EDK3664F
Low-Cost Evaluation Board
Tutorial Manual
for
Hitachi H8S, H8/300 Series C/C++ Compiler

For H8/300H Tiny

3664

On-chip FLASH Microcontroller

PREFACE

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CONTENTS

1. EDK USAGE TUTORIALS

This manual answers, in tutorial form, the most common questions asked about using this evaluation board:

- How do I compile, link, download, and run a simple program?
- How does building an embedded application differ from application programming?
- How do I use Hitachi's tools?

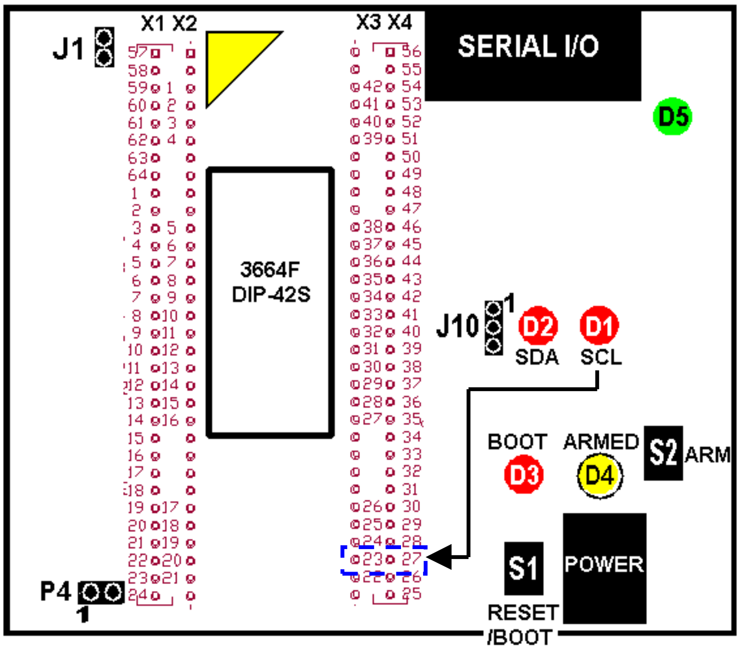
Files referred to in this manual are installed using the project generator as you work through the tutorials. The tutorial examples in this manual assume that installation procedures described in the EDK User manual have been completed.

Source code listings in this manual are for explanation purposes only. Due to software revisions, the listings may not be identical to the listings on the disk.

Note: These tutorials are designed to show you how to use the EDK, and are not intended as a comprehensive introduction to HDI-M, Hitachi Embedded Workshop (HEW) or the compiler toolchains - please consult the relevant manuals for more in-depth information.

1.1 TUTORIAL A: "ON OFF"

The EDK is equipped with a TWO RED LEDs that may be controlled by a program. LED D1 is connected to the 3664F port 5 bit 7 (pin 30 on X3:underside of board / X4:topside of board). LED D2 can be connected to port 5 bit 6 (Board pin 31 on X3 / X4) or port 8 bit 2 (pin 19 on X3 / X4) by setting jumper J10 (see Section 2.2.1) . For this tutorial we will be using LED D1. Below is a picture of the EDK3664F showing the LEDs.



EDK3664 Board layout

The numbers next to X2 and X3 are for DIP-42S package. The numbers next to X1 and X4 are for QFP-64 package. For example Pin 3 on X1 and X2 is connected to Pin 59 on QFP-64 and Pin 1 on DIP-42S.

LED	X3/X4 Pin	QFP-64 Pin	DIP-42S Pin	Pin Function
D1	30	27	23	Port 5 Bit 7 / SCL

This first tutorial example shows how to turn the LED D1 on and off. In the process, you will also learn:

- How to access on-board H8/300HTiny 3664F peripheral control registers.
- How to set up an H8/300HTINY 3664F I/O port for output.
- How to toggle a bit on an H8/300HTINY 3664F I/O port.
- How to download and run a simple program using the HDI debugger.

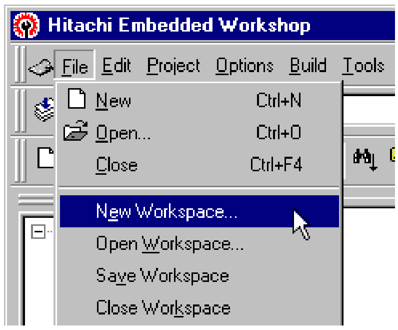
1.1.1 SOURCE FILE

Here is a listing of the source file **On_Off.c**:

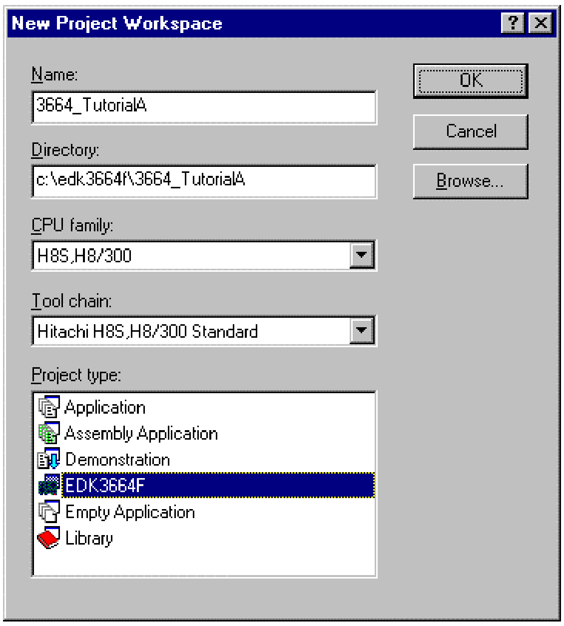
```
#include "iodefine.h"          /* 3664 Onchip peripheral registers */

void main(void);               /* function prototype */

void main(void)
{
      IO.PCR5.BYTE = 0x80;     /* Set PORT 5 BIT 7 for output */

      while(1)
      {
            IO.PDR5.BIT.B7 = 0;     /* turn on LED */
            IO.PDR5.BIT.B7 = 1;     /* turn off LED */
      }
}
```

To look at the program start Hitachi Embedded Workshop from the Windows Start Menu or from its icon:

- Open a new tutorial workspace from the 'File | New Workspace…' menu or select 'Create a new project workspace' if you are presented with the 'Welcome!' dialog.



- Enter a name and path, for example: **3664_TutorialA** and **C:\...\3664_TutorialA**, select "Hitachi H8S, H8/300 Standard" Tool chain and Project type "EDK3664F".
- Click OK to start the EDK3664F Project Generator wizard.
- Select "Tutorial Projects" as the type of project to generate and then click "Next".
- Choose "1. On/Off Tutorial" as the project to generate.
- Click "Finish" to create the project.

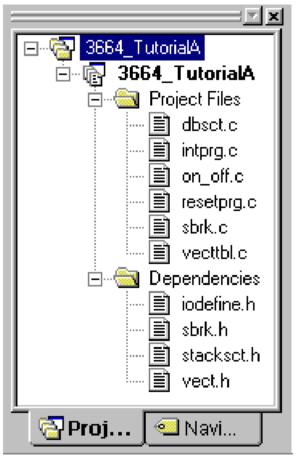


The project generator wizard will create the project *OnOff* and insert the necessary files.

- If the Workspace window is not visible, show it now by clicking the Workspace window icon on the toolbar:

(Alternatively you can select the 'Window | Workspace' menu item or press 'Alt-K' on the keyboard.)

You will see a tree display showing all the files in this project.



- To view the file **On_Off.c** double-click on the file in the Workspace window. A new window will open showing the code above.

File Component Details:
The `#include "iodefine.h"` include at the start of the file sets up a data structure that allows us to access the data direction register of the port, and also individual bits of a byte of data, in this case the data register of the port. See *H8/300H TINY 3664F Series Hardware Manual*, for details on how the data direction register is used to set individual bits of ports for input or output.

The `#define` statement in iodefine.h assigns the data structure to an absolute address in the H8/3664 memory space by using a pointer declaration:

```
#define IO      (*(volatile struct st_io    *)0xFFD0)  /* IO    Address*/
```

Setting the structure to start at this address allows the structure elements to map onto the corresponding Port 5 peripheral control registers in the device's address space. By taking the time to set up this structure, the actual code in the `main()` function can be created very simply.

First we set bit 7 in the data direction register, which controls whether a particular bit of the port is for input or output, to one to set the corresponding bit in the port as an output. By default all data direction bits are set to zero making all the port bits inputs.

```
IO.PCR5.BYTE = 0x80;   /* Set PORT 5 BIT 7 for output all others inputs*/
```

The bit 7 pin of the port itself, and thus the LED D1, can then be controlled just by setting the individual value of bit 7 in the port's data register to a 1 (LED off) or a zero (LED on). We can do this very simply using the structure expression:

```
IO.PDR5.BIT.B7 = 0;    /* turn on LED */
IO.PDR5.BIT.B7 = 1;    /* turn off LED */
```

These two statements are contained inside a `while(1){…}` loop, and so will alternate between setting the LED D1 on and off forever, until we stop the program. Next we will try running the program.

- Click the Build project icon or press <F7>.

This will build the first tutorial and create an s-record for downloading onto the 3664 Flash.

1.1.2 PROGRAMMING THE FLASH ON 3664 USING FDT

Because the EDK3664 has limited RAM and is a single chip microcontroller the HDI monitor code is built with the user's code. To debug the user code both user code and the monitor code must be programmed into flash whenever the user code is built. The HDI monitor library has been built and linked with the user code for this project into an s-record which has the same name as the project. The s-record is `\3664_TutorialA\debug\3664_TutorialA.mot`. Until this file is flashed onto the microcontroller no debug can be performed with HDI.

To flash the EDK3664 first ensure that FDT and the 3664 Flash Kernels Patch have been installed from the EDK3664 CD see user manual for installation instructions. Run FDT using the start menu item or the icon.

WARNING: Do not create an FDT workspace, we will be using the Quick Programming method!

- Once the 'Welcome!' screen for FDT is displayed press CANCEL. **DO NOT** create a workspace. FDT should now be running with no open workspace or file.

Now load the s-record created when the project was built

- Load the s-record `3664_TutorialA.mot` by selecting the menu item 'File | Open' or the icon 

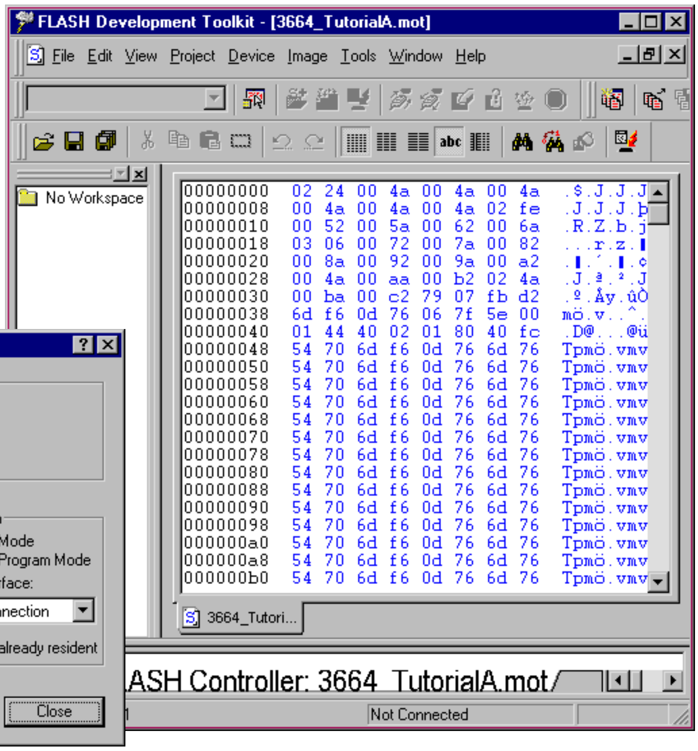
Once the s-record has been loaded into FDT it should be visible in the work area

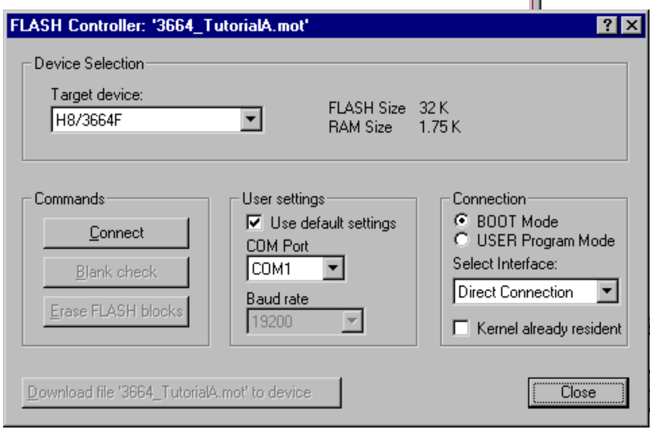
Open the 'FLASH Controller' window

- Select the menu item 'Image | Download Image' or the download image icon 

Setup the 'FLASH Controller' window

- Select *H8/3664* as the 'Target device', *select BOOT mode* and ensure that the 'Select Interface' is set to *Direct Connection*. Ensure correct COM Port is selected for the PC being used.



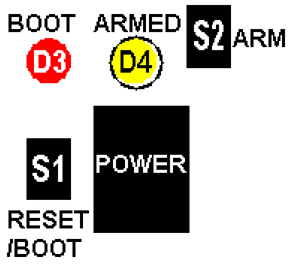


Once this screen has been configured the EDK3664 must be placed in BOOT mode before a connection is made. The EDK3664 is placed in BOOT mode using the switches S1 and S2.

- Connect the supplied serial cable to your PC and the 'UART' RS-232 port on the EDK and apply 5V to the EDK's power terminals. The green power LED (D5) should light indicating power is being supplied to the board

- Press the 'ARM' switch S2. The yellow 'ARMED' LED D4 will light indicating the EDK can be placed in BOOT mode.

