



# ModelSim® SE Tutorial

Software Version 10.1

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## Assumptions

Using this tutorial for ModelSim™ is based on the following assumptions:

- You are familiar with how to use your operating system, along with its window management system and graphical interface: OpenWindows, OSF/Motif, CDE, KDE, GNOME, or Microsoft Windows XP.
- You have a working knowledge of the language in which your design and/or test bench is written (such as VHDL, Verilog, or SystemC). Although ModelSim is an excellent application to use while learning HDL concepts and practices, this tutorial is not intended to support that goal.

## Where to Find ModelSim Documentation

**Table 1-1. Documentation List**

Document	Format	How to get it
<i>Installation &amp; Licensing Guide</i>	PDF	<b>Help &gt; PDF Bookcase</b>
	HTML and PDF	<b>Help &gt; InfoHub</b>
<i>Quick Guide</i> (command and feature quick-reference)	PDF	<b>Help &gt; PDF Bookcase</b> and <b>Help &gt; InfoHub</b>
<i>Tutorial</i>	PDF	<b>Help &gt; PDF Bookcase</b>
	HTML and PDF	<b>Help &gt; InfoHub</b>
<i>User's Manual</i>	PDF	<b>Help &gt; PDF Bookcase</b>
	HTML and PDF	<b>Help &gt; InfoHub</b>
<i>Reference Manual</i>	PDF	<b>Help &gt; PDF Bookcase</b>
	HTML and PDF	<b>Help &gt; InfoHub</b>
<i>Foreign Language Interface Manual</i>	PDF	<b>Help &gt; PDF Bookcase</b>
	HTML	<b>Help &gt; InfoHub</b>

**Table 1-1. Documentation List**

Document	Format	How to get it
Command Help	ASCII	type <b>help</b> [command name] at the prompt in the Transcript pane
Error message help	ASCII	type <b>verror</b> <msgNum> at the Transcript or shell prompt
Tcl Man Pages (Tcl manual)	HTML	select <b>Help &gt; Tcl Man Pages</b> , or find <i>contents.htm</i> in <i>\modeltech\docs\tcl_help_html</i>
Technotes	HTML	available from the support site

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<http://supportnet.mentor.com/about/>

If you have questions about this software release, please log in to the SupportNet web site. You can search thousands of technical solutions, view documentation, or open a Service Request online at:

<http://supportnet.mentor.com/>

If your site is under current support and you do not have a SupportNet login, you can register for SupportNet by filling out the short form at:

<http://supportnet.mentor.com/user/register.cfm>

For any customer support contact information, refer to the following web site location:

<http://supportnet.mentor.com/contacts/supportcenters/>

## Before you Begin

Preparation for some of the lessons leaves certain details up to you. You will decide the best way to create directories, copy files, and execute programs within your operating system.

(When you are operating the simulator within ModelSim's GUI, the interface is consistent for all platforms.)

Examples show Windows path separators - use separators appropriate for your operating system when trying the examples.

## Example Designs

ModelSim comes with Verilog and VHDL versions of the designs used in these lessons. This allows you to do the tutorial regardless of which license type you have. Though we have tried to minimize the differences between the Verilog and VHDL versions, we could not do so in all cases. In cases where the designs differ (e.g., line numbers or syntax), you will find language-specific instructions. Follow the instructions that are appropriate for the language you use.





# Chapter 2

## Conceptual Overview

---

### Introduction

ModelSim is a verification and simulation tool for VHDL, Verilog, SystemVerilog, SystemC, and mixed-language designs.

This lesson provides a brief conceptual overview of the ModelSim simulation environment. It is divided into five topics, which you will learn more about in subsequent lessons.

- Design Optimizations — Refer to the [Optimizing Designs with vopt](#) chapter in the User's Manual.
- Basic simulation flow — Refer to Chapter 3, *Basic Simulation*.
- Project flow — Refer to Chapter 4, *Projects*.
- Multiple library flow — Refer to Chapter 5, *Working With Multiple Libraries*.
- Debugging tools — Refer to remaining lessons.

