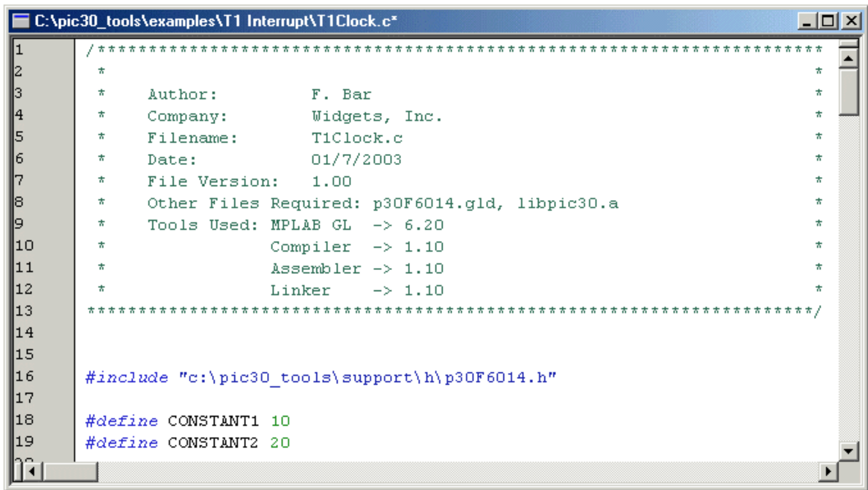
Follow the steps from **Chapter 2. "Tutorial 1 - Creating A Project"** to use the project wizard to create the new project T1Clock in this directory, add `T1Clock.c` as the only source file, and add the linker script for the dsPIC30F6014. After double clicking on the file name `T1Clock.c` in the Project window, the desktop should look something like this:

FIGURE 3-1: VIEW T1CLOCK.C



Some of the header comments for this generic template can now be removed and application-specific information entered for the new project. The header area at the beginning of the file should contain information on the new project. After editing is finished, it might look something like this:

FIGURE 3-2: EDITED T1CLOCK.C HEADER



For this tutorial, one constant, two variables and an array need to be defined. The constants defined in the template are named `CONSTANT1` and `CONSTANT2`. Comment those out, and below the `CONSTANT2` line add a comment and the definition for `TMR1_PERIOD 0x1388`:

```
/* Timer1 period for 1 ms with FOSC = 20 MHz */
#define TMR1_PERIOD 0x1388
```

Note:	The period 0x1388 = 5000 decimal. The timer will count at a rate one fourth the oscillator frequency. 5000 cycles at 5 MHz (the 20 MHz oscillator is divided by four) yields a time-out for the counter at every 1 ms.

Define some variables to track the code operation in this example. Position these in the `GLOBAL DEFINITIONS` area, after the definition of `variable3`. Add two new integer variables, `main_counter` and `irq_counter`. Then, for the interrupt timer routine, create a structure of three unsigned integer variable elements, `timer`, `ticks` and `seconds`, named `RTclock`:

EXAMPLE 3-3: VARIABLE DEFINITIONS

```
/* Define global variables without attributes       */

int variable3;

int main_counter;
int irq_counter;

struct clockType
    {
    unsigned int timer;     /* countdown timer, milliseconds */
    unsigned int ticks;     /* absolute time, milliseconds */
    unsigned int seconds;   /* absolute time, seconds */
    } RTclock;
```

The other template code in this tutorial can be left in or commented out. It is probably better to comment it out at this time since these definitions will get compiled and take up memory space. Make sure to comment out all the sample arrays, since they use the macros which can be commented out. Also, as the code grows, it may be difficult to remember which code is used by the application and which was part of the original template.

> **Note:** When using the template, remember that when beginning to code the application, only a few elements of the template may be needed. It may be helpful to comment out those portions of code that are not being used so that later, when similar elements are needed, they can be referred back to as models.

After the section labelled `END OF GLOBAL DEFINITIONS` type in this routine to initialize Timer 1 as an interrupt timer using the internal clock (the bolded text is the code that should be typed in):

EXAMPLE 3-4: RESET_CLOCK CODE

```
/************** END OF GLOBAL DEFINITIONS ***********/

void reset_clock(void)
  {
  RTclock.timer = 0;              /* clear software registers */
  RTclock.ticks = 0;
  RTclock.seconds = 0;
  TMR1 = 0;                       /* clear timer1 register */
  PR1 = TMR1_PERIOD;              /* set period1 register */
  T1CONbits.TCS = 0;              /* set internal clock source */
  IPC0bits.T1IP = 4;              /* set priority level */
  IFS0bits.T1IF = 0;              /* clear interrupt flag */
  IEC0bits.T1IE = 1;              /* enable interrupts */
  SRbits.IPL = 3;                 /* enable CPU priority levels 4-7 */
  T1CONbits.TON = 1;              /* start the timer */
  }

/************* START OF MAIN FUNCTION ***************/
```

This routine uses special function register names, such as `TMR1` and `T1CONbits.TCS` that are defined in the header file `p30F6014.h`. Refer to the data sheet for more information on these control bits and registers for Timer 1.