- Press the 'RESET/BOOT' switch S1. The red 'BOOT' LED D3 will light indicating the EDK is now in BOOT mode. If S1 is pressed again while the yellow 'ARMED' LED is lit the EDK can be taken in and out of BOOT mode and the red 'BOOT' LED D3 will turn on and off to indicate this.



Once both the yellow 'ARMED' LED D4 and the red 'BOOT' LED D3 are lit FDT can connect to the EDK and program it with the desired s-record.

- Press the 'Connect' button in the 'FLASH Controller' Window of FDT. FDT will connect to the EDK and the FDT output window will indicate this.

- Once connected the 'Download file *project_name*.mot to device' button will be available. Press this button and FDT will download the s-record to the device and the FDT output window will indicate this.

Once downloading of the s-record is complete the EDK can be taken out of BOOT mode and FDT disconnected from the board

- Press the 'RESET/BOOT' switch S1. The red 'BOOT' LED D3 will turn off indicating the EDK is not in BOOT mode.

- Press the 'ARM' switch S2. The yellow 'ARMED' LED D4 will turn off and the EDK cannot be put into BOOT mode.

- Press the 'Disconnect' button in the 'FLASH Controller' Window of FDT. FDT will disconnect from the EDK.

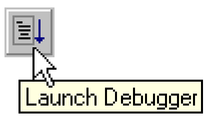
Now the 'RESET/BOOT' switch S1 can be used only as a RESET source to the H8/3664. Before trying to connect HDI to the EDK ensure the connection with FDT is no longer operational, if it is HDI will not be able to acquire the serial port from the Windows operating system

- Ensure the code is running on the EDK by pressing reset button S1 again

1.1.3 Connecting Hitachi Debugging Interface - Monitor

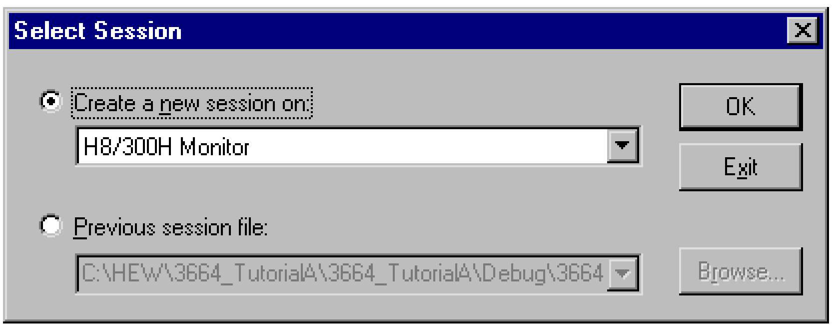
Installed with HEW is the modular Hitachi Debugging Interface (HDI), an embedded monitor kernel programmed onto the EDK (HDI-m) with the user code allows you to debug the user code running on it using HDI. For more information about the HDI debugging monitor (HDI-m) on the EDK see the *EDK3664 User Manual* HDI Section.

- Connect the supplied serial cable to your PC and the 'UART' RS-232 port on the EDK and apply 5V to the power terminals.
- Run HDI by clicking on the Launch Debugger icon on the HEW toolbar.

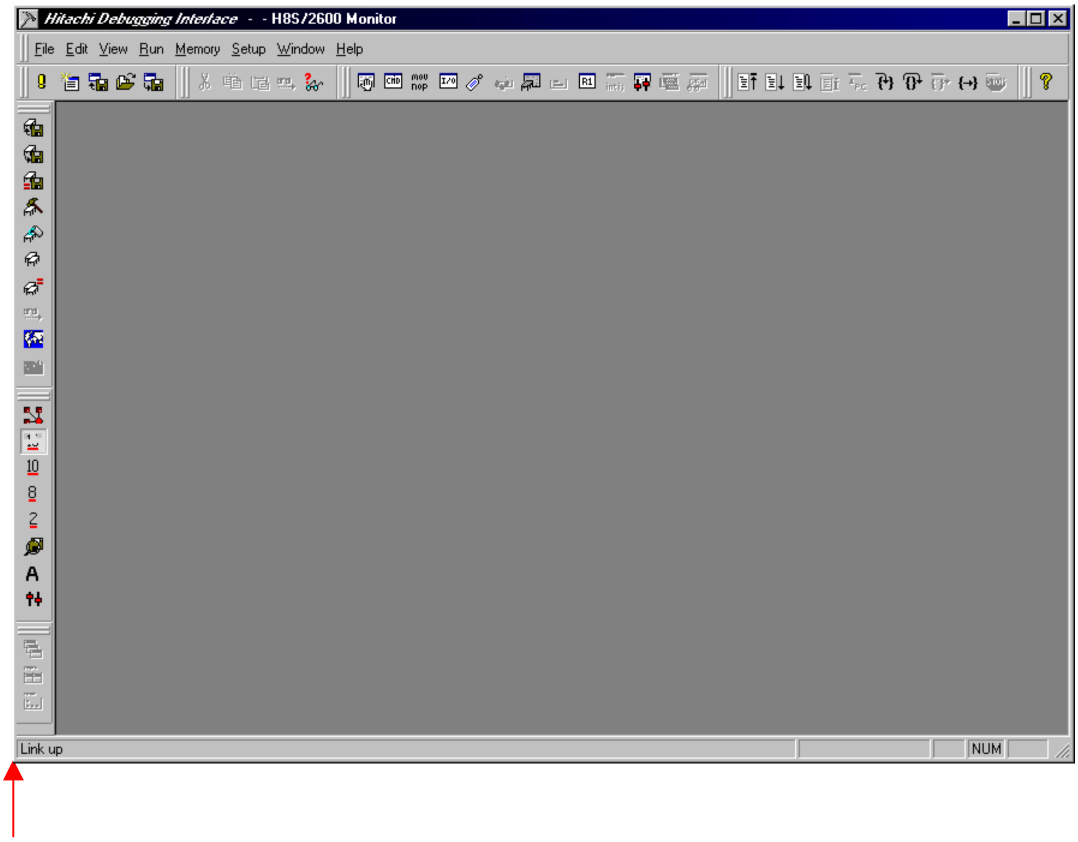


A Select Session dialog should appear as below,

- select a new session on H8/300H Monitor.



You should see the window below appear.



Note: The status bar shows the message 'Link up' to indicate successful connection to the HDI-M monitor on the EDK. If the EDK does not link up ensure the Baud rate is set to 19200 and that the correct PC serial port is selected.

1.1.4 RUNNING TUTORIAL A

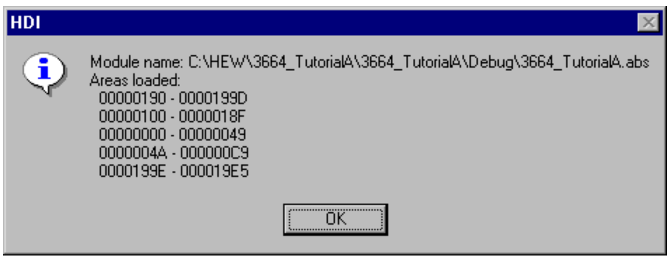
The executable code for Tutorial A is provided in file
C:\...\3664_TutorialA\debug\3664_TutorialA.abs.

- To download the code to the EDK, select the 'File | Load Program…' menu option in HDI, or click on the Load Program button in the Toolbar:

Menu Command:	Accelerator	Toolbar Button
File | Load Program	**none**	

- Once the file has been specified, click on the OK button to perform the download.

'Downloading…' should appear in the HDI status bar. If errors occur in downloading these will be displayed on the status bar too. If errors occur this is an indication that the code programmed onto the chip is not the same as the code being downloaded onto HDI. On completion of the download a status window should appear similar to the one below:



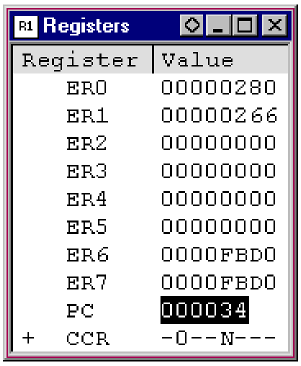
This information shows that HDI-m has loaded the file and summarises the memory regions used by the program.

To start executing the program you must set the Program Counter (PC) register to the address of the beginning of the `main()` function.

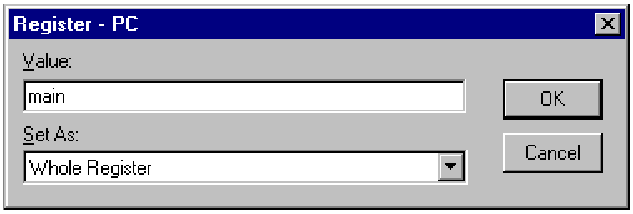
- HDI provides a simple method to see and edit the CPU registers - first open the Register window using one of the command entry options listed below:

Menu Command:	**Accelerator**	**Toolbar Button**
View | Register Window	**Ctrl-R**	

The register window will appear.



- Use the mouse to position the cursor over the ‘PC’ register value field and double-click on it. A register edit window will appear, which should be set as below:

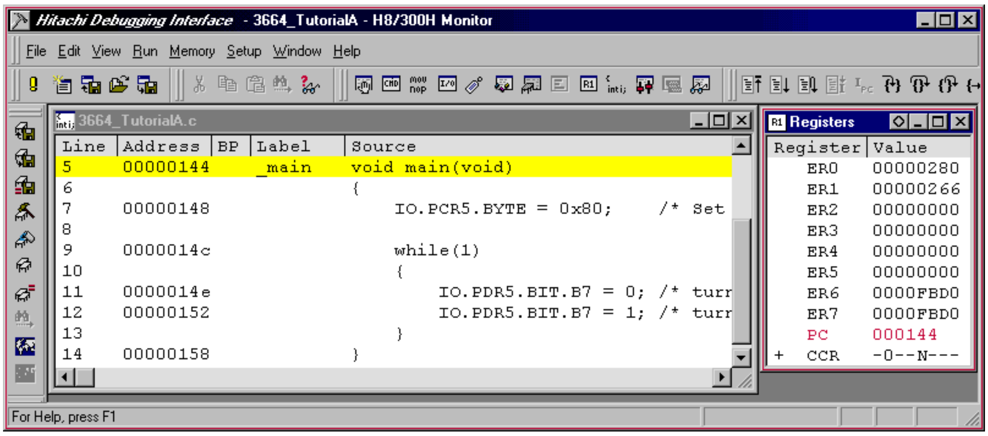


The PC will now be set to the main() function, so you can perform a program step.

- To verify this open a source code window and choose **C:\...\3664_TutorialA\On_Off.c** from the file selection dialog.

Menu Command:	Accelerator	Toolbar Button
View | Program Window	**Ctrl-K**	

A window appears showing the C source code with the first line, corresponding to the PC value highlighted.



- To make the screen layout more readable you might like to "dock" the register window. To do this click on the dock button in the window's title bar: 

The window will automatically dock to the right-hand side of the HDI main window. To dock to another side, just drag the window by its title bar, a dotted outline will appear which will "snap" to the sides of the main window. When it snaps where you want the window, release the mouse button and the window will dock. To undock a window just click the dock button again.

- To execute the first line of the program, select the 'Step Over' command using one of the methods listed below.

Menu Command:	Accelerator	Toolbar Button
Run | Step Over	F7	

- Repeat the 'step over' process for the next line and you will see the LED D1 on the board turn on. Step again and the LED D1 turns off. Stepping repeatedly will cycle around the while() loop turning the LED D1 on and off.

- We would like to turn the LED D1 on and off without having to keep stepping in the debugger, you can use the Go command to do this, try it:

Menu Command:	Accelerator	Toolbar Button
Run | Go	**F5**	

- You can stop the program running using the Halt command:

Menu Command:	Accelerator	Toolbar Button
Run | Halt	**ESC**	

Did you see what you expected? Did the LED D1 flash on and off, or did it instead just glow dimly?

The LED D1 *is* actually flashing on and off, but the micro-controller is doing it so fast you cannot actually see it (instead it looks dim). This is because the processor operates much faster than we can step manually. In order to see it flash at a rate visible to humans, we need to slow it down using a delay. We will do this in the next tutorial.

1.2 TUTORIAL B: "FLASHER"

This tutorial shows how to build a program that automatically flashes the EDK's red LED D1, and how to use HDI-m to download, run, and modify this program. In the process, you will see how to:

- Use header files for declaring data structures.
- Use a delay loop to set human-visible delays.
- Use HDI-m for examining and debugging a program.

1.2.1 SOURCE FILES

Here is a listing of the source file for Tutorial B:

```
#include "iodefine.h" /* register definition header file */

void main(void)
{
    unsigned short ii=0;

       IO.PCR5.BYTE = 0x80; /* Set PORT 5 BIT 7 for output all others inputs*/

    while (1)
    {
        ii++;
        if (ii == 30000)
        {
                      IO.PDR5.BIT.B7 = 0;    /* turn on LED */
        }
        else if (ii == 60000)
        {
                      IO.PDR5.BIT.B7 = 1;    /* turn off LED */
        }
    }
}
```

The structure definition and assignment that we did in Tutorial A to make it easy for us to access the on-chip peripheral control registers has already been done for *all* the device's peripheral registers and the code for this is in a header file called **'iodefine.h'**. This file is created when you generate a new project in HEW. So for this tutorial example all we have to do is include the file in our C file:

```
#include "iodefine.h" /* register definition header file */
```

With this file included we can then use any structures or assignments declared in it in our C program. Note that each *separate* C file that uses any of these definitions must `#include` the header file in it.

In the `main()` function the local variable `ii` is incremented in an endless `while` loop and adds delay to the setting and resetting of the LED D1 bit of port 5. When `ii` is equal to 30000 the LED D1 is switched on, when `ii` is equal to 60000 the LED D1 is switched off. The `unsigned short ii` has a range of 0 to 65535, so on reaching 65535 it increments back to 0 thus keeping both `if` and `else if` statements valid.