### Design Optimizations

Before discussing the basic simulation flow, it is important to understand design optimization. By default, ModelSim optimizations are automatically performed on all designs. These optimizations are designed to maximize simulator performance, yielding improvements up to 10X, in some Verilog designs, over non-optimized runs.

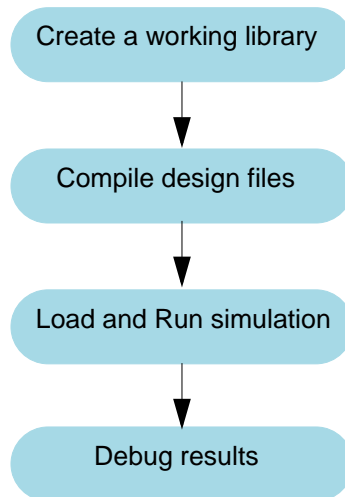
Global optimizations, however, may have an impact on the visibility of the design simulation results you can view – certain signals and processes may not be visible. If these signals and processes are important for debugging the design, it may be necessary to customize the simulation by removing optimizations from specific modules.

It is important, therefore, to make an informed decision as to how best to apply optimizations to your design. The tool that performs global optimizations in ModelSim is called **vopt**. Please refer to the [Optimizing Designs with vopt](#) chapter in the ModelSim User's Manual for a complete discussion of optimization trade-offs and customizations. For details on command syntax and usage, please refer to [vopt](#) in the Reference Manual.

## Basic Simulation Flow

The following diagram shows the basic steps for simulating a design in ModelSim.

**Figure 2-1. Basic Simulation Flow - Overview Lab**



- **Creating the Working Library**

In ModelSim, all designs are compiled into a library. You typically start a new simulation in ModelSim by creating a working library called "work," which is the default library name used by the compiler as the default destination for compiled design units.

- **Compiling Your Design**

After creating the working library, you compile your design units into it. The ModelSim library format is compatible across all supported platforms. You can simulate your design on any platform without having to recompile your design.

- **Loading the Simulator with Your Design and Running the Simulation**

With the design compiled, you load the simulator with your design by invoking the simulator on a top-level module (Verilog) or a configuration or entity/architecture pair (VHDL).

Assuming the design loads successfully, the simulation time is set to zero, and you enter a run command to begin simulation.

- **Debugging Your Results**

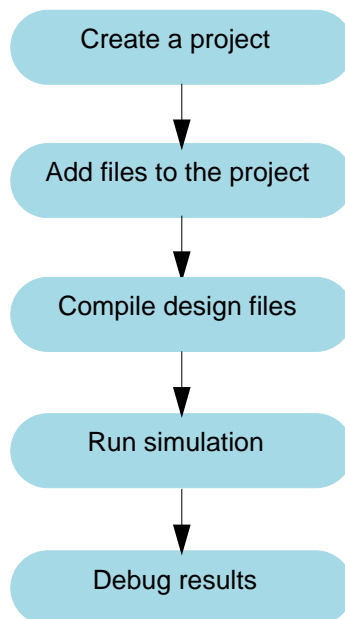
If you don't get the results you expect, you can use ModelSim's robust debugging environment to track down the cause of the problem.

## Project Flow

A project is a collection mechanism for an HDL design under specification or test. Even though you don't have to use projects in ModelSim, they may ease interaction with the tool and are useful for organizing files and specifying simulation settings.

The following diagram shows the basic steps for simulating a design within a ModelSim project.

**Figure 2-2. Project Flow**



As you can see, the flow is similar to the basic simulation flow. However, there are two important differences:

- You do not have to create a working library in the project flow; it is done for you automatically.
- Projects are persistent. In other words, they will open every time you invoke ModelSim unless you specifically close them.