A main routine and an interrupt service routine may need to be written. The most complex routine is the interrupt service routine. It is executed when Timer 1 counts down 0x1388 cycles. It increments a counter `sticks` at each of these 1 ms interrupt until it exceeds one thousand. Then it increments the `seconds` variable in the `RTclock` structure and resets `sticks`. This routine should count time in seconds. In the section labelled "`START OF INTERRUPT SERVICE ROUTINES`" where a template for the `_T1Interrupt()` code is written, replace the comment

"`/* Interrupt Service Routine code goes here */`"

with these lines of code (added code is bold):

EXAMPLE 3-5: INTERRUPT SERVICE ROUTINE

```
/* Interrupt Service Routine 2                    */
/* Fast context save (using push.s and pop.s)     */

void __attribute__((__interrupt__, __shadow__)) _T1Interrupt(void)
  {
  static int sticks=0;

  irq_counter++;

  if (RTclock.timer > 0)              /* if timer is active */
  RTclock.timer -= 1;                 /* decrement it */

  RTclock.ticks++;                    /* increment ticks counter */

  if (sticks++ == 1000)
    {                                 /* if time to rollover */
    sticks = 0;                       /* clear seconds ticks */
    RTclock.seconds++;                /* and increment seconds */
    }

  IFS0bits.T1IF = 0;                  /* clear interrupt flag */

  }

/* Interrupt Service Routine 3: INT0Interrupt     */
/* Save and restore variables var1, var2, etc.    */
```

There are three sample interrupt functions in the template file. Comment out `_INT0Interrupt()` because it uses two of the template file sample variables and, as a result, will not compile. `_ADCInterrupt()` can be commented out too, since it will not be used in this tutorial.

By comparison to the Timer 1 interrupt code, the `main()` code is simple. Type this in for the body, replacing the line "`/* code goes here */`" (added code is bold):

EXAMPLE 3-6: MAIN CODE

```
/************* START OF MAIN FUNCTION ***************/

int main ( void )
    {
    reset_clock();

    for (;;)
        main_counter++;
    }

/****** START OF INTERRUPT SERVICE ROUTINES *********/
```

The `main()` code is simply a call to our Timer 1 initialization routine, followed by an infinite loop, allowing the Timer 1 interrupt to function. Typically, an application that made use of this timer would be placed in this loop in place of this test variable, `main_counter`.

The final code should now look like this:

EXAMPLE 3-7: FINAL C CODE FILE

```
/**********************************************************************
 *                                                                    *
 *    Author:        F. Bar                                           *
 *    Company:       Widgets, Inc.                                    *
 *    Filename:      T1Clock.c                                        *
 *    Date:          08/20/2004                                       *
 *    File Version:  1.30                                             *
 *    Other Files Required: p30F6014.gld, libpic30.a                  *
 *    Tools Used: MPLAB GL  -> 6.60                                   *
 *                Compiler  -> 1.30                                   *
 *                Assembler -> 1.30                                   *
 *                Linker    -> 1.30                                   *
 *********************************************************************/

#include "c:\pic30_tools\support\h\p30F6014.h"

/* Define constants here                           */
/* #define CONSTANT1 10
   #define CONSTANT2 20                            */
/* Timer1 period for 1 ms with FOSC = 20 MHz       */
#define TMR1_PERIOD 0x1388

/* Define macros to simplify attribute declarations */

#define ModBuf_X(k) __attribute__((__space__(xmemory), __aligned__(k)))
#define ModBuf_Y(k) __attribute__((__space__(ymemory), __aligned__(k)))

/************* START OF GLOBAL DEFINITIONS **********/
/* Define arrays: array1[], array2[], etc.         */
/* with attributes, as given below                 */

/* either using the entire attribute               */
/*
 int array1[CONSTANT1] __attribute__((__space__(xmemory), __aligned__(32)));
 int array2[CONSTANT1] __attribute__((__space__(ymemory), __aligned__(32)));
*/
/* or using macros defined above                  */
/* int array3[CONSTANT1] ModBuf_X(32);
   int array4[CONSTANT1] ModBuf_Y(32);            */
/* Define arrays without attributes               */
/* int array5[CONSTANT2]; */  /* array5 is NOT an aligned buffer */

/* ----------------------------------------------- */

/* Define global variables with attributes          */
/* int variable1 __attribute__((__space__(xmemory)));
   int variable2 __attribute__((__space__(ymemory)));*/

/* Define global variables without attributes      */
/* int variable3; */
int main_counter;
int irq_counter;

struct clockType
    {
    unsigned int timer;     /* countdown timer, milliseconds */
    unsigned int ticks;     /* absolute time, milliseconds */
    unsigned int seconds;   /* absolute time, seconds */
    } RTclock;
```

```
/************** END OF GLOBAL DEFINITIONS ***********/

void reset_clock(void)
    {
    RTclock.timer = 0;   /* clear software registers */
    RTclock.ticks = 0;
    RTclock.seconds = 0;
    TMR1 = 0;            /* clear timer1 register */
    PR1 = TMR1_PERIOD;   /* set period1 register */
    T1CONbits.TCS = 0;   /* set internal clock source */
    IPC0bits.T1IP = 4;   /* set priority level */
    IFS0bits.T1IF = 0;   /* clear interrupt flag */
    IEC0bits.T1IE = 1;   /* enable interrupts */
    SRbits.IPL = 3;      /* enable CPU priority levels 4-7 */
    T1CONbits.TON = 1;   /* start the timer */
}

/************* START OF MAIN FUNCTION ***************/
int main ( void )
    {
    reset_clock();

    while (1)
        main_counter++;
    }

/****** START OF INTERRUPT SERVICE ROUTINES *********/
/* Interrupt Service Routine 1                      */
/* No fast context save, and no variables stacked   */
/* void __attribute__((__interrupt__)) _ADCInterrupt(void)
*/

/* Interrupt Service Routine 2                      */
/* Fast context save (using push.s and pop.s)       */

void __attribute__((__interrupt__, __shadow__)) _T1Interrupt(void)
    {
    static int sticks=0;

    irq_counter++;

    if (RTclock.timer > 0)   /* if countdown timer is active */
        RTclock.timer -= 1;  /* decrement it */

    RTclock.ticks++;         /* increment ticks counter */

    if (sticks++ > 1000)
        {                    /* if time to rollover */
        sticks = 0;          /* clear seconds ticks */
        RTclock.seconds++;   /* and increment seconds */
        }

    IFS0bits.T1IF = 0;        /* clear interrupt flag */

    return;
    }

/* Interrupt Service Routine 3: INT0Interrupt       */
/* Save and restore variables var1, var2, etc.      */
/* void __attribute__((__interrupt__(__save__(variable1)))) _INT0Interrupt(void)
*/

/********* END OF INTERRUPT SERVICE ROUTINES ********/
```