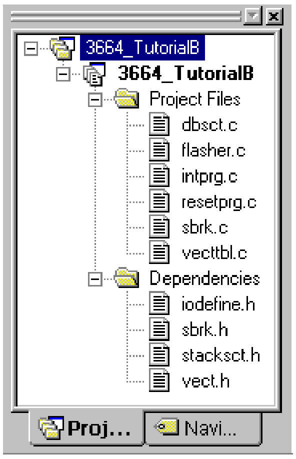
1.2.2 HDI-M LIBRARY FILE INCLUSION

By looking at the menu item 'Options | Linker | Input' you can see that the monitor library has been included in this build. The library is in the project directory and is **3664HDIMLIB.lib**. Use of this library is described in the next tutorials and specifically in Section 3.2.

1.2.3 BUILDING THE FLASHER PROJECT

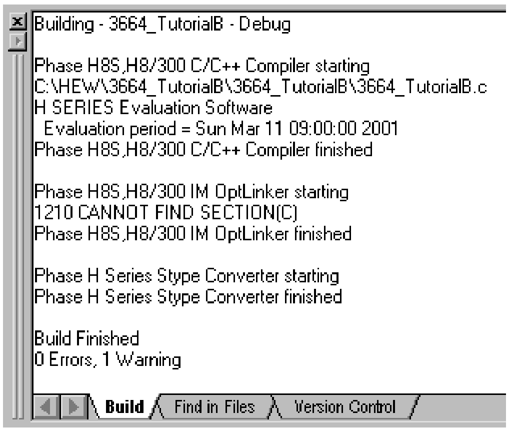
This next section will outline how to build a project to run with HDI-M. First start Hitachi Embedded Workshop from its icon or the Windows Start Menu, the previous workspace will automatically be loaded.

- Create a new workspace as in Tutorial A, but this time call the project "**3664_TutorialB**" and select "2. Flasher tutorial" as the project to generate in the Project generator wizard.



- Click the Build project icon  or press <F7>.

If it is not already open, the output window will open and the progress of the build will be displayed.



You will see a warning from the linker "1210 CANNOT FIND SECTION(C)", this is not a major problem in this case. Section C is used to store constant data and an entry has been put in the linker section options list for this section. The linker is complaining that it cannot find any data for that section, because as this code has no Constants, no constant data is generated. This will be explained further in Tutorial C Section 2.1.3.

1.2.4 FLASHING TUTORIAL B ONTO THE EDK

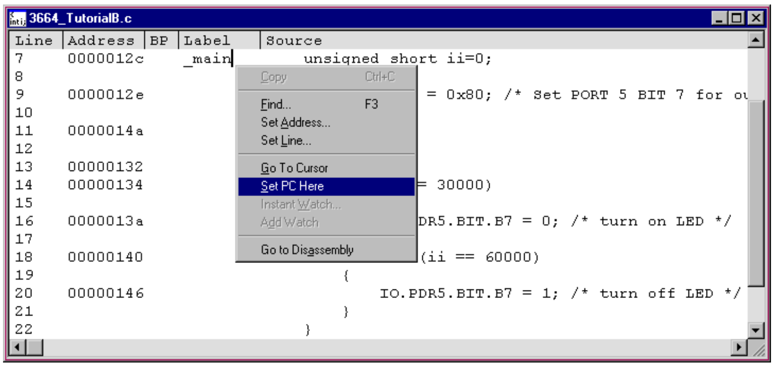
The HDI monitor library has been built with the user code for this project into an s-record which has the same name as the project. The s-record is `\3664_TutorialB\debug\3664_TutorialB.mot`. Until this file is flashed onto the microcontroller no debug can be performed with HDI. Ensure that no programs are using the serial port (i.e. the last session of HDI must be closed) and flash the `3664_TutorialB.mot` file onto the EDK using the same method described in Tutorial A Section 1.1.2. Once programmed ensure that FDT is disconnected from the EDK and proceed to the next section on debugging the code.

1.2.5 SETTING AND VIEWING BREAKPOINTS

Now launch the debugger again and this time load the file that we have just built **C:\...\3664_TutorialB\debug\3664_TutorialB.abs** the same way as you did in Tutorial A.

Open the program window as before, this time with the file
C:\...\ 3664_TutorialB\Flasher.c.

- To set the PC register to the start of the program, click on the _main label in the Label column of the Program Window to position the cursor, right-click to pop up the local menu and select 'Set PC Here'. The line should then be highlighted to show that it is at the current PC address.



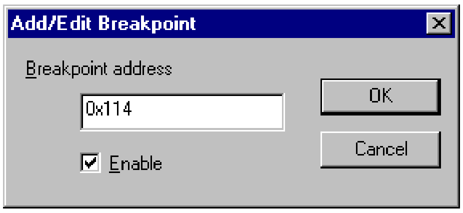
To check that the program does what we expect, we will first set breakpoints to stop at the line in the code where the port bit controlling the LED D1 is toggled.

- To set a breakpoint, open the breakpoint control window using the commands shown below.

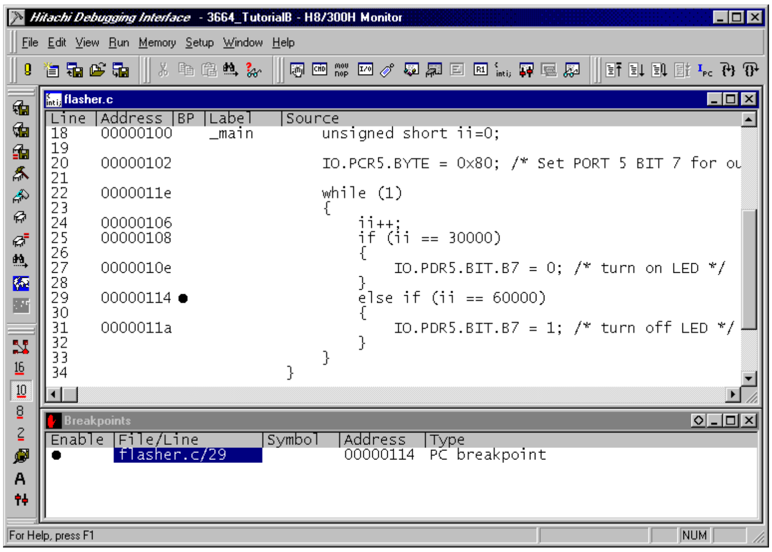
Menu Command:	Accelerator	Toolbar Button
View | Breakpoints	**Ctrl-B**	

- Right-click in the breakpoint window to pop up the local menu, select the 'Add…' item and enter the address shown below:

```
114                 else if (ii == 60000)
```



Once entered, the break window will show the new breakpoint, and also the code window will have a black dot next to the line of code in the BP column.



If the line you wish to break on is visible in the code window, a quicker way to set breakpoints is to double-click in the BP column on the same line as the code.

You should see the black dot appear and an entry for that breakpoint appear in the breakpoint window.

If you double-click again you can remove the breakpoint, you should see the black dot in the program window and the entry in the breakpoint window disappear.

- Ensure a breakpoint is set on address 0x114

WARNING: The EDK3664 will only allow ONE breakpoint to be assigned at any one time. If a breakpoint is set then the command 'Go to Cursor' will not work as this command uses a temporary breakpoint.

1.2.6 RUNNING THE PROGRAM AND HALTING EXECUTION

- To run to the breakpoint, select the Go command:

Menu Command:	Accelerator	Toolbar Button
Run | Go	**F5**	

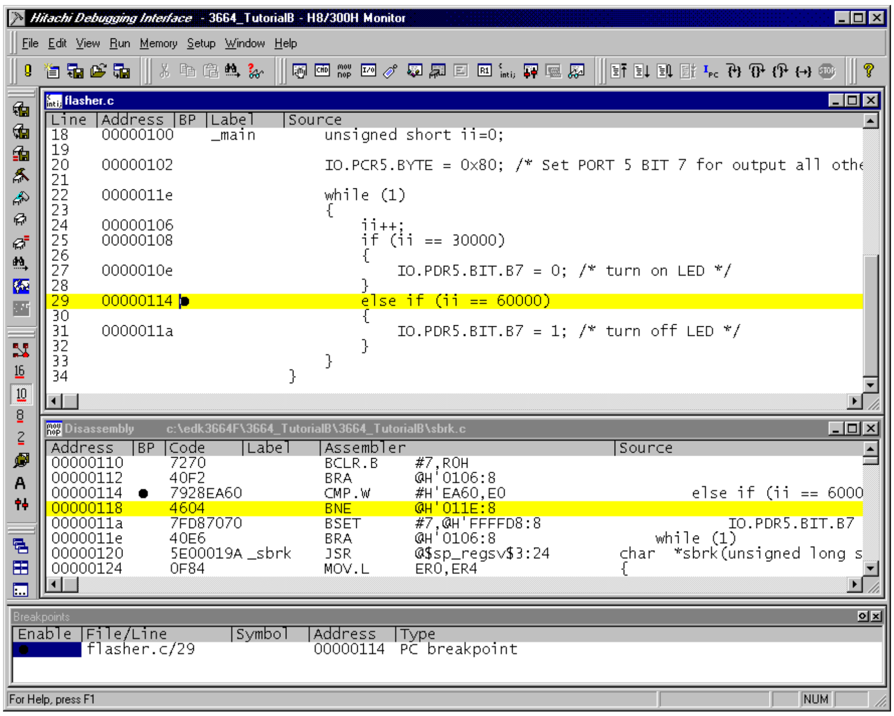
The program stops and the yellow highlight bar will now be placed on the breakpoint in the main function in the code window. The status bar indicates the cause of the break, i.e. that we have reached the breakpoint:

The highlight bar shows the position in the code corresponding to the value of the program counter (PC) register and indicates what will be the *next* instruction to be executed if we Go or Step.

WARNING: For EDK3664 the Breakpoints are controlled though the Address Break Controller. The line of code where the breakpoint is placed is EXECUTED and the program stops on the next assembly line following the breakpoint.

- Open a disassembly window by using the local menu item 'GO Disassembly'

You will notice that the line where the breakpoint has been placed has been executed and the PC and highlighted line is on the next line of code in this case at address 0x118 rather than 0x114!



If you look at the LED D1 on the EDK it should be on.

- Go again and you should see the LED D1 stay on and the program stop at the breakpoint again.

If you keep issuing the Go command you will see the LED D1 flash once the program is executed to the breakpoint about 60000 times!!.

Now we would like to run the code at full speed and see the delay loops making the flash of the LED D1 visible.

We can temporarily disable a breakpoint by selecting it in the Breakpoint window and choosing 'Disable' from the right-mouse button local menu. If you do this you will see the black dot disappear from the Enable column in the Breakpoint window and also the corresponding dot disappear from the BP column in the Program window. Alternatively you can double-click on the dot in the Breakpoint window Enable column to toggle the enabled/disabled state for the breakpoint. Note even though the breakpoint is disabled it is still valid and so no more breakpoints may be added.

- Make sure the breakpoint is disabled, and start the program running with the Go command.

You should now see the LED D1 flashing visibly on the EDK and the message on the status bar should read 'User Program is Running…'.

So now our program is running at full speed, but how do we stop it? To halt program execution:

Menu Command:	**Accelerator**	**Toolbar Button**
Run | Halt	**ESC**	

The program will stop with the highlight bar in the Program window showing the current location and the User Break message on the status bar 'Break = User Break'

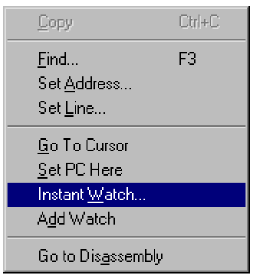
WARNING: Be very careful when placing breakpoints, always use the 'Disassembly window' and be aware of instruction prefetches after branch instructions. A breakpoint set on a branch will break on the line of code that the instruction branches to. A breakpoint set on a line of code after a branch may never be triggered because the line of code may always be prefetched. Try putting a breakpoint at address 0x11a, this will never be triggered because the compare and branch instructions before the code cause the code at 0x11a to always be prefetched.

1.2.7 VIEWING VARIABLES

We would like to view the value of the `ii` variable.

- Place the cursor in the code window over `ii`, after a short delay a tool-tip style information box will pop up showing the value of `ii`. This gives you a quick way of viewing a variable's value.

- Alternatively click to locate the cursor on the variable then use the right mouse button to pop up the local menu:



- Select the Instant Watch… option, a dialog will open showing you that `ii` is equal to 0.

This dialog is useful if the variable is more complex e.g. a pointer, array or structure.

- Select the 'Add Watch' option and the main Watch window will open showing the count variable.

Note that the default display for the variable shows its value in hexadecimal (H'). However, our code test values are decimal so it would be more useful to be able to view the value of the watched variable in decimal.

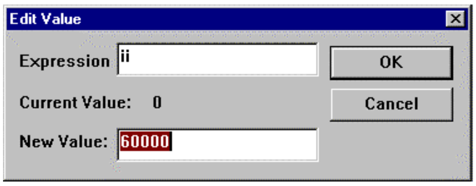
- To change the radix of the watchpoint display, click on the variable name in the Watch window and pop up the local menu, select Radix | Decimal:

The value in the watch window will then be displayed in decimal. The Watch window will display the current value of ii whenever the program has stopped.

1.2.8 USING HDI-M TO MODIFY A VARIABLE

- To see this working, set a breakpoint on the line of code where ii is incremented (`ii++;`) and Go to this point.

- In the watch window, place the cursor on the `ii` variable, and press the right mouse button to show the Watch window's local menu again. Select 'Edit Value' to display the dialog below:



- Now change the value of `ii` to 59999, and run to the next instruction, you should see that the value of `ii` has been incremented to 60000. Step to the test:

```
if (ii == 30000)
```

- Step again and you will see that the program steps past to the next `if()` test as this test is not satisfied.