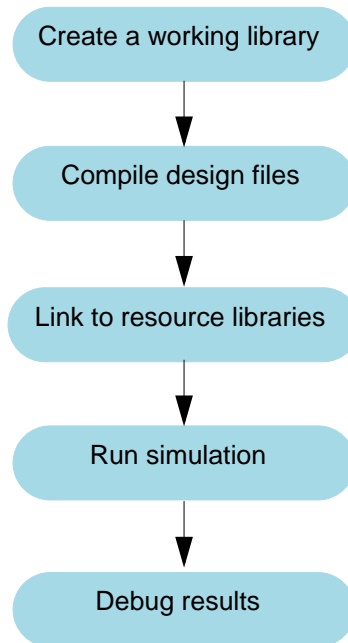
## Multiple Library Flow

ModelSim uses libraries in two ways: 1) as a local working library that contains the compiled version of your design; 2) as a resource library. The contents of your working library will change as you update your design and recompile. A resource library is typically static and serves as a parts source for your design. You can create your own resource libraries, or they may be supplied by another design team or a third party (e.g., a silicon vendor).

You specify which resource libraries will be used when the design is compiled, and there are rules to specify in which order they are searched. A common example of using both a working library and a resource library is one where your gate-level design and test bench are compiled into the working library, and the design references gate-level models in a separate resource library.

The diagram below shows the basic steps for simulating with multiple libraries.

**Figure 2-3. Multiple Library Flow**



You can also link to resource libraries from within a project. If you are using a project, you would replace the first step above with these two steps: create the project and add the test bench to the project.

## Debugging Tools

ModelSim offers numerous tools for debugging and analyzing your design. Several of these tools are covered in subsequent lessons, including:

- Using projects
- Working with multiple libraries
- Simulating with SystemC
- Setting breakpoints and stepping through the source code
- Viewing waveforms and measuring time

- Exploring the "physical" connectivity of your design
- Viewing and initializing memories
- Creating stimulus with the Waveform Editor
- Analyzing simulation performance
- Testing code coverage
- Comparing waveforms
- Debugging with PSL assertions
- Using SystemVerilog assertions and cover directives
- Using the SystemVerilog DPI
- Automating simulation



# Chapter 3

## Basic Simulation

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### Introduction

In this lesson you will go step-by-step through the basic simulation flow:

1. [Create the Working Design Library](#)
2. [Compile the Design Units](#)
3. [Optimize the Design](#)
4. [Load the Design](#)
5. [Run the Simulation](#)

### Design Files for this Lesson

The sample design for this lesson is a simple 8-bit, binary up-counter with an associated test bench. The pathnames are as follows:

**Verilog** – `<install_dir>/examples/tutorials/verilog/basicSimulation/counter.v` and `tcounter.v`

**VHDL** – `<install_dir>/examples/tutorials/vhdl/basicSimulation/counter.vhd` and `tcounter.vhd`

This lesson uses the Verilog files `counter.v` and `tcounter.v`. If you have a VHDL license, use `counter.vhd` and `tcounter.vhd` instead. Or, if you have a mixed license, feel free to use the Verilog test bench with the VHDL counter or vice versa.

### Related Reading

User's Manual Chapters: [Design Libraries](#), [Verilog and SystemVerilog Simulation](#), and [VHDL Simulation](#).

Reference Manual commands: [vlib](#), [vmap](#), [vlog](#), [vcom](#), [vopt](#), [view](#), and [run](#).

## Create the Working Design Library

Before you can simulate a design, you must first create a library and compile the source code into that library.

1. Create a new directory and copy the design files for this lesson into it.

Start by creating a new directory for this exercise (in case other users will be working with these lessons).