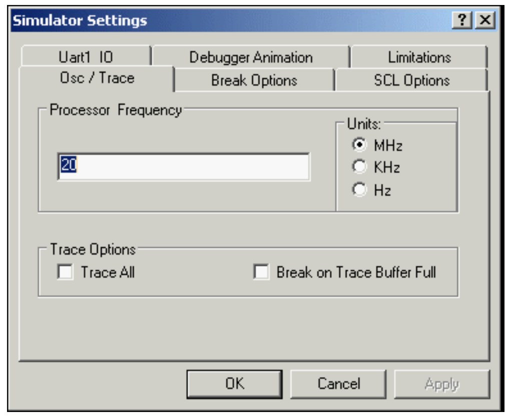
If everything is typed correctly, then selecting *Project>Build All* should result in a successful compilation. Double click on any errors appearing in the output window to return to the source code to fix typos and rebuild the project until it builds with no errors.

3.4 DEBUGGING WITH THE MPLAB SIM SIMULATOR

The MPLAB SIM simulator can now be used to test the code. Make sure that *Debugger>Select Tool>MPLAB SIM* is selected. Then set the processor clock speed for the simulator by selecting *Debugger>Settings*. The Oscillator (**Osc/Trace**) tab is a dialog to set the clock frequency of the simulated dsPIC30F6014. Set it to 20 MHz.

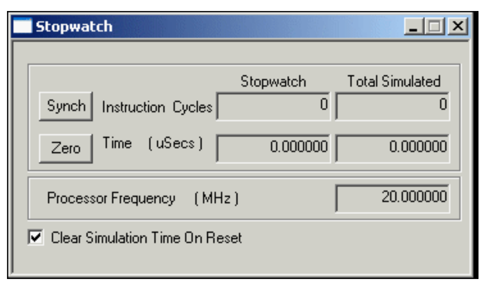
Note:	The simulator runs at a speed determined by the PC, so it will not run at the actual dsPIC30F MCU speed as set by the clock in this dialog. However, all timing calculations are based on this clock setting, so when timing measurements are made using the simulator, times will correspond to those of an actual device running at this frequency.

FIGURE 3-3: STIMULUS OSCILLATOR FREQUENCY



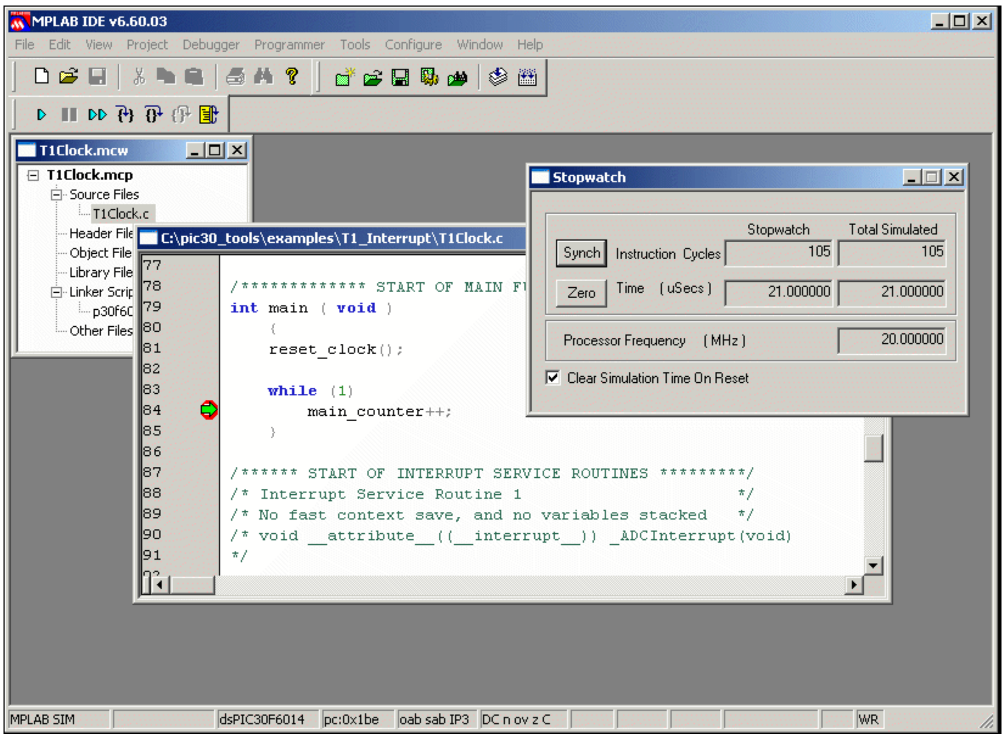
One way to measure time with the simulator is to use the Stopwatch. Select *Debugger>Stopwatch* to view the Stopwatch dialog, and make sure that the box labeled “Clear Simulation on Reset” is checked.