- Step again and you will see that the next test is satisfied (we can see in the Watch window that `ii` does equal 60000) and so the LED is turned off.

2. EMBEDDED CODE TUTORIALS

Up to now all of our examples have assumed that we are writing code within the 'friendly' environment provided by HDI-M, and that only the basic features of the H8/300HTINY 3664F are being used. This second set of tutorials provides an example set of applications to allow you to write code which is intended for execution without HDI-M being present, i.e. code for a final application.

The tutorials address the following issues:

- Using the Hitachi Embedded Workshop(HEW) to build a project
- Using an example startup code file which allows the static data sections to be initialised, provision is also made for stack pointer initialisation, hardware setup and exit code.
- The use of the on-chip timer module is examined. This highlights the use of the on-chip control registers and in particular the interrupt mechanism within the EDK standard environment. This includes creation of the interrupt vector table and the use of in-line hardware control functions to control the CPU from C.
- The final tutorial allows the HDI-M monitor in flash to be replaced with a user's application code - this will then operate without the overheads (but also the protection) of HDI-M, and represents the final version of an application which would be used in target user hardware.

Throughout code listings are given, where appropriate, in the text.

2.1 Tutorial C: "STATICS"

The source files for this tutorial are generated in the project "**3. Statics tutorial**".

2.1.1 Need for the startup code

Most C applications will have a certain number of variables which are of either global or module scope. These variables are referred to as 'static', as they require statically allocated (i.e. at build time) space. Static variables may be of any valid type and may, or may not, be given an initial value. In an embedded system the code is resident in some form of non-volatile memory (ROM, Flash) and the application must boot from an uninitialised state at power-on. In such systems the static data must be set to its initial values before the user's application code is called (i.e. before `main()` executes). In addition it is common for the application's data area to be located in some form of memory which requires the system hardware to be initialised before it can be accessed e.g. RAM. These systems require startup code to perform the initialisation from reset, and then to pass execution to the user code. If the user's code should ever return from `main()` (not really a good idea in an embedded system), then some valid operation should be performed, rather than randomly executing code which happens to exist past the call to `main()` in the startup code.

The information on how to initialise the static areas must be stored in non-volatile memory (i.e. ROM), so that the startup code knows what to do. However the most desirable situation is one where the user can happily forget about the startup because initialisation information is automatically created and referenced using the compiler build tools. This is the goal of tutorial C, to demonstrate that this code has indeed worked. A small example file statics.c is created and then run under HDI-M to verify the result.

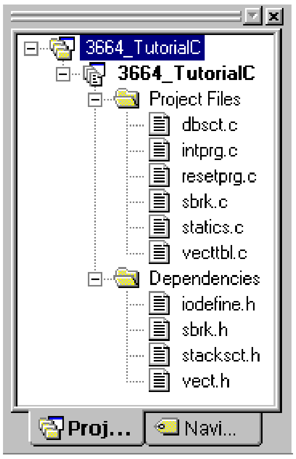
- Create a new workspace as we did in Tutorial B, but this time call the project "**3664_TutorialC**" and select "3. Statics tutorial" as the project to generate in the Project generator wizard.

2.1.2 Startup code detail

- Setup the reset vector

The vector table including the reset vector is defined in the file **vecttbl.src** and its associated include file **vect.inc**. As HDI-m is being used the reset vector must point to `startup()` which is the HDI-m startup function. This is covered in Tutorial E interrupt tutorial.

Here is a list of the startup code for **resetprg.c**.




```
#include        <machine.h>
#include        "stacksct.h"

#pragma entry PowerON_Reset

extern void main(void);
extern void _INITSCT(void);

#pragma section ResetPRG

void PowerON_Reset(void);
void PowerON_Reset(void)
{
         set_imask_ccr(0);
        _INITSCT();

/*      HardwareSetup();*/     /* Remove the comment when
                   you use Hardware Setup */

        main();

        while(1)
                sleep();        /* Catch return from main */
}
```

The operations to be performed by the startup code are:

- Unmask all interrupts

`set_imask_ccr(0)` is library function used to clear the interrupt mask bit of the system control register CCR.

- Set the stack pointer to a valid address.

The initialisation process can be viewed in the function `PowerON_Reset()` in the project file **resetprg.c**. This function is declared as the entry point of the system using the "entry" #pragma, this tells the compiler to insert assembly code at the beginning of the function to set up the stack pointer using the section name S and the stack size stored in **stacksck.h**. For more details on setting the stack see the *Hitachi H8S, H8/300 Series C/C++ Compiler User's Manual [ADE-702-189]*.

```
#pragma entry PowerON_Reset
```

- Set the static variables with initial values to the correct values.
- Reset all other static variables to 0.

According to the ANSI C language specification all uninitialised static data must be cleared to zero at startup. Any global variable that has not been given initial value when it is declared can be classed as an uninitialised data variable and should be initialised to zero. Similarly initialised static variables that *have* been given initial values when declared must be initialised at startup with these values. For your C program to be able to manipulate the resultant initialised data it must reside in RAM. However, the initial values for the data must be stored in non-volatile memory (to survive a power-on reset) and copied to RAM at startup, thus initialising the data.

Static variable initialisation is done by a library function __INITSCT which is called from **resetprg.c**. Sections to be initialised are defined in **dbsct.c**. If the user creates a data section with a different name from the standard sections then they must be added to **dbsct.c**. Memory Sections are described in the 2.1.3.

- Call the hardware initialisation code.

If the comments are removed hardware initialisation function `HardwareSetup()` is called. It is up to you to define this function and include it in your project if you need to initialise your hardware

A good example of low level initialisation is SDRAM setup. Most of Hitachi's microcontrollers have direct interfaces to many different types of memory, but some of these interfaces have to be setup before the memory can be accessed. The interface should be setup in `HardwareSetup()`, before static initialisation so that any static variables within this memory can be initialised later in the startup code. For H8/3664 there is no external bus to interface so the Hardware setup file could be used to initialise the microcontroller's on chip peripherals. This is covered in Tutorial D Timer.

- Call the users main routine.

main() is called.

- If the users code returns, call the exit routine.

Finally the `PowerON_Reset()` function ends with a `sleep()` intrinsic function call to put the microcontroller into a safe state.

WARNING: When using HDI-m the `PowerON_Reset()` function must always be used. This is explained in STANDALONE Section 3.2.

2.1.3 VIEWING THE STATICS

The example C file **Statics.c** is shown below:

```
unsigned char string[] = "hello world";      /* Global variables */
int count;

void main (void)
{
        int volatile loc;
        for (count=0; count<12; count++)
        {                                     /* overwrite the characters in string[] */
                string[count] = 'a' + (unsigned char) count;
                loc++;
        }
}
```

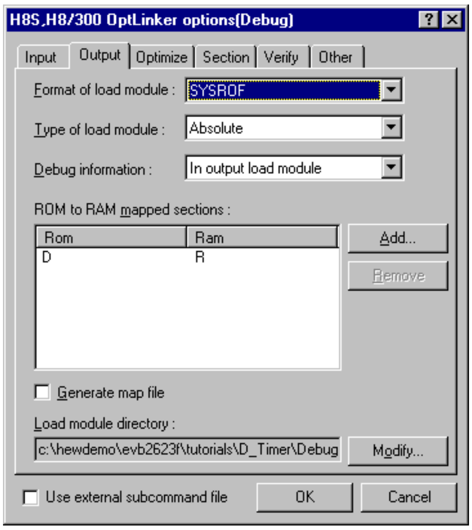
This file has been built to run with HDI-m. There are three variables in this code, two global and one local. The character string `string[]` has an initial value, integer `count` does not and neither does the local int `loc`.

By default the sections have the following names.

ANSI C Section	Hitachi Compiler/Linker section name
Program	P
Constants	C
Initialised Data	D
Uninitialised Data	B

The uninitialised integer count is in section B (RAM) and is initialised to zero by _INITSCT. The local integer `loc` is uninitialised in accordance with the ANSI C specification and has an undetermined initial value.

The code in _INITSCT copies the initial value of `string[]` in ROM to RAM. The initial value is in section D (ROM) and is copied to R (RAM), this can be seen in the Ouput tab of the 'Options | Linker | Output' menu item.



If the user adds their own section names using the #pragma section statement 4 new sections could be created, for example:

```
#pragma section ResetPRG
```

If there is code following this section definition the code will be stored in a section named **PResetPRG CResetPRG DResetPRG** and **BResetPRG**. depending on the data types shown in the table above.

DResetPRG and **BResetPRG** must be added to **dbsct.c** and **RResetPRG** must be defined in the section definitions under menu item 'Options | Linker | Sections'. **DResetPRG** and **RResetPRG** must also be added to the ROM to RAM mapping.

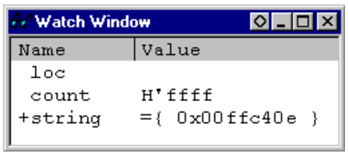
Custom sections are described in more detail in Section STANDALONE 3.2.

NOTE: If a section is defined in the link map ('Options | Linker | Sections' menu item) **but no data is assigned to it the linker will issue a warning *1210 Cannot Find Section(*name*)*.**

2.1.4 RUNNING THE CODE

- Now disconnect HDI from the EDK and Flash it with the file **C:\...\3664_TutorialC\debug\3664_TutorialC.mot** as described in Tutorial A. Disconnect FDT from the EDK and restart HDI and load **C:\...\3664_TutorialC\debug\3664_TutorialC.abs**

- Open a program window for **Statics.c** and place a breakpoint at the first line of code in main(). Place a watch on the three variables `loc`, `string[]` and `count` using the same method used in Tutorial B.



The watch window should show something similar to the picture. It can be seen from this that before initialisation `loc` has no value, as it is a stack based local variable. `count` and the character string `string[]` have random values.

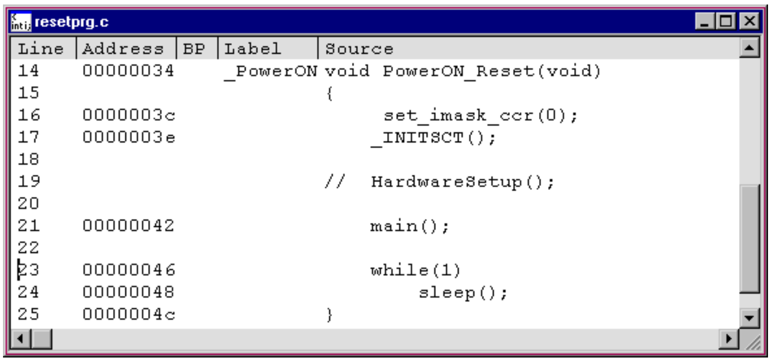
- Now reset the processor and then Step once.

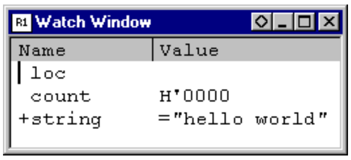
Menu Command:	**Accelerator**	**Toolbar Button**
Run | Reset	-	

A source code window will open showing the **resetprg.c** file with the PC highlight bar in the `PowerON_Reset()` function:

This first step will have executed the assembly code that sets up the stack pointer (you can check in the disassembly window if you want to verify this).

- Step again to set the interrupt mask, the highlight will now be on the call to the _INITSCT() function.
- If you Step Over this call while inspecting the Watch Window you will see that the variables `string[]` and `count` have now been initialised, with our initial data and zero respectively.

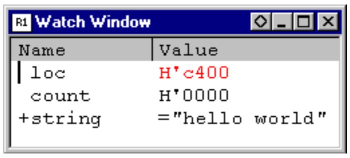




Now both `count` and `string[]` have been initialised but the local `loc` has not, its value is in fact blank. This is because local variables only have a valid scope *inside* their functions i.e. local to them.

- Let the program continue with the Go command, it will stop at the breakpoint in main().

You can see that `loc` now has a value, because the PC is now in the scope of the local variable i.e. in its function.



Local variables are stored on the stack and the values that they have are indeterminate, being whatever happens to be at that location on the stack. Therefore they need to be initialised manually in the code as the compiler does not initialise them on the stack, alternatively the STATIC keyword could be used to ensure that the local variable is stored at a memory location.

```
int loc=0;      or      static int loc;
```

Now test the execution of the main code by setting a break after the main() function call in `PowerOn_Reset()` (line 0x46) and running to this break. The string variable `string[]` will now contain the sequence 'abcdefghijkl' rather than 'Hello World'.