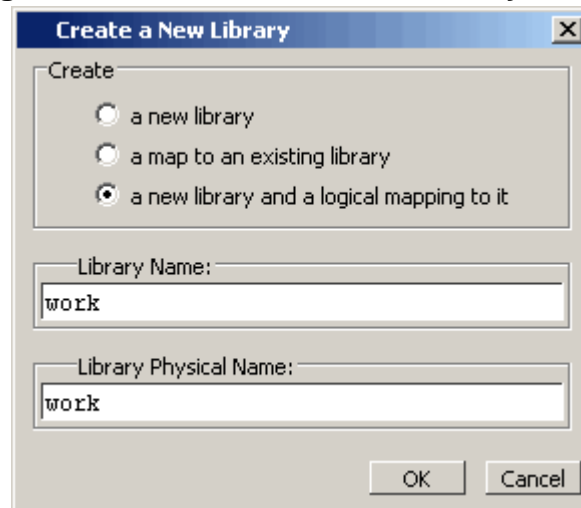
**Verilog:** Copy *counter.v* and *tcounter.v* files from  
/*<install\_dir>/examples/tutorials/verilog/basicSimulation* to the new directory.

**VHDL:** Copy *counter.vhd* and *tcounter.vhd* files from  
/*<install\_dir>/examples/tutorials/vhdl/basicSimulation* to the new directory.

2. Start ModelSim *if necessary*.
  - a. Type **vsim** at a UNIX shell prompt or use the ModelSim icon in Windows.  
  
Upon opening ModelSim for the first time, you will see the Welcome to ModelSim dialog. Click **Close**.
  - b. Select **File > Change Directory** and change to the directory you created in step 1.
3. Create the working library.
  - a. Select **File > New > Library**.

This opens a dialog where you specify physical and logical names for the library (Figure 3-1). You can create a new library or map to an existing library. We'll be doing the former.

**Figure 3-1. The Create a New Library Dialog**



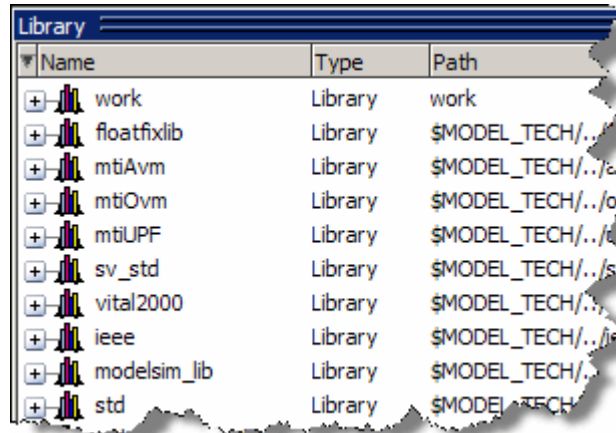
- b. Type **work** in the Library Name field (if it isn't already entered automatically).
  - c. Click **OK**.

ModelSim creates a directory called *work* and writes a specially-formatted file named *\_info* into that directory. The *\_info* file must remain in the directory to distinguish it as a ModelSim library. Do not edit the folder contents from your operating system; all changes should be made from within ModelSim.



ModelSim also adds the library to the Library window (Figure 3-2) and records the library mapping for future reference in the ModelSim initialization file (*modelsim.ini*).

**Figure 3-2. work Library Added to the Library Window**



When you pressed OK in step 3c above, the following was printed to the Transcript window:

```
vlib work
vmap work work
```

These two lines are the command-line equivalents of the menu selections you made. Many command-line equivalents will echo their menu-driven functions in this fashion.

## Compile the Design Units

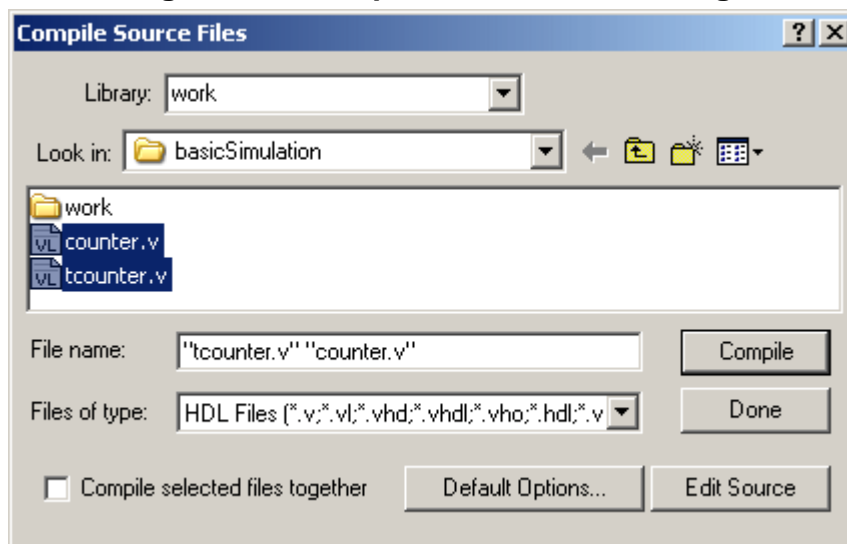
With the working library created, you are ready to compile your source files.