FIGURE 3-4: SIMULATOR STOPWATCH



A good first test is to verify that, at a minimum, the program runs. For this purpose, set a breakpoint at the line in `main()` that increments `main_counter` (right mouse click on the line and select “Set Breakpoint”), then press the Run icon or select *Debugger>Run*. The Stopwatch and the screen should like this after the breakpoint is reached.

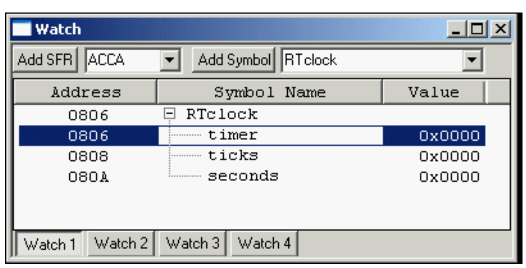
FIGURE 3-5: TIME MEASUREMENT



If the run was successful, then a Watch window can be set to inspect the program’s variables. Select *View>Watch* to bring up a Watch window. Add the variable `RTclock` (from the drop-down box next to **Add Symbol**.)

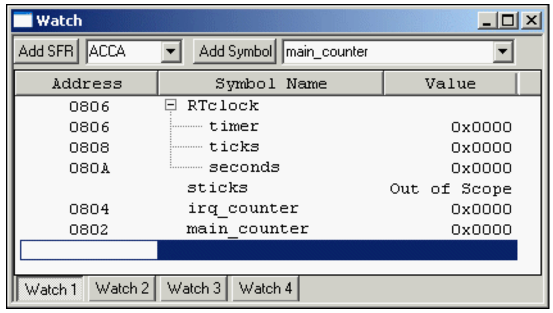
`RTclock` is a structure, as indicated by the small plus symbol in the box to the left of its name. Click on the box to expand the structure so it looks like this:

FIGURE 3-6: WATCH STRUCTURE VARIABLE



In addition to `RTclock`, add the variables `sticks`, `irq_counter`, and `main_counter` to the Watch window.

FIGURE 3-7: ALL WATCH VARIABLES



The Value column may be expanded wider in order to read the text on the `sticks` variable. You will see that it says "Out of Scope." This means that, unlike `RTclock`, `irq_counter`, and `main_counter`, this is not a global variable, and its value can only be accessed while the function `_T1Interrupt()` is executing.

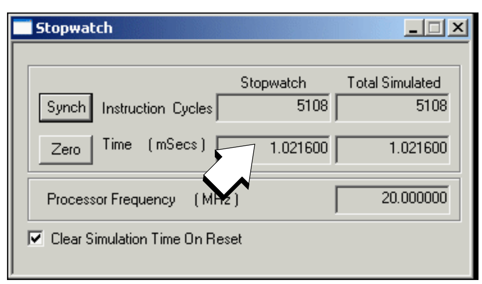
> **Note:** The Address column for `sticks` does not have a value. This is another indication that `sticks` is a local variable.

When inspecting the variables in the Watch window at this first breakpoint, all of them should be equal to zero. This is to be expected, since Timer 1 just has been initialized and `counter` has not yet been incremented for the first time.

Press the Step Into icon to step once around the `main()` loop. The value of `main_counter` should now show 0001. The interrupt routine has not yet fired. Looking at the Stopwatch window, the elapsed time only increments by a microsecond each time through the `main()` loop. To reach the first interrupt, you would have to step a thousand times (1000 x 1 us = 1 ms).

In order to test the interrupt functionality, remove the breakpoint at `main_counter++` by clicking on the highlighted line with the right mouse button and select "Remove Breakpoint". Now select "Set Breakpoint" in the right mouse menu to put a breakpoint in the interrupt service routine at the `irq_counter++` statement. Then, press Run. The Stopwatch should look like this:

FIGURE 3-8: STOPWATCH AT FIRST INTERRUPT

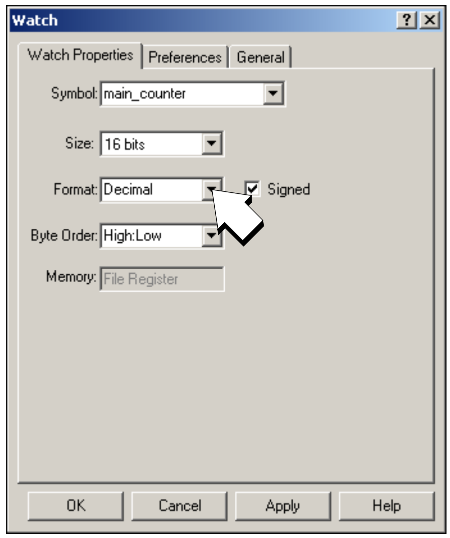


The value shown in the Time window is 1.0216 ms. This is about what was expected, since the interrupt should happen every millisecond. There was some time since RESET that was counted by the Stopwatch, including the C start-up code and the Timer 1 initialization.

Look at the Watch window. The variable `main_counter` is showing a value of 0x3E8. To change the radix of this display to decimal, do the following:

1. Click `main_counter` to select the line in the Watch window. Then, using the right mouse button, choose “Properties”.
2. In the Watch dialog on the **Watch Properites** tab, select “Decimal” from the “Format” pull-down menu.
3. Click **OK**.