2.1.5 MEMORY MAP FOR EDK3664F WITH HDI-M

The processor on the EDK is in single chip mode and cannot be changed. This means the chip is in normal mode with on-chip ROM(Flash) enabled. The processor can access 64Kbytes of memory space (see H8/300HTINY 3664F Hardware Manual CPU Section) HDI-M sets up system registers in order to communicate with the user code, these peripheral registers should not be changed once HDI-M is running. The Peripherals used by HDI-M are:

1. SCI3 for serial communications
2. Address Break controller for stepping and breakpoint control
3. NMI control for Flash Programming

<u>EDK H8\3664F TINY Memory Map with HDI-m</u>

Address	Area
H'0000	Vector area
H'0034	HDI-Monitor code. (Relocatable) 6Kbytes
H'17F6	Free FLASH. (For User Code) 26Kbytes
H'7FFF	Unpopulated
H'F780	Flash work Area And User RAM 1Kbytes
H'FB80	Internal RAM For User code 778Bytes
H'FE8A	Internal RAM For Monitor Work Area (Relocatable) 245Bytes
H'FF80	Internal Registers
H'FFFF	

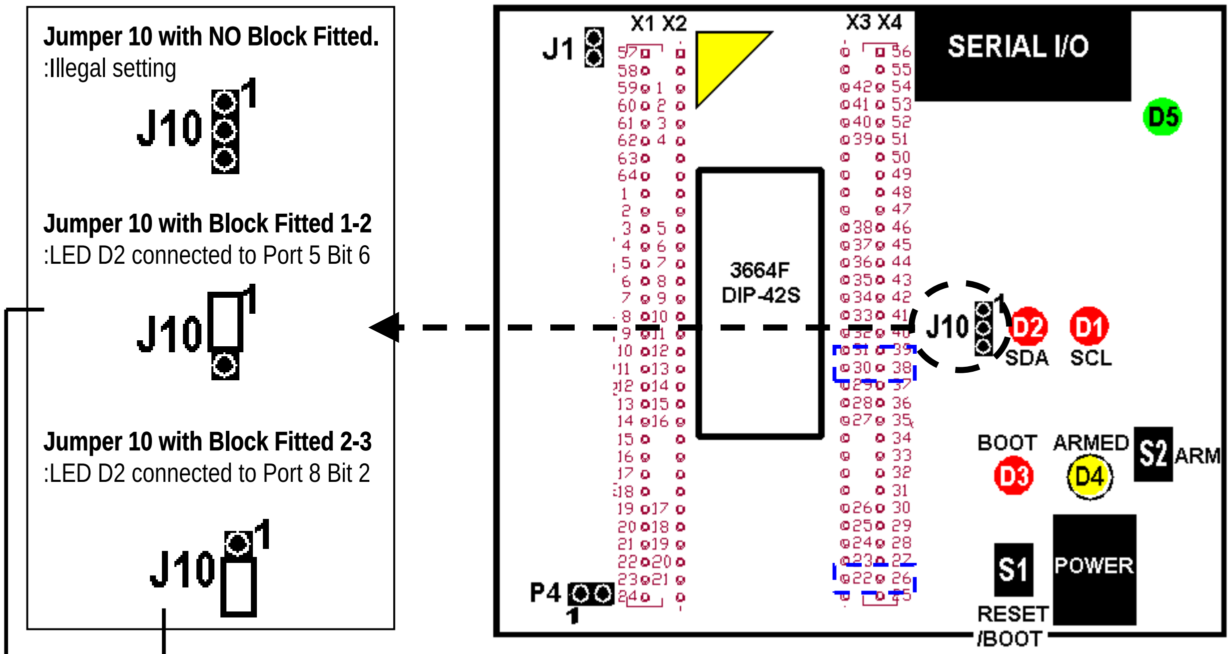
2.2 TUTORIAL D: "TIMER"

2.2.1 SETTING THE LED D2 TO THE CORRECT PORT

The EDK is equipped with a TWO RED LEDs that may be controlled by a program. LED D1 is connected to the 3664F port 5 bit 7 (pin 30 on X3:underside of board / X4:topside of board). LED D2 can be connected to port 5 bit 6 (Board pin 31 on X3 / X4) or port 8 bit 2 (pin 19 on X3 / X4) by setting jumper J10. Below is a description of jumper, LED and pin positions. A table of LED to port, bit and board pin is also below. For a more detailed description of the pin out of the EDK refer to the EDK3664F User manual.

For this tutorial we will be using LED D2 connected to port 8 bit 2 (X3/X4 PIN 19) which is also a timer output pin.

- Ensure J10 is connected with a jumper block across **2-3** as shown below.



EDK3664 Board layout

LED	J10 Block Position	X3/X4 Pin	QFP-64 Pin	DIP-42S Pin	Pin Function
D2	1-2	31	26	22	Port 5 Bit 6 / SDA
D2	2-3	19	38	30	Port 8 Bit 2 / FTIOB

2.2.2 ACCESSING THE CONTROL AND STATUS REGISTERS

The H8/300HTINY 3664F microcontroller contains a lot more than simply a CPU. A whole host of peripherals are available to you for use in a target application. Each peripheral module has a set of control and status registers, which act as the interface to the CPU, many peripherals also have pins associated with them, which act as the interface to the outside world. Each peripheral can signal a change in its status by setting bits in one of its registers, or by sending an interrupt to the CPU, prompting immediate action.

The control and status registers of the peripheral modules are memory mapped, each one having a unique address at the top of the address space. Registers vary in type, from byte wide to long word wide and from read/write to read or write only. To allow simple access to the registers the flexible casting feature of C may be used. As we saw in Tutorials A and B, a symbol can be defined which corresponds to the access inside the address of the given register. This requires the address, which is a constant integer value, to be treated as an address reference (i.e. a pointer), and then pointer indirection to be used to access the contents of the address. To further complicate matters, the entire construct must be declared as 'volatile' to stop the C compiler from optimising away accesses to the register. This is because the registers may be modified by some operation other than one performed by the CPU, and thus the compiler can have no visibility of this. Optimising compilers often remove accesses to what appears to be redundant information - this must be stopped in the case of peripheral control and status registers, hence the use of the 'volatile' keyword.

If you remember in Tutorial A we defined the i/o registers as below:

```
#define IO      (*(volatile struct st_io    *)0xFFD0) /* IO    Address*/
```

and in Tutorial B we learned that to simplify the construction of user code the header file **iodefine.h** has been created which contains all of the on-chip peripheral registers for the H8/300HTINY 3664F.

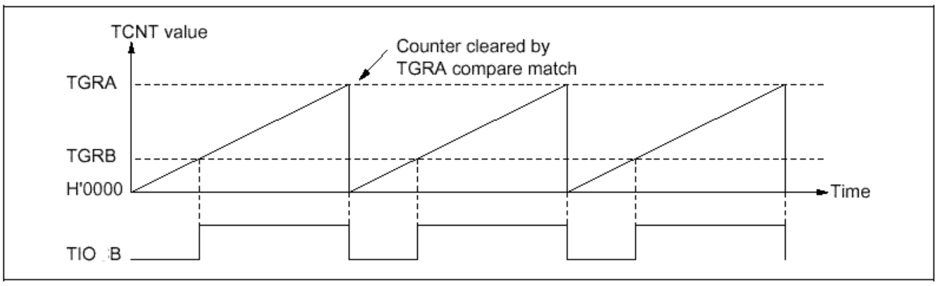
The file **iodefine.h** follows the naming scheme used in the hardware manual. The name of the structure corresponds to that of the peripheral module, and the structure elements to the control registers and even individual bits in those registers.

Note: The addresses used in the header file are those defined in the hardware manual for the device operating in 64kbyte mode - if an address greater than 64K Bytes is offered to the CPU, the most significant bits are ignored. Thus there is no need to re-write the file for use in 64KByte systems.

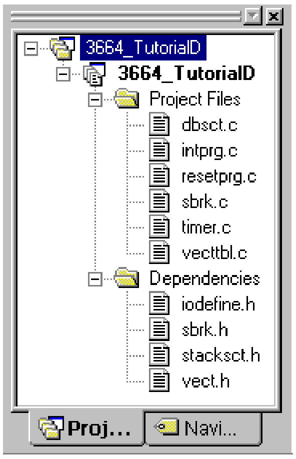
2.2.3 THE TIMER PROGRAM

The Tutorial project '4. Timer Tutorial' contains the source files for this tutorial, the main module **Timer.c** is listed below. The application flashes the LED D2 using one of the on-chip 16 bit timer modules, Timer W, instead of by software. We will use the timer to output a PWM square wave signal on timer output TIOB which is multiplexed with Port 8 Bit 2 of the device, to which the LED D2 is connected via **J10 2-3** on the EDK. Port 8 and the timer output TIOB both share this pin, but cannot use it at the same time. The cycle period for the waveform is set by the value in the timer's TGRA register and the duty cycle is set by the value in the TGRB register.

When the timer is enabled it will start counting up. When the value in the TCNT register matches the value in the TGRB register the output of the pin will go to 1 turning the LED D2 off, and the counter will continue to increment. When the value in the TCNT register matches the value in the TGRA register the TCNT register will be reset to zero, causing the cycle to reset and the output of the pin to be cleared turning the LED D2 on.



- Generate a new tutorial project as done in previous tutorials but this time select '4. Timer Tutorial' and call it **3664_TutorialD**. The following workspace view should be seen.



- View the file **Timer.c** by double clicking on it in the workspace window

```
#include "iodefine.h"

/* Define constants for peripheral register vaules */
#define TCR_CCLR   1              /* Set TCNT cleared by TGRA match */
#define TCR_CKS    3              /* Clock source internal/8 */
#define TMR_PWMB   1              /* PWM mode in channel B */
#define TCR_TOB    0              /* output 0 on TIOB at start */

void main(void)
{
    volatile unsigned short duty;

    TMRW.GRB = duty = 0x7fff;     /* Set duty of LED 50% by GRB */
    TMRW.TMR.BIT.CTS = 1;         /* Start Timer W */

    while(1)
            TMRW.GRB = duty;      /* Change duty cycle */

}

void HardwareSetup(void)
{
    MSTCR1.BIT.MSTTW = 0;         /* Enable TimerW module */
    TMRW.TMR.BIT.CTS = 0;         /* Timer off */
    TMRW.TCR.BIT.CCLR = TCR_CCLR; /* TCNT clear on GRA match */
    TMRW.TCR.BIT.CKS =  TCR_CKS;  /* Clock = phi/8*/
    TMRW.TMR.BIT.PWMB = TMR_PWMB; /* PWM mode for channel B */
    TMRW.TCR.BIT.TOB = TCR_TOB;   /* initial output is 0 */
    TMRW.GRA = 0xffff;            /* Set cycle period by GRA */
}
```

- The function `HardwareSetup()` sets up the control registers in the timer module. In order for it to be called we must ensure the function is called at the start of **resetprg.c**.
- **resetprg.c** then calls `main()` in which the duty cycle register is set up and the timer started.
- The program then goes into a loop setting the duty cycle (this is so that we can easily modify the value).

2.2.4 RUNNING TIMER

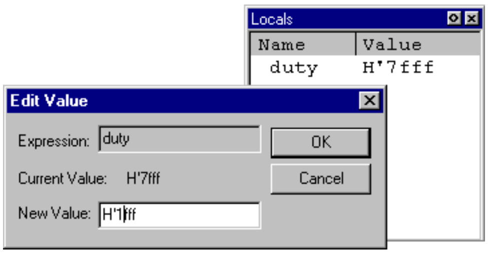
- Build the code generated from the project generator.
- Now disconnect HDI from the EDK and Flash it with the file **C:\...\3664_TutorialD\debug\3664_TutorialD.mot** as described in Tutorial A. Disconnect FDT from the EDK and restart HDI and load **C:\...\3664_TutorialD\debug\3664_TutorialD.abs**
- Open a code window with **Timer.c** and set a breakpoint at the start of main().
- Reset Go and the program should stop at the breakpoint.

Menu Command:	Accelerator	Toolbar Button
Run | Reset Go	**Shift-F5**	

- Step over the instruction to set the duty cycle
- Step over the instruction to start the timer, you should see the LED D2 start flashing with a duty cycle of 50%.
- Remove the breakpoint on main()
- Set a breakpoint in the while() loop where the duty duty cycle is changed and Go to the breakpoint. (Remember to check if the instruction will break the process)
- Open a local watch window , you can see the value of the variable duty.

Menu Command:	Accelerator	Toolbar Button
View | Locals	**Ctrl-Shift-W**	

Now you can modify the duty value in the Local watch window by double-clicking on the value field in the window, try a new value of H'1fff.



- Go again to write the value into the TGRB register and you will see the duty cycle of the LED flash has changed on EDK. Try different duty cycle values and see what effect it has on the LED's flashing.

2.2.5 VARIATIONS

You could try changing the period value in the TGRA register to change the cycle time for the LED D2 flashing or modify the program to vary the duty cycle and create different PWM patterns.

2.3 TUTORIAL E: "INTERRUPT"

2.3.1 INTERRUPTS ON THE H8/300HTINY 3664F

In most user applications the rapid response of the system to external stimuli is essential, in such systems the CPU must be informed of the change in the system status immediately. To rely on polled tests of the various peripheral control registers represents a large CPU overhead. The H8/300H TINY series of microcontrollers all support a wide range of on-chip peripherals; each being capable of generating at least one CPU interrupt. In addition the CPU may be signalled from external devices using the NMI or one of the IRQ interrupt signals. In this tutorial we will use the TGRB compare/match interrupt of the PWM Timer W to vary the duty cycle of the flashing LED D2.

The H8/300H TINY architecture provides direct hardware support for interrupts, via the interrupt controller. Each interrupt source is allocated a special vector address. The vector address is used to store the address of the interrupt service routine (ISR) which is to be executed when the relevant interrupt is accepted. The interrupt controller tests the priority level of an incoming interrupt against the priority level that the CPU will currently accept. If the incoming interrupt is higher than the current CPU interrupt mask level (stored in the condition code register), then interrupt processing begins. The program counter (PC) and the condition code register (CCR) are stacked, and the PC set to the value contained in the relevant vector address. Execution then continues from the new PC value. The ISR should be terminated with a return from exception (RTE) instruction to ensure that the PC and CCR are correctly restored on exit.

In this H8/300H Tiny we can only use interrupt mode 0. This means that the I bit in the CCR is the interrupt mask bit. If I is set to 0 interrupts will be enabled, i.e. not masked. See the *H8/3664F Hardware Manual* Interrupt Section for more information on interrupt control

2.3.2 CREATION OF AN ISR IN C

It is often desirable to write all your application code in C, where possible. The Hitachi tools support extensions to the ANSI C language to allow interrupt service routines (ISR) to be written. As mentioned above an ISR is distinguished from a normal function by the fact that it is terminated using a RTE instruction. However, this is not the only difference. ISRs are by nature asynchronous and thus you cannot rely on the state of the registers on entry to the function. In addition the ISR must preserve the state of all registers, as there is no way of telling which registers were currently in use by the CPU when the exception occurred.