You can compile by using the menus and dialogs of the graphic interface, as in the Verilog example below, or by entering a command at the ModelSim> prompt.

1. Compile *counter.v* and *tcounter.v*.
  - a. Select **Compile > Compile**. This opens the Compile Source Files dialog (Figure 3-3).

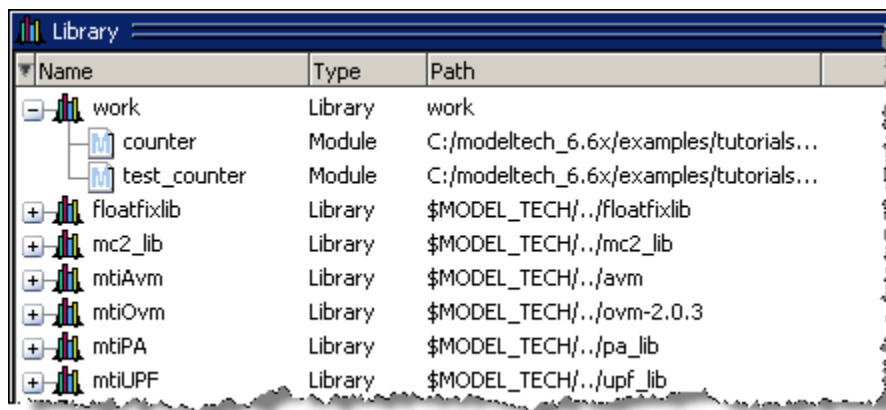
If the Compile menu option is not available, you probably have a project open. If so, close the project by making the Library window active and selecting File > Close from the menus.
  - b. Select both *counter.v* and *tcounter.v* modules from the Compile Source Files dialog and click **Compile**. The files are compiled into the *work* library.
  - c. When compile is finished, click **Done**.

Figure 3-3. Compile Source Files Dialog



2. View the compiled design units.
  - a. In the Library window, click the '+' icon next to the *work* library and you will see two design units (Figure 3-4). You can also see their types (Modules, Entities, etc.) and the path to the underlying source files.

Figure 3-4. Verilog Modules Compiled into work Library



## Optimize the Design

1. Use the **vopt** command to optimize the design with full visibility into all design units.
  - a. Enter the following command at the ModelSim> prompt in the Transcript window:

**vopt +acc test\_counter -o testcounter\_opt**

The **+acc** switch provides visibility into the design for debugging purposes.

The **-o** switch allows you designate the name of the optimized design file (testcounter\_opt).

**Note**

You must provide a name for the optimized design file when you use the vopt command.