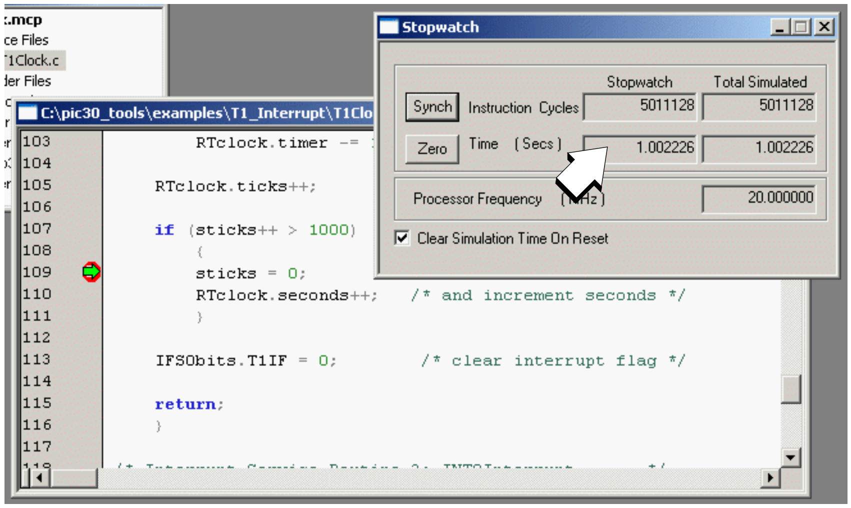
FIGURE 3-9: SET WATCH RADIX



The `main_counter` value should now show 1000. Press the Step Into icon a few more times to see the changing variables, especially `sticks` and `irq_counter`, which are incrementing each time the interrupt happens.

Remove the breakpoint from the `irq_counter++;` line, and put a breakpoint inside the conditional statement that increments `sticks` (at the line `sticks = 0;`). Click Run to run and halt at this breakpoint. The window should look like this:

FIGURE 3-10: MEASURE INTERRUPT PERIOD



The Stopwatch Time window shows 1.002226 seconds, which is close to a one second interrupt. A good time measurement would be to measure the time to the next interrupt. That value could then be subtracted from the current time. Or, since it doesn't matter how much time it took to get here – the main interest is the time between interrupts – press Zero on the Stopwatch and then press Run.

> **Note:** The Stopwatch always tracks total time in the windows on the right side of the dialog. The left windows can be used to time individual measurements. Pressing zero will not cause the total time to change.

3.5 EXPLORING FURTHER

Go ahead and experiment with this example program. Things to explore include:

- Measure the overhead of the interrupt, calculate how this will affect the timing, and try to adjust the constant `TMR1_Period` to adjust the interrupt to get better 1 second accuracy.
- What is the maximum time (in minutes) measured by this routine? What can be done to extend it?
- Add a routine that outputs a two millisecond pulse every second from a port. Verify the pulse duration with the stopwatch.

NOTES:

Chapter 4. Tutorial 3 - Mixed C and Assembly Files

4.1 INTRODUCTION

This tutorial will show how to make a project that uses an assembly language routine that is called from a C source file.

This tutorial consists of:

- Getting Project Source Files
- Creating and Building the Project
- Examining the Program
- Exploring Further
- Where to Go from Here

4.2 GETTING PROJECT SOURCE FILES

The files for this tutorial are available in the `\Examples` folder and are called `example3.c`, a C source code file, and `modulo.s`, an assembly language file. Create a folder in the `\Examples` folder called `\DSP_ASM` and copy these two files to that new folder. See **Chapter 3. "Tutorial 2 - Real-Time Interrupt"** for how to do this.

For reference, Example 4-1and Example 4-2 show listings of these two files.

EXAMPLE 4-1: C SOURCE FILE

```
/**********************************************************************
 *    Filename:       example3.c                                      *
 *    Date:           08/20/2004                                      *
 *    File Version:   1.30                                            *
 *    Tools used: MPLAB     -> 6.60                                   *
 *                Compiler  -> 1.30                                   *
 *                Assembler -> 1.30                                   *
 *                Linker    -> 1.30                                   *
 *    Linker File:    p30f6014.gld                                    *
 **********************************************************************/

#include "p30f6014.h"
#include <stdio.h>

/* Length of output buffer (in words) */
#define PRODLEN 20

/* source arrays of 16-bit elements */
unsigned int array1[PRODLEN/2] __attribute__((__space__(xmemory), aligned(32)));
unsigned int array2[PRODLEN/2] __attribute__((__space__(ymemory), aligned(32)));

/* output array of 32-bit products defined here */
long array3[PRODLEN/2];   /* array3 is NOT a circular buffer */

/* Pointer for traversing array */
unsigned int array_index;

/* 'Point-by-point array multiplication' assembly function prototype */
extern void modulo( unsigned int *, unsigned int *, unsigned int *, unsigned int );

int main ( void )
{
/* Set up Modulo addressing for X AGU using W8 and for Y AGU using W10 */
/* Actual Modulo Mode will be turned on in the assembly language routine */
```

```
    CORCON |= 0x0001;     /* Enable integer arithmetic */
    XMODSRT = (unsigned int)array1;
    XMODEND = (unsigned int)array1 + PRODLEN - 1;
    YMODSRT = (unsigned int)array2;
    YMODEND = (unsigned int)array2 + PRODLEN - 1;

/* Initialize 10-element arrays, array1 and array2 */
/* to values 1, 2, ...., 10 */
   while (1)           /* just do this over and over */
    {

            for (array_index = 0; array_index < PRODLEN/2; array_index++)
        {
            array1[array_index] = array1[array_index] + array_index + 1;
            array2[array_index] = array2[array_index] + (array_index+1) * 3;
        }

/* Call assembly subroutine to do point-by-point multiply      */
/* of array1 and array2, with 4 parameters:                    */
/* start addresses of array1, array2 and array3, and PRODLEN-1 */
/* in that order                                               */
        modulo( array1, array2, array3, PRODLEN-1 );
    }
}
```