You also need to create an entry in the vector table that gives the address of the ISR for the given interrupt. Each vector is located at a fixed address, so care must be taken to place it correctly. To define a function as an ISR, simply precede it by the following form of statement:

```
#pragma interrupt (INT_TMW)
```

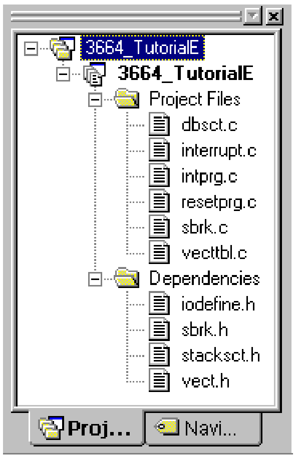
This instructs the compiler to treat the function `INT_TMW`, when it is defined in the source code as an ISR, and hence to preserve the register values, and to terminate with a RTE instruction. When the interrupt occurs the corresponding ISR function address is fetched from the vector table and the program will jump to that address. Therefore the address of the `INT_TMW` ISR needs to be stored in the correct place in the vector table. When you create a new project in HEW, several files defining the vector table and ISRs are created:

vecttbl.c	- actually defines the vector table itself and the vector entries
vect.h	- declares the ISR function names as external symbols
intprg.c	- a default ISR function for all interrupts not used by HDI-m or the User's Code (a 'catch-all')

An added complication when using HDI-M is that the vector table is located from address H'0, which is in the Flash ROM area used by HDI-m and the user's code. To allow us to develop with interrupts, the HDI-monitor must be built with the user code and the power on reset vector must point to HDI-m code. HDI-m also uses the serial and address break interrupts so these cannot be used if HDI-m is built with the user code

2.3.3 INTERRUPTS AND HDI-M

- Generate a new tutorial project as done in previous tutorials but this time select '5. Interrupt Tutorial' and call it **3664_TutorialE**. The following workspace view should be seen.



Vecttbl.c actually defines the vector table itself and creates a section named DVECTTBL which contains the power on reset function vector and also a section named DINTTBL which contains the vector entries for all interrupts available on the H8/3664F. As this project has been built for use with HDI-m the Reset vector in DVECTTBL points to the power on reset vector for HDI-m.

If HDI-m is to be used this power on reset vector must always be used.
-Power on reset vector when using HDI-m is `startup()`.

Within the interrupt table DINTTBL there are 3 interrupts that cannot be changed if operation with HDI-m is desired. These vectors are:
-NMI interrupt `NMIcapture()` for flash programming control
-SCI3 interrupt `SCIint()` for communications between the PC and the EDK
-UBC interrupt `UBCint()` for breakpoint control.

If any of these interrupt functions are omitted from the interrupt table HDI-m will not operate correctly.

All other interrupts in this table are serviced by 'catch all' functions defined in **intprg.c**. All the functions are blank except one, the timer interrupt `INT_TMW()` is commented out. This is the interrupt routing for the timer used in this tutorial. The ISR `INT_TMW()` can be found in **Interrupt.c**.

If you want to add your own interrupt functions it is advisable to keep the same names already in the tables and simply comment out the 'catch all' function in **intprg.c** and write another elsewhere. Always remember to use the following compiler syntax when writing an interrupt routine.

`#pragma interrupt` (interrupt name)

Here is the code listing for **intprg.c**

```
#pragma section IntPRG

void Dummy(void){;}
/* void NMIcapture(void){;}   Monitor NMI capture */
 void INT_TRAP0(void){;}
 void INT_TRAP1(void){;}
 void INT_TRAP2(void){;}
 void INT_TRAP3(void){;}
/* void UBCint(void){;}       Monitor address break interrupt */
 void INT_SDT(void){;}
 void INT_IRQ0(void){;}
 void INT_IRQ1(void){;}
 void INT_IRQ2(void){;}
 void INT_IRQ3(void){;}
 void INT_WKP5(void){;}
 void INT_TMAOVF(void){;}
/* dummy*/
/* void INT_TMW(void){;}      Used in tutorial E main() function */
 void INT_TMV(void){;}
/* void SCIint(void){;}       Monitor serial port interrupt */
 void INT_I2C(void){;}
 void INT_ADEND(void){;}
```

2.3.4 UNDERSTANDING THE INTERRUPTS TUTORIAL

The file **Interrupt.c** contains the source for the tutorial:

```
#include <machine.h> /* So that we can use language extensions for embedded systems */
#include "iodefine.h"

/* Define constants for peripheral register vaules */
#define TCR_CCLR        /* Set TCNT cleared by TGRA match */
#define TCR_CKEG        /* Default clock edge */
#define TCR_TPSC        /* Clock source internal/256 */
#define TCR_TOB                /* Set pin ouput modes: TIOB */

/* Function Prototypes */
void main(void);
void HardwareSetup(void);
#pragma interrupt (INT_TMW)

void main(void)
{
        unsigned short duty;

        TMRW.GRB= duty = 0x7fff;      /* Set duty of LED 50% by TGRB */
        TMRW.TMR.BIT.CTS = 1;         /* Start Channel 1 */

        while(1);                     /* Loop forever */
}

void HardwareSetup(void)
{
        set_imask_ccr(0);             /* Enable interrupts to CPU */
        MSTCR1.BIT.MSTTW = 0;         /* Enable TimerW module */
        TMRW.TMR.BIT.CTS = 0;         /* Timer off */

        TMRW.TIER.BYTE &= 0x00;       /* dissable all interrupts */
        TMRW.TSR.BYTE &= 0x00;        /* Clear any pending interrupts */

        TMRW.TCR.BIT.CCLR = TCR_CCLR; /* TCNT clear on GRA match */
        TMRW.TCR.BIT.CKS =  TCR_CKS;  /* Clock = phi/8*/
        TMRW.TMR.BIT.PWMB = TMR_PWMB; /* PWM mode for channel B */
        TMRW.TCR.BIT.TOB = TCR_TOB;   /* initial output is 0 */
        TMRW.GRA = 0xffff;            /* Set cycle period by GRA */
        TMRW.TIER.BIT.OVIE = 0;       /* Disable the OVERFLOW interrupt */
        TMRW.TIER.BIT.IMIEB = 1;      /* Enable the GRB Match interrupt */
}

void INT_TMW(void)
{
        TMRW.TSR.BIT.IMFB &= 0;       /* clear B compare/match bit */
        TMRW.GRB -= 0x400;            /* Decrement duty value by 400 */
}
```

The main function is very similar to the main function from Tutorial D. Because the ISR changes the duty value we do not need to do this in the main and so it just sits in a `while` () loop.

The `INT_TMW(void)` function is the interrupt service routine. This corresponds to the symbol entry in the vector table definition in **vecttbl.c**. The first line clears the timer's compare/match interrupt bit, if the interrupt is not cleared, another interrupt will immediately be generated on return from the ISR.

The second line in the ISR decrements the duty value in the TGRB register to shorten the 'off' time of the LED, when it is decremented past 0 the value in the register will underflow and start again at a high value i.e. with a short pulse on the LED. Note we decrement the value rather than increment it, because if we incremented then very shortly after returning from the interrupt, we would get a compare/match on this larger value (as the timer is still counting) rather than waiting until another complete cycle period has been completed.

The startup function `HardwareSetup()`has been increased to include an additional line of code to enable the Timer module channel B compare/match interrupt:

```
    TMRW.TIER.BIT.IMIEB = 1;  /* Enable the GRB Match interrupt */
```

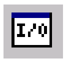
This causes an interrupt to occur whenever the value in the TCNT register matches that in the TGRB register. The special function set_imask_ccr(0) is added, this is an in-line function to insert an instruction to change the CCR values and unmask the interrupts, in order to use this special function we have to include the header file **machine.h**. This contains a number of functions definitions to allow access to CPU operations like accessing the condition code register (CCR) and using specific instructions e.g. trapa, sleep, movfpe, eepmov, mac, rotlw, dsub, nop. These functions may be used in an application to gain access to the CPU, they should be used with care as they directly control the underlying hardware and are not subject to checking by the compiler. For more information on these function see the *Hitachi H8S, H8/300 Series C/C++ Compiler User's Manual [ADE-702-189]*.

2.3.5 VIEWING AND RUNNING THE APPLICATION

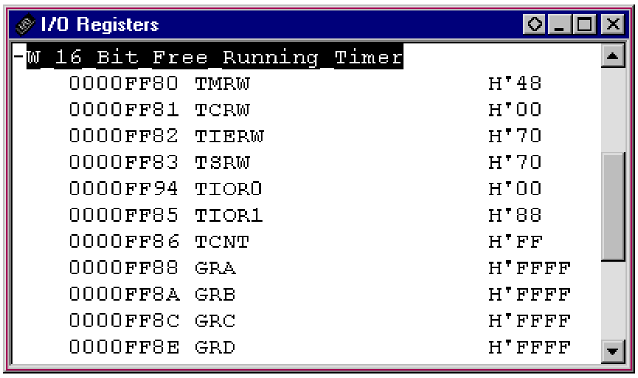
- Select the project **3664_TutorialE** and execute a build to create the debug absolute load file, and an S-record to download to flash using FDT.
- Now disconnect HDI from the EDK and Flash it with the file **C:\...\3664_TutorialE\debug\3664_TutorialE.mot** as described in Tutorial A. Disconnect FDT from the EDK and restart HDI and load **C:\...\3664_TutorialE\debug\3664_TutorialE.abs**
- Open a code window with the file **interrupt.c** and set a breakpoint at the following line in the ISR **INT_TMW**:

```
TMRW.GRB -= 0x400;    /* Decrement duty value by 1000 */
```

- Open an I/O register window. It is **H83664.io** located in the HDI directory. Install it using menu item 'Setup | Configure Platform'

Menu Command:	Accelerator	Toolbar Button
View | I/OArea	**Ctrl-I**	

This window lists all of the on-chip peripheral modules, you can expand the module name to show its registers by double-clicking on the module name. Expand the **W_16_Bit_Free_Running_Timer** module. You can see the duty cycle value in the GRB register.



- Reset Go and the program should stop at the breakpoint.

You should see the GRB updated with the initial duty value H'7fff and the LED start flashing with a duty cycle of 50%.

- Run to the breakpoint again.

You should see the GRB value decrement by H'400, continue running and stopping at the breakpoint. You can see the duty value change and the corresponding flash period of the LED also change. Note that when the program is stopped the duty value does not change even though the LED continues to flash and compare/match occurs. Although this does in fact cause an interrupt request, HDI masks interrupts while the program is stopped.

- Remove the breakpoint and Go.

You cannot see the TGR1B value decrement while the program is running, however you can see the duty value of the LED flash change.

WARNING: To use this I/O window HDI-m must read a mode bit at address H'FFF1. This is the address for the SYSCR2 register which controls the subactive clock frequency. A 1 must be written to this register in order for the I/O window to be used and so the subactive clock cannot be /8.

2.3.6 VARIATIONS

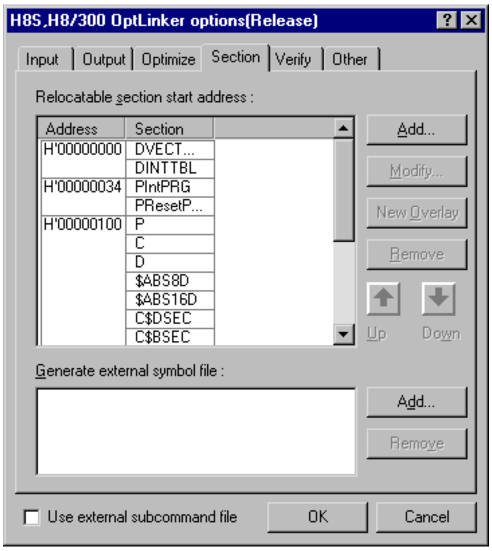
Once interrupts have been mastered programming for real-time applications becomes much simpler. In addition the removal of polled loops enables many tasks to be performed, seemingly at the same time. In tutorial E_Interrupt the main program does nothing as it just sits in a while() loop, you could try performing some useful operation in this loop Alternatively you could try using some of the other on-chip modules. See the H8S hardware users manual for more information on them.

2.4 TUTORIAL F: "LONER"

The final example simply takes the code from Tutorial E and makes it run on the EDK *without* HDI-M. The aim of this example is to show that an application can be created using these tools which will be capable of running 'stand-alone'. The majority of the work has already been done - the startup code was created in Tutorial C, the peripheral register address header file was used in Tutorials B & D and the interrupt vector table was explained in Tutorial E. This example uses similar source files that were used in Tutorial E. The main difference is that since HDI-m will not be resident, a real power on reset vector must be created and not one that calls HDI-m initialisation function `startup()`. Tutorial F is a version of Tutorial E Interrupt that will run from Flash without HDI-m. Also since HDI is no longer using the UART serial interface this is now available to our application, we will use it to write a sign on banner and echo back characters from an external terminal (in this case Hyperterminal).

2.4.1 CREATION OF A VECTOR TABLE IN C WITHOUT HDI-M

- Generate a new tutorial project as done in previous tutorials but this time select '6. Loner Tutorial' and call it **3664_TutorialF**.
- If you now look at the linker section map in HEW (menu item 'Options | Linker | Section') you can see that the reset vector section DVECTTBL is placed at H'0 followed by the interrupt vector section DINTTBL as in previous tutorials.



The interrupt vector table must be located at this address to ensure startup code is executed first on reset. The startup code in file **resetprg.c** does not change but the power on reset vector points to `PowerOn_Reset()`rather than the HDI-m initialisation function `startup()`.

The vector table definition in **vecttblt.c** does not contain any of the HDI-m interrupts described in Section 2.3.3. instead these peripherals are available to the user.

Note also that in the menu item 'Options | Linker | Input' there is NO inclusion of the HDI-m library file.