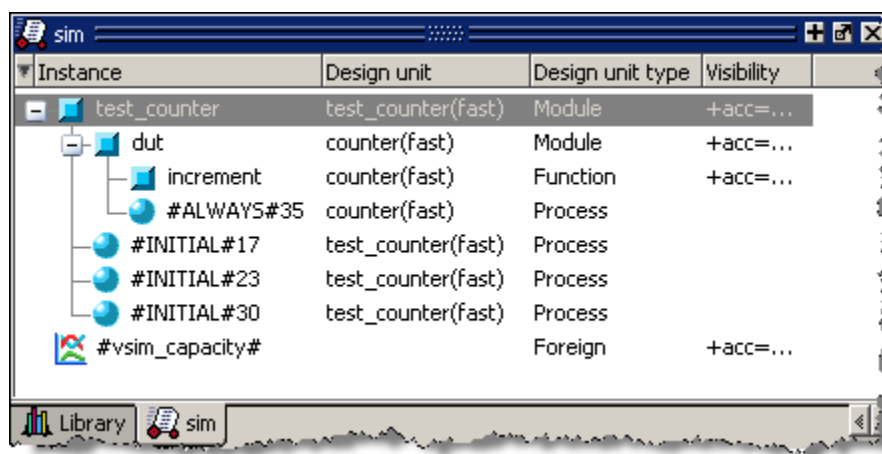
## Load the Design

1. Load the *test\_counter* module into the simulator.
  - a. Use the optimized design name to load the design with the **vsim** command:

**vsim testcounter\_opt**

When the design is loaded, a Structure window opens (labeled **sim**). This window displays the hierarchical structure of the design as shown in [Figure 3-5](#). You can navigate within the design hierarchy in the Structure (**sim**) window by clicking on any line with a '+' (expand) or '-' (contract) icon.

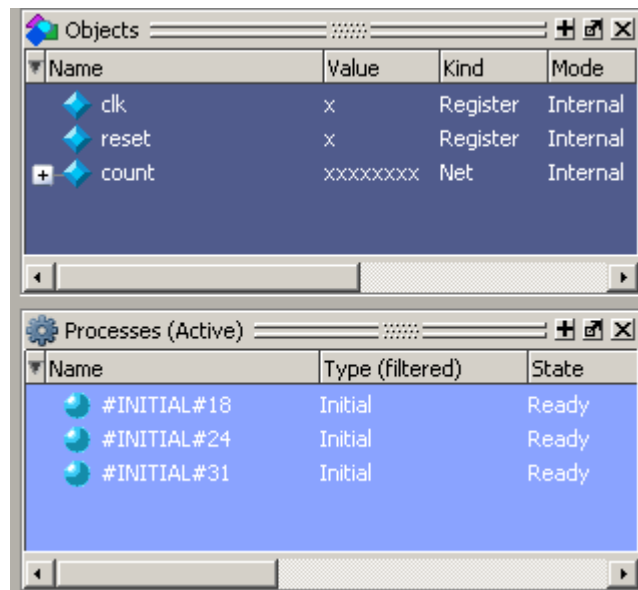
**Figure 3-5. The Design Hierarchy**



In addition, an Objects window and a Processes window opens ([Figure 3-6](#)). The Objects window shows the names and current values of data objects in the current region selected in the Structure (sim) window. Data objects include signals, nets, registers, constants and variables not declared in a process, generics, parameters, and member data variables of a SystemC module.

The Processes window displays a list of HDL and SystemC processes in one of four viewing modes: Active, In Region, Design, and Hierarchical. The Design view mode is intended for primary navigation of ESL (Electronic System Level) designs where processes are a foremost consideration. By default, this window displays the active processes in your simulation (Active view mode).

**Figure 3-6. The Object Window and Processes Window**



## Run the Simulation

We're ready to run the simulation. But before we do, we'll open the Wave window and add signals to it.