EXAMPLE 4-2: MODULO.S ASM SOURCE FILE

```
/**********************************************************************
 *    Filename:       modulo.s                                        *
 *    Date:           08/20/2004                                      *
 *    File Version:   1.30                                            *
 *                                                                    *
 *    Tools used: MPLAB     -> 6.60                                   *
 *                Compiler  -> 1.30                                   *
 *                Assembler -> 1.30                                   *
 *                Linker    -> 1.30                                   *
 *                                                                    *
 *    Linker File:    p30f6014.gld                                    *
 *    Description: Assembly routine used in example3.C                *
 **********************************************************************/

         .text

         .global _modulo
_modulo:

             ; If any of the registers W8 - W15 are used, they should be saved
         ; W0 - W7 may be used without saving
         PUSH   W8
         PUSH   W10

         ; turn on modulo addressing
         MOV    #0xC0A8, W8
         MOV    W8, MODCON

             ; The 3 pointers were passed in W0, W1 and W2 when function was called
         ; Transfer pointers to appropriate registers for MPY
         MOV    W0,  W8    ; Initializing X pointer
         MOV    W1,  W10   ; Initializing Y pointer

         ; Clear Accumulator and prefetch 1st pair of numbers
         CLR    A, [W8]+=2, W4, [W10]+=2, W7

         LSR    W3, W3
         RCALL  array_loop ; do multiply set
         INC2   W8,  W8    ; Change alignment of X pointer
         RCALL  array_loop ; second multiply set

         POP    W10
         POP    W8

         RETURN
         ; Return to main C program
```

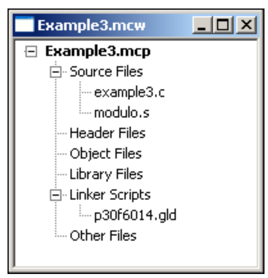


```
array_loop:
                ; Set up DO loop with count 'PRODLEN - 1' (passed in W3)
         DO     W3,   here

         ; Do  a point-by-point multiply
         MPY    W4*W7, A, [W8]+=2, W4, [W10]+=2, W7

         ; Store result in a 32-bit array pointed by W2
         MOV    ACCAL, W5
         MOV    W5, [W2++]

         MOV    ACCAH, W5
here:    MOV    W5, [W2++]

         ; turn off modulo addressing
         CLR    MODCON

         RETURN

 .end
```

4.3 CREATING AND BUILDING THE PROJECT

Using the Project Wizard, create a new project with these two source files and add the linker script `p30f6014.gld`. See **Chapter 2. "Tutorial 1 - Creating A Project"** for how to do this. The project window should look like this:

FIGURE 4-1: PROJECT WINDOW



This tutorial will use the standard I/O function `printf()` to display messages to the output window. In order to use `printf()`, the build options for the linker need to have the heap enabled. Make sure that the linker build option is set as shown in **Figure 2-8** with 512 bytes allocated for the heap.

When building the project (*Project>Build All*), it should compile with no error messages. If an error is received, make sure the project is set up with the same options as for the previous two tutorials.

This tutorial sets up three arrays. It fills two of them with a test numerical sequence, then calls an assembly language routine that multiplies the values in the two 16-bit arrays and puts the result into the third 32-bit array. Using modulo arithmetic for addressing, the two source arrays are traversed twice to generate two sets of products in the output array, with the pointer to one array adjusted at the second pass through the multiply loop to change the alignment between the multipliers. Using an assembly language routine ensures that the arithmetic will be done using the DSP features of the dsPIC30F6014.

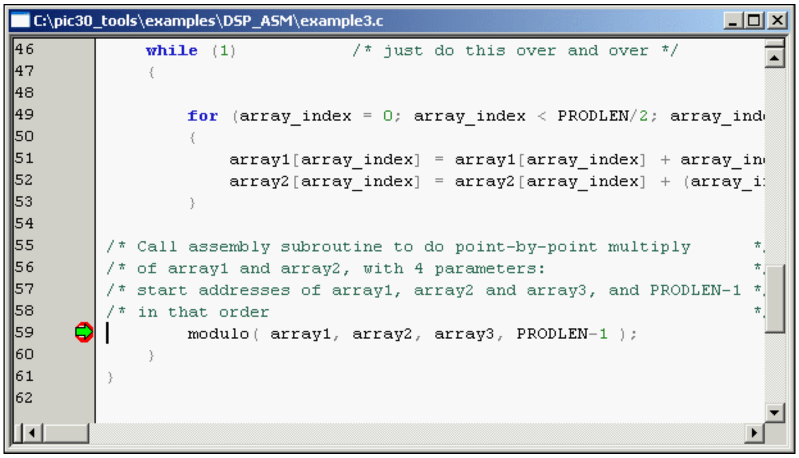
The assembly language routine takes four parameters: the addresses of each of the three arrays and the array length. It returns its result in the product array.

This routine runs in a continual loop, with the source arrays getting increasingly larger numbers as the program repeatedly executes the main endless loop.