2.4.2 LOW LEVEL INITIALISATION

As we saw in the previous tutorials, low level initialisation occurs before the user's code is called in order to set up the bus protocol and essential peripherals. Since we are running stand-alone we cannot rely on HDI to initialise the EDK environment for us. Therefore we must do it ourselves in `Hardware_setup()` which is shown in the source below from **Loner.c**.

```
void HardwareSetup(void)
{
        set_imask_ccr(0);              /* Enable interrupts to CPU */
        MSTCR1.BIT.MSTTW = 0;          /* Enable TimerW module */
        TMRW.TMR.BIT.CTS = 0;          /* Timer off */
        TMRW.TIER.BYTE &= 0x00;        /* dissable all interrupts */
        TMRW.TSR.BYTE &= 0x00;         /* Clear any pending interrupts */

        TMRW.TCR.BIT.CCLR = TCR_CCLR;  /* TCNT clear on GRA match */
        TMRW.TCR.BIT.CKS =  TCR_CKS;   /* Clock = phi/8*/
        TMRW.TMR.BIT.PWMB = TMR_PWMB;  /* PWM mode for channel B */
        TMRW.TCR.BIT.TOB = TCR_TOB;    /* initial output is 0 */

        TMRW.GRA = 0xffff;             /* Set cycle period ~1s by GRA */
        TMRW.TIER.BIT.OVIE = 0;        /* Disable the OVERFLOW interrupt */
        TMRW.TIER.BIT.IMIEB = 1;       /* Enable the GRB Match interrupt */

        /* Serial Port 3 Setup */
        IO.PMR1.BIT.TXD = 1;           /* Enable SCI3 TX out */
        InitSCI3(SCI_Init_Data);        /* initialise serial port */
}
```

Most of this file is identical to Tutorial E except for the initialisation of the serial port SCI3. This function is described in Section 2.4.4.

2.4.3 THE MAIN() FUNCTION

The `main()` function in is displayed below:

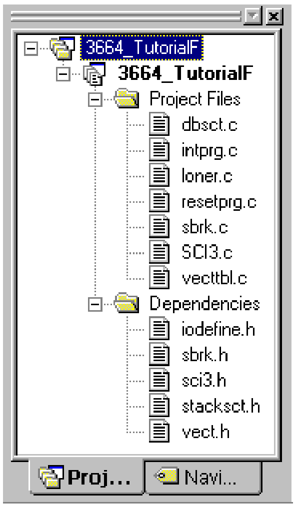
```
#include <machine.h>  /* So that we can use language extensions for embedded systems */
#include "iodefine.h"
#include "SCI3.h"
/* Define constants for peripheral register values */
#define TCR_CCLR      1              /* Set TCNT cleared by TGRA match */
#define TCR_CKS       3              /* Clock source internal/8 */
#define TMR_PWMB      1              /* PWM mode in channel B */
#define TCR_TOB       0              /* output 0 on TIOB at start */
/* SCI Initialisation data structure */
struct SCI_Init_Params SCI_Init_Data={B9600,P_NONE,1,8};
/* Function Prototypes */
void main(void);
void HardwareSetup(void);
#pragma interrupt (INT_TMW)

void main(void)
{
       volatile unsigned short duty;

       TMRW.GRB = duty = 0x7FFF;     /* Set duty cycle at 50% in GRB */
       TMRW.TMR.BIT.CTS = 1;         /* Start the timer */

       PutStr((unsigned char *)"\r\nEDK3664F Demo serial output\r\n");

       while(1)
       {
              PutChar(GetChar());
       }
}

void INT_TMW(void)
{
       TMRW.TSR.BIT.IMFB &= 0;       /* Clear the interrupt */
       TMRW.GRB -= 0x400;            /* Decrement duty cycle by 0x400 */
}
```

This function is much like Tutorial E's `main()` function. Three serial functions have been added, one to print out a text string and the others to echo any characters received by the serial port input in the while statement. The timer interrupt also remains unchanged.

2.4.4 THE SERIAL I/O FUNCTIONS

SCI3.c and **SCI3.h** are the files containing the four serial functions shown in the table below.

Function	Return	Arguments	Description
InitSCI3	unsigned char	struct SCI_Init_Params	Initialises serial port using data in structure and returns error flags
GetChar	unsigned char	void	Returns a character received by SCI3
PutChar	void	unsigned char	Transmits a character
PutStr	void	unsigned char *	Transmits a string of characters (NULL terminated)



This is example code for control of the SCI3 port. The initialisation function takes a structure containing four variables set in `SCI_Init_Data`:

```
struct SCI_Init_Params
{
       unsigned char Baud;    /* baud rate register value BRR */
       unsigned char Parity;  /* Parity P_NONE, P_EVEN, P_ODD */
       unsigned char Stops;   /* Number of stop bits 1,2 */
       unsigned char Length;  /* Length of byte transmitted 7,8 */
};

struct SCI_Init_Params SCI_Init_Data={B9600,P_NONE,1,8};
```

The baud rate can be either B9600 for 9600 baud or B19200 for 19200 baud.

2.4.5 LINKING FOR STAND-ALONE CODE

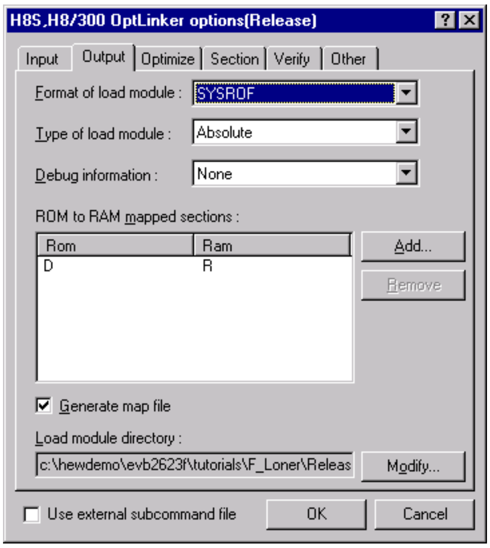
For an application to exist successfully in a stand-alone environment like the EDK, it must be able to stand the removal of power from the system and initialise itself from a subsequent Power-On reset condition. To achieve this the parts of the application which setup the system, including all of the code and constant sections must be placed non-volatile memory, such as Flash.

In order to be able to store and modify variables and data structures, these must exist in RAM.

To allow the system to start correctly the stack will be placed in the on-chip. Below is the linker map file for Tutorial F in **C:\...\3664_TutorialF\debug\3664_TutorialF.H8L**, this file lists information about how the linker has built the application and where it has located the program sections according to the addresses defined in the HEW linker options. You can see that the data sections have been placed in on-chip RAM.

```
    ent _PowerON_Reset
    ro (D,R)
    p "c:\hew\3664_TutorialF\3664_TutorialF\Release\3664_TutorialF.map"
    nooptimize
    st
    DVECTTBL,DINTTBL(00),PIntPRG,PResetPRG(034),P,C,D,$ABS8D,$ABS16D,C$DSEC,C$BSEC(0100),B,$AB
    S8B,$ABS16B,R,$ABS8R,$ABS16R,S(0FB80)
    o "c:\hew\3664_TutorialF\3664_TutorialF\Release\3664_TutorialF.abs"
    i "c:\hew\3664_TutorialF\3664_TutorialF\Release\dbsct.obj"
    i "c:\hew\3664_TutorialF\3664_TutorialF\Release\sbrk.obj"
    i "c:\hew\3664_TutorialF\3664_TutorialF\Release\vecttbl.obj"
    i "c:\hew\3664_TutorialF\3664_TutorialF\Release\resetprg.obj"
    i "c:\hew\3664_TutorialF\3664_TutorialF\Release\Loner.obj"
    i "c:\hew\3664_TutorialF\3664_TutorialF\Release\intprg.obj"
    i "c:\hew\3664_TutorialF\3664_TutorialF\Release\SCI3.obj"
    lib "c:\hew\tools\hitachi\h8\3_0a_0\lib\c38hn.lib"
    lib "c:\hew\tools\hitachi\h8\3_0a_0\lib\ec2hn.lib"
EXI
```

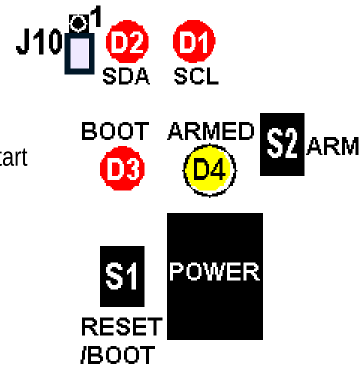
Another difference in linking compared with Tutorial E concerns the output format of the absolute load module.



Since we wish to program the absolute file into the Flash memory rather than debugging it with HDI-m, we want an S-Record format output file rather than a SYSROF debug file, the build process includes a final build phase that creates a **.mot** s-record file from the **.abs** file. Also debug information is of no use to us, by default the output format for the "Release" build configuration is to not include debug information in the output file.

- You can inspect these options in the Ouput tab of the 'Options | Linker…' dialog in HEW.
- The s-record final build phase setup can be viewed in 'Options | S-Type Converter…' dialog in HEW.
- Loading the built file into the Flash device using Hitachi's Flash Development Toolkit (FDT) as discussed in the Tutorial A Section 1.1.2.

2.4.6 RUNNING THE CODE

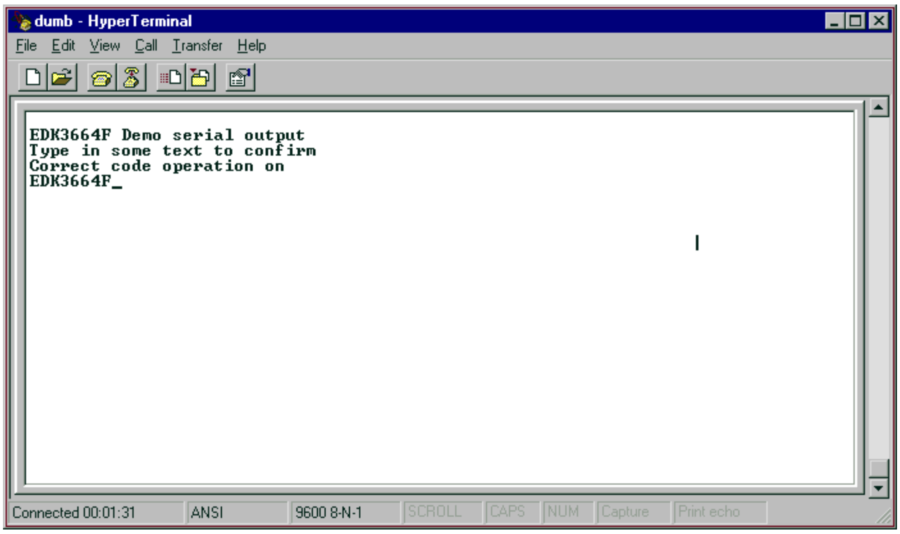


- Ensure that FDT is disconnected from the EDK and jumper J10 is fitted with a block connecting Pins 2-3. Press the reset button S1 on the EDK .

This will reinitialise the H8/300HTINY 3664F into normal execution mode. An RS-232 cable may then be connected to the 'UART' port of the EDK3664F. The LED should start to flash with a decreasing duty.

To verify that the character echo code is functioning as previously described in this tutorial:

- Start a terminal emulation program (such as Hyperterminal)
- Connect to the EDK with the correct protocol settings set in **Loner.c**, the structure `struct SCI_Init_Params SCI_Init_Data={B9600,P_NONE,1,8};` in this case 9600 baud, 8 bit, no parity, 1 stop.
- On pressing reset button S1 the RED LED D2 should start to flash with the varying duty cycle, indicating correct operation of the interrupt code and you should see the sign on banner.



- Characters typed on the keyboard should be echoed back in the terminal window.

2.4.7 VARIATIONS

Now that successful programming of the on-chip FLASH has been completed, it is possible to program the H8/300HTINY 3664F with any application.

3. NORMAL PROJECT

The EDK3664 Project generator comes with a 'Normal' project generater as well as the 'Tutorial' and 'Completed' project generator. This section of the tutorial manual explains this function of the Normal Project and the 2 build configurations. One build configuration is 'Debug' which provides an empty project which is already linked to HDI-m Library code enabling the user code to run with HDI through the serial port SCI3. The other configuration is 'Release' which provides an empty project without HDI-m code for standalone operation on the EDK, much like Tutorial F.

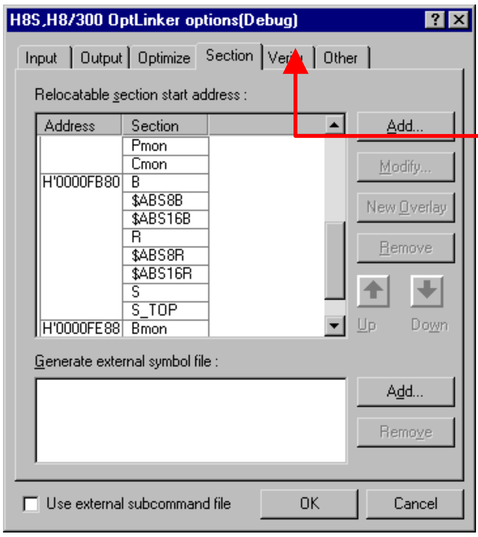
3.1 'NORMAL' PROJECT

3.1.1 CREATING THE NORMAL PROJECT

- Generate a new Workspace as done in previous tutorials but this time select 'Normal Project' and call it **3664_Standalone**.

3.1.2 HEW BUILD CONFIGURATIONS

All the files generated by the Normal project generation wizard are common to both build configurations. HEW allows you to define different configurations for building executable modules from *the same set of source files* in a project. Each different configuration may have different compiler, assembler and linker options and may exclude files from the build. When you create the Normal project, two configurations 'Debug' and 'Release' are created automatically. You can select the current configuration from the standard tool bar:



If you use the EDK project generator wizard to create a new project, the **Debug configuration** will set up the linker to place the HDI-m Library file and its associated setup in the code, so that HDI-m can download your application to the board.

In the **Release configuration** the sections are defined to create an absolute module that you can program into the Flash ROM of the device for standalone operation (i.e. without HDI-m).

3.2 'DEBUG' CONFIGURATION FOR OPERATION WITH HDI-M

This configuration will generate a standard s-record for downloading to the EDK for operation with HDI.