4.4 EXAMINING THE PROGRAM

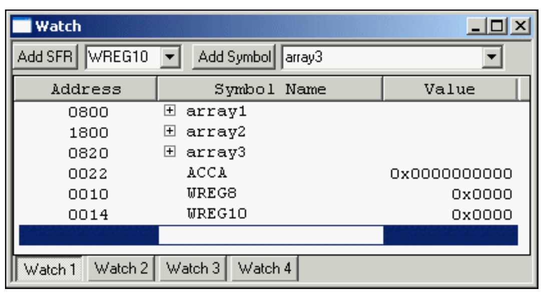
Once the project is set up and successfully built, the operation of the program can be inspected using MPLAB SIM simulator (*Debugger>Select Tool>MPLAB SIM*). Set up and run to a breakpoint on the function that calls the assembly language routine, `modulo()`, from `example3.c`.

FIGURE 4-2: BREAKPOINT IN C CODE FILE



Set up a Watch window to look at the variables involved in this calculation. Add the three arrays `array1`, `array2` and `array3`. Also add the SFRs (Special Function Registers) `ACCA`, `WREG8` and `WREG10`. The watch window should look like this:

FIGURE 4-3: WATCH WINDOW

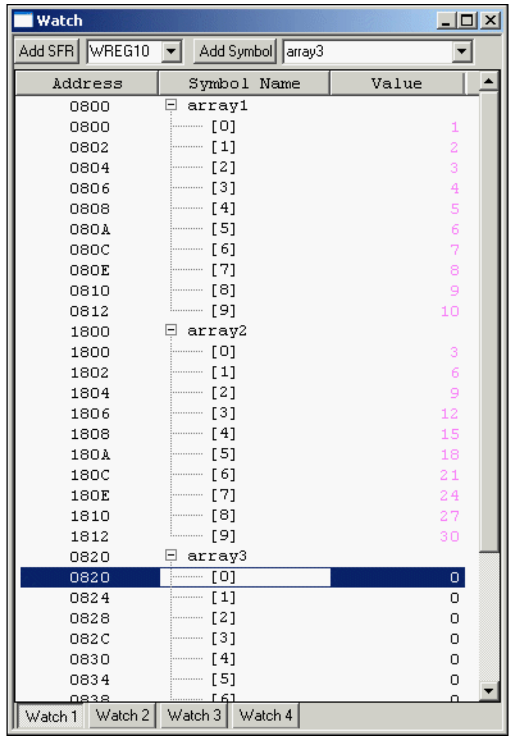


Click on the plus symbol to the left of the symbol name to expand the arrays. At this point in the program, both `array1` and `array2` should have been set up with initial values, but `array3` should be all zeros, since the `modulo()` routine has not yet been called.

Click on any element in the array to select the element, and then right-click on the element to change the radix of the display. Change the radix for all three arrays to decimal.

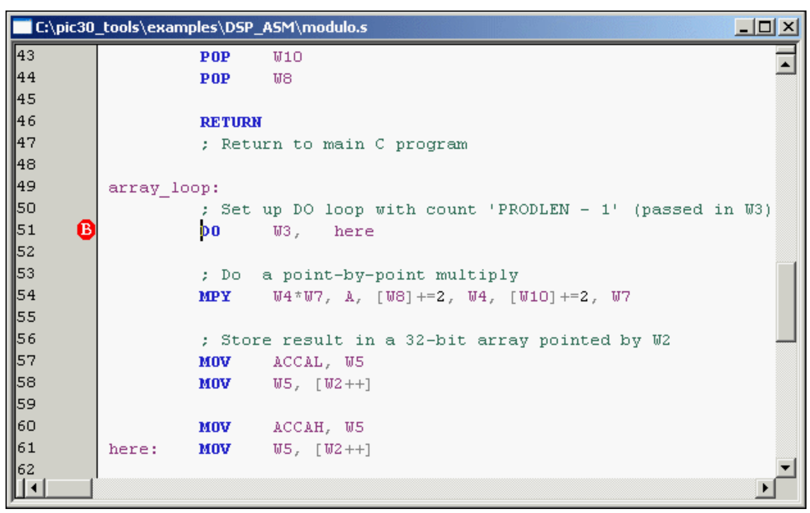
> **Note:** Changing the radix for any element of an array changes the radix for all elements in that array.

FIGURE 4-4: ARRAYS SET TO DECIMAL



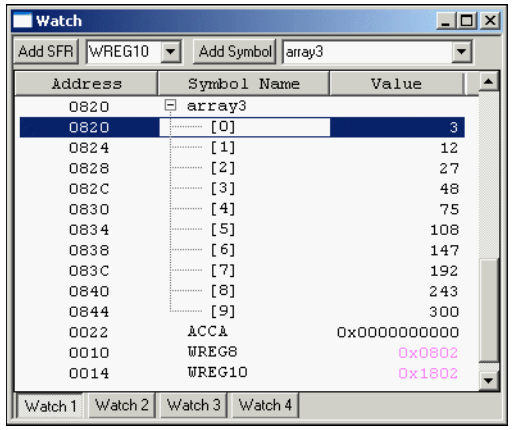
Set a breakpoint in the `modulo.s` file at the start of the `DO` loop.