- Ensure the Configuration is set to Debug

3.2.1 LINKER SETUP AND SECTION MAP

- Select the menu item 'Options | Linker | Sections' and inspect the linker section map shown above:

The Linker section map for the 'Debug' Configuration contains 5 extra section names for HDI-m:

Section Name	Description	Location	Size
Pmon	HDI-m Code	Flash	6010 bytes
Cmon	HDI-m Constants	Flash	72 bytes
Bmon	HDI-m Uninitialised Data	RAM	111 bytes
MONSTACK	HDI-m Stack pointer	RAM	132 bytes
S_TOP	User initial stack pointer Address	RAM	see `stacksct.h`

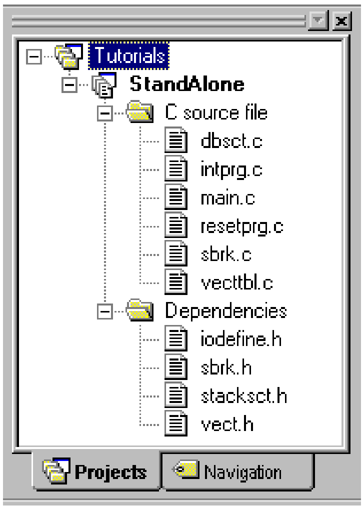
When these section are linked with the code care must be taken that they are all in valid memory locations. Check the link map file **3664_STANDALONE.map** to ensure this is the case and check with Section 4.4 H8/3664 Memory Map.

- Select the menu item 'Options | Linker | Input' and inspect the libraries built with 'Debug' configuration. Ensure that **3664HDIMLIB.lib** HDI-m Library file is included

WARNING: S_TOP is set by the user code but it must be placed after the user stack section S in the linker sections window. This Section name is used by HDI-m Library to set the reset stack S for the user code. `Power_ONReset()` must always be the name of the users startup function and it must always be where the user stack is set using `#pragma entry PowerON_Reset`
HDI-m Library uses the `Power_ONReset()` function name in referencing user startup code, this CANNOT be changed.

3.2.2 INCLUDED FILES AND COMPILER SETUP

This Project contains many of the same files seen previously. The main difference is the **vecttbl.c** and **vect.h** files. The reset vector tables now contain a conditional preprocessor command shown below:




```
#pragma section VECTTBL
void *RESET_Vectors[] = {          /* 0 Power On Reset */
#ifdef DEBUG                       /* Monitor Reset capture */
#else
      (void *)( PowerON_Reset )    /* User standalone Reset */
#endif
};
```

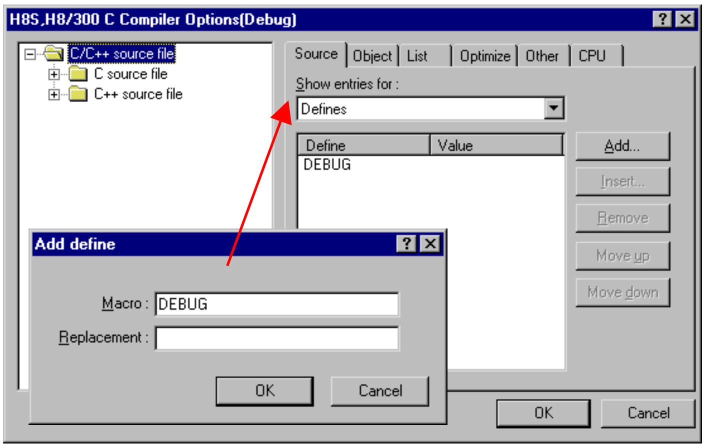
If the symbol DEBUG is defined then the HDI-m Library initialisation function `startup()` is the reset function otherwise `PowerON_Reset()` is the reset function

For the interrupt vector table the same method is employed to include the HDI-m interrupt vectors

```
…
#ifdef DEBUG
        (void *)NMIcapture,     /* Monitor NMI capture */
#else
        (void *)( INT_NMI ),    /* User NMI for standalone build configuration */
#endif
…
#ifdef DEBUG
        (void *)(UBCint),       /* Monitor address break interrupt */
#else
        (void *)( INT_UBC ),    /* User address break interrupt for standalone configuration */
#endif
…
#ifdef DEBUG
        (void *)(SCIint),       /*  Serial port interrupt */
#else
        (void *)( INT_SCI ),    /* User Serial port interrupt for standalone configuration */
#endif
…
```

The DEBUG defined symbol is added to the project via the compiler options in the following manor

- Open the Compiler options dialog (Options | Compiler | Source…) dialog and select the "Defines" option from the "Show entries for:" drop down list.
- Click on the "Add…" button, a symbol entry dialog appears:
- Enter the symbol "DEBUG" for the defined macro name.
- The symbol DEBUG is now defined.



This results in the application vector table containing HDI-m interrupt and power on vectors if the Debug configuration is built,

As stated before `Power_ONReset()` must have the user stack initialised by declaring `#pragma entry Power_ONReset()` in **resetprg.c**, the user hardware initialisation code can then be placed in. The user application code can then be written in the `main()` function in **Main.c**. Remember that some of the memory is used by HDI-M library code as described in Section 3.2.1

3.3 'RELEASE' CONFIGURATION FOR STANDALONE OPERATION

This configuration will generate a standard s-record for downloading to the EDK for operation without any debugger. This is the same as Tutorial F but without any functionality, i.e. blank `main()` and `HardwareSetup()` functions.

- Ensure the Configuration is set to 'Release'

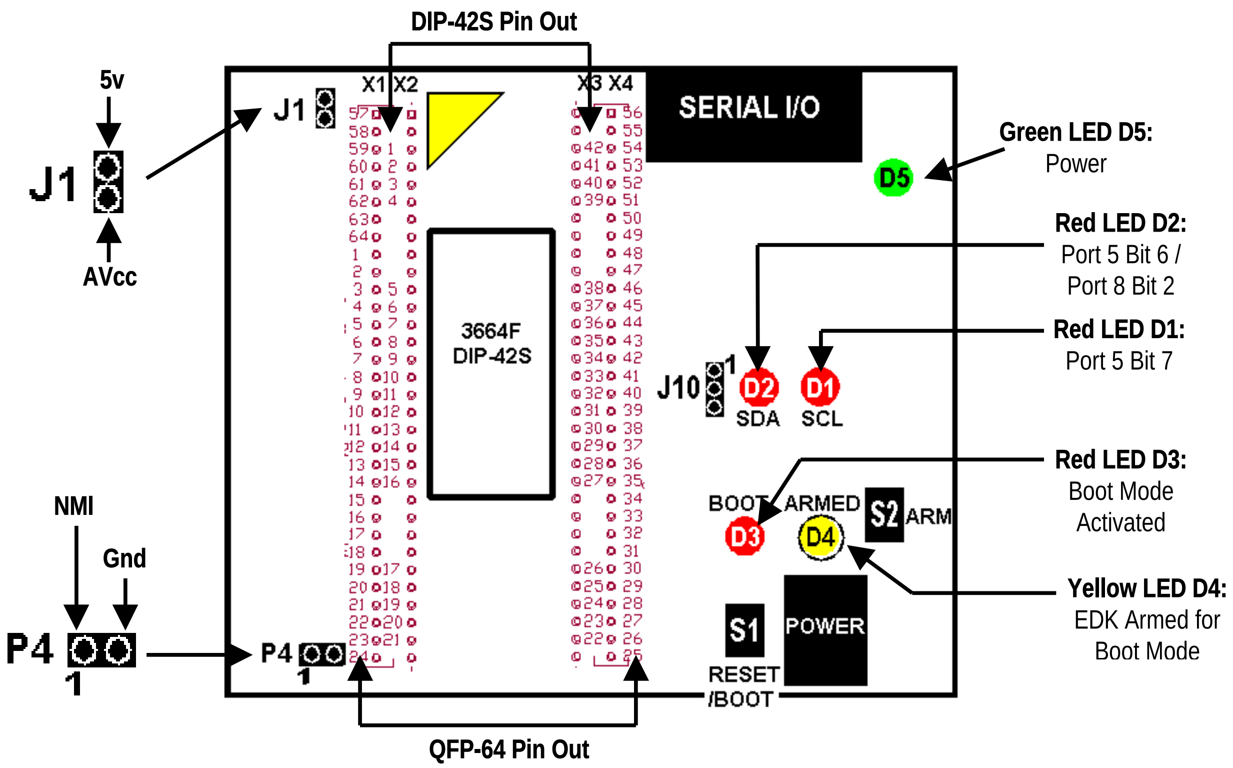
3.3.1 LINKER SETUP

- Select the menu item 'Options | Linker | Sections' and inspect the linker section map, check that there are no HDI-m sections defined.
- Select the menu item 'Options | Linker | Input' and select the "Defines" option from the "Show entries for:" drop down list. Check to see that the symbol DEBUG is NOT defined.

All the same files are used in this configuration but all H8/3664 hardware is available because HDI-m is not built with this code.

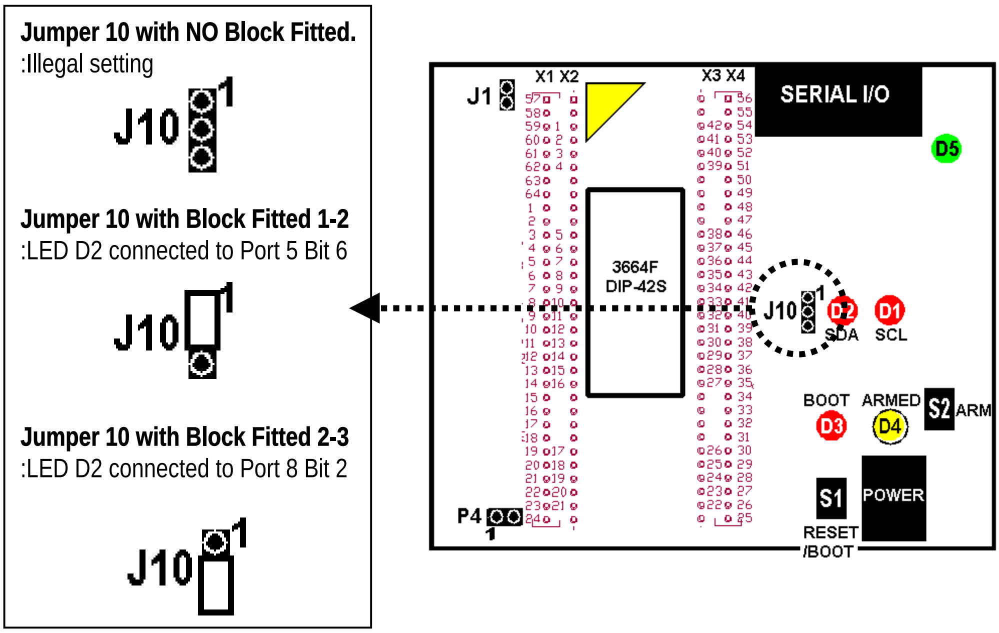
4. Appendix

4.1 Board Overview



4.2 LED Pin Out

LED	J10 Block Position	X3/X4 Pin	QFP-64 Pin	DIP-42S Pin	Pin Function
D1	--	30	27	23	Port 5 Bit 7 / SCL
D2	1-2	31	26	22	Port 5 Bit 6 / SDA
D2	2-3	19	38	30	Port 8 Bit 2 / FTIOB



4.3 PIN OUT FOR X1, X2, X3 & X4

X1/X2	QFP-64	DIP42S	PIN DESCRIPTION	X3/X4	QFP-64	DIP-42S	PIN DESCRIPTION
1	57		PB6/AN8	1	56		PB5/AN5
2	58		PB7/AN7	2	55		PB4/AN4
3	59	1	PB3/AN3	3	54	42	P17/IRQ3*/TRGV
4	60	2	PB2/AN2	4	53	41	P16/IRQ2*
5	61	3	PB1/AN1	5	52	40	P15/IRQ1*
6	62	4	PB0/AN0	6	51	39	P14/IRQ0*
7	63		NC	7	50		NC
8	64		NC	8	49		NC
9	1		NC	9	48		NC
10	2		NC	10	47		NC
11	3	5	Avcc	11	46	38	P22/TXD
12	4	6	X2 (note 1)	12	45	37	P21/RXD
13	5	7	X1 (note 1)	13	44	36	P20/SCK3
14	6	8	VCL	14	43	35	P87
15	7	9	RES*	15	42	34	P86
16	8	10	TEST	16	41	33	P85
17	9	11	Vss	17	40	32	P84/FTIOD
18	10	12	OSC2 (note 2)	18	39	31	P83/FTIOC
19	11	13	OSC1 (note 2)	19	38	30	P82/FTIOB
20	12	14	Vcc	20	37	29	P81/FTIOA
21	13	15	P50/WKP0	21	36	28	P80/FTCI
22	14	16	P51/WKP1	22	35	27	NMI*
23	15		NC	23	34		NC
24	16		NC	24	33		NC
25	17		NC	25	32		NC
26	18		NC	26	31		NC
27	19	17	P52/WKP2	27	30	26	P76/TMOV
28	20	18	P53/WKP3	28	29	25	P75/TMCIV
29	21	19	P54/WKP4	29	28	24	P74/TMRIV
30	22	20	P55/WKP5	30	27	23	P57/SCL
31	23	21	P10/TMOV	31	26	22	P56/SDA
32	24		P11	32	25		P12

NOTES:
1 - pins 12 & 13 from X1 are always connected to the H8/3664
pins 13 & 13 from X2 depend on jumpers J2/J3 for function (Rev B boards only)
2 - pins 18 & 19 from X1 are always connected to the H8/3664
pins 18 & 19 from X2 depend on jumpers J5/J6 for function (Rev B boards only)

4.4 H8/3664 MEMORY MAP

HDI-m Example Memory Map **H8\3664F Memory Map**