FIGURE 4-5: BREAKPOINT IN ASSEMBLY CODE FILE



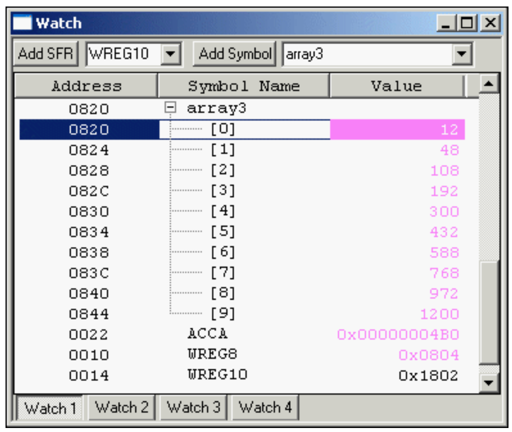
Run to the breakpoint and scroll the watch window to look at `array3`. It should still be all zeroes. Press Run again, to run once through the `DO` loop. Now the first half of `array3` should show values representing the product of each element pair from the source arrays:

FIGURE 4-6: ARRAY3 RESULTS - 1ST PASS



Press Run again to see the results for the second pass through the `DO` loop:

FIGURE 4-7: ARRAY3 RESULTS - 2ND PASS



Remove the breakpoint from `modulo.s` and press Run to see the next time through the loop. Press Run a few more times to see the values change with subsequent executions of this multiplication process. Finally, remove the breakpoint from `example3.c`.

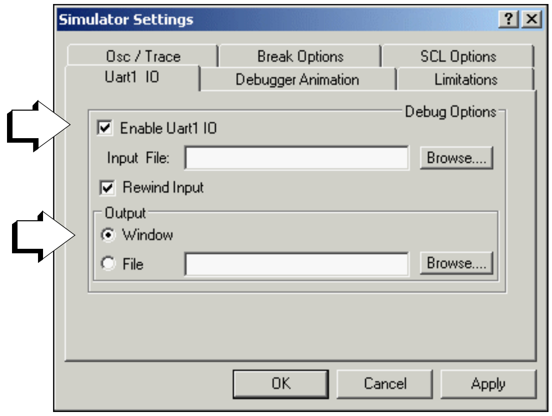
With Watch windows, data can be examined as code is run and halted with breakpoints. The simulator can also output data as it executes, providing a log that can be inspected and sent to other tools for graphing and analysis. Insert a `printf()` statement after the `modulo()` function call to monitor the values in the output array. The code should look like this (added code is bold):

EXAMPLE 4-3: `printf()` MONITOR

```
modulo( array1, array2, array3, PRODLEN-1 );

printf("Product Array\n");

  for (array_index=0; array_index<PRODLEN/2; array_index++)
     printf("%ld\n",array3[array_index]);
```

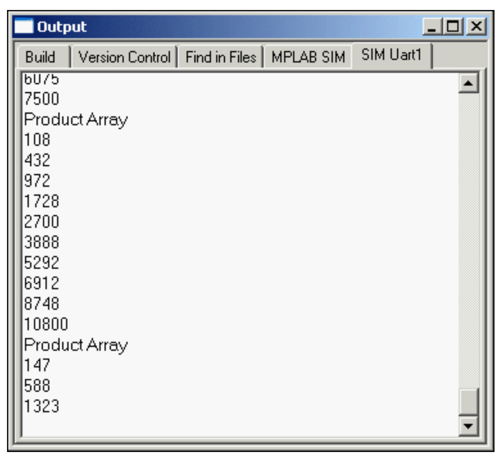

The `printf()` function uses the UART1 functions of the dsPIC being simulated to write messages either to a file or to the output window. Select _Debugger>Settings_ to bring up the simulator Settings dialog. Click the **UART1 IO** tab, check "Enable UART I/O", and then select the radio button to send text from the `printf()` statement to the output window. Click **OK**.

FIGURE 4-8: UART1 I/O - printf( ) SETUP



Now recompile your project (_Project>Build All_). Press Run, let it run for a few seconds, then press Halt. If the output window is not present, enable it on _View>Output_. Click the **SIM UART1** tab. A log of the contents of `array3` should have been generated in the output window.

FIGURE 4-9: `printf()` OUTPUT



4.5 EXPLORING FURTHER

Go ahead and experiment with this example program. Things to explore include:

- Some of the other DSP instructions can be tried to further process the numbers in these arrays.
- Use the `printf()` function to output lists of values that can then be imported into a spreadsheet. Graph the values.
- Further generalize the code so that all of the modulo indexing is set up from within `modulo.s` (i.e., convert these lines from Example 4-1 into assembly code that sets up the modulo addressing parameters from the parameters passed into the array).

```
XMODSRT = (unsigned int)array1;
XMODEND = (unsigned int)array1 + PRODLEN - 1;
YMODSRT = (unsigned int)array2;
YMODEND = (unsigned int)array2 + PRODLEN - 1;
```

4.6 WHERE TO GO FROM HERE

These tutorials were designed to help you gain familiarity with using the MPLAB C30 compiler in the MPLAB IDE environment. There are many features of MPLAB IDE and the MPLAB C30 compiler that were not covered here. For more information, reference the current MPLAB IDE on-line help, *MPLAB C30 C Compiler User's Guide* and *MPLAB ASM30, MPLAB LINK30 and Utilities User's Guide* to start using these tools for individual applications.

Instant help can be obtained from MPLAB IDE's on-line help or by logging on to Microchip's web conference for MPLAB C products at www.microchip.com. Go to the Technical Support section and then to the On-line Discussion Groups. The Development Systems web board also has a section devoted to MPLAB C30 compiler discussion.

By subscribing to the Customer Change Notification service on Microchip's web site, customers can register to be notified of changes to the MPLAB C30 C compiler. Choose the MPLAB C compiler category in Development Tools to receive notices when new versions are available and to receive timely information on the MPLAB C30 compiler.

Index

NOTES:

NOTES:

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