1. Open the Wave window.
  - a. Enter **view wave** at the command line.

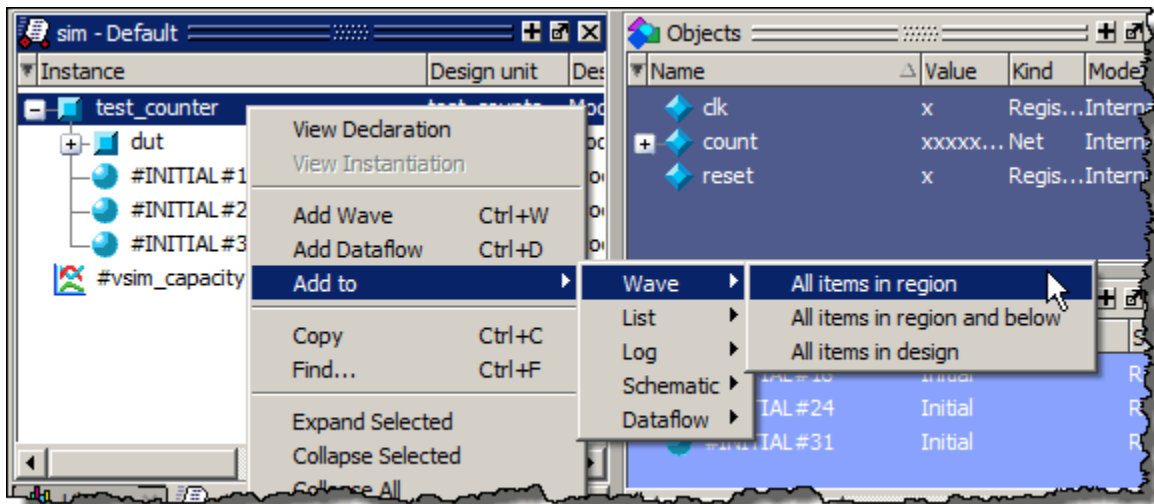
The Wave window opens in the right side of the Main window. Resize it so it is visible.

You can also use the **View > Wave** menu selection to open a Wave window. The Wave window is just one of several debugging windows available on the **View** menu.

2. Add signals to the Wave window.
  - a. In the Structure (sim) window, right-click *test\_counter* to open a popup context menu.
  - b. Select **AddTo > Wave > All items in region** (Figure 3-7).

All signals in the design are added to the Wave window.

**Figure 3-7. Using the Popup Menu to Add Signals to Wave Window**



3. Run the simulation.

a. Click the Run icon.

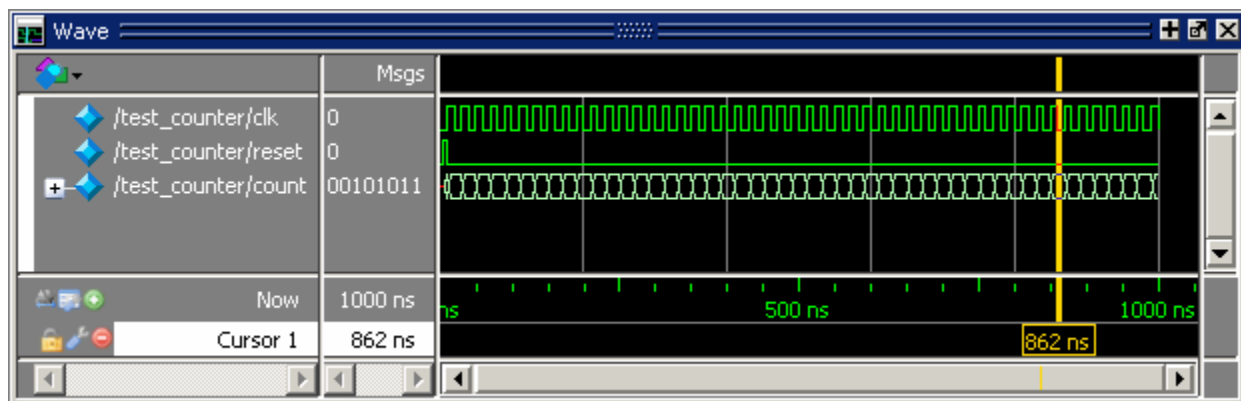
The simulation runs for 100 ns (the default simulation length) and waves are drawn in the Wave window.



b. Enter **run 500** at the VSIM> prompt in the Transcript window.

The simulation advances another 500 ns for a total of 600 ns (Figure 3-8).

**Figure 3-8. Waves Drawn in Wave Window**



c. Click the **Run -All** icon on the Main or Wave window toolbar.

The simulation continues running until you execute a break command or it hits a statement in your code (e.g., a Verilog \$stop statement) that halts the simulation.



d. Click the Break icon



to stop the simulation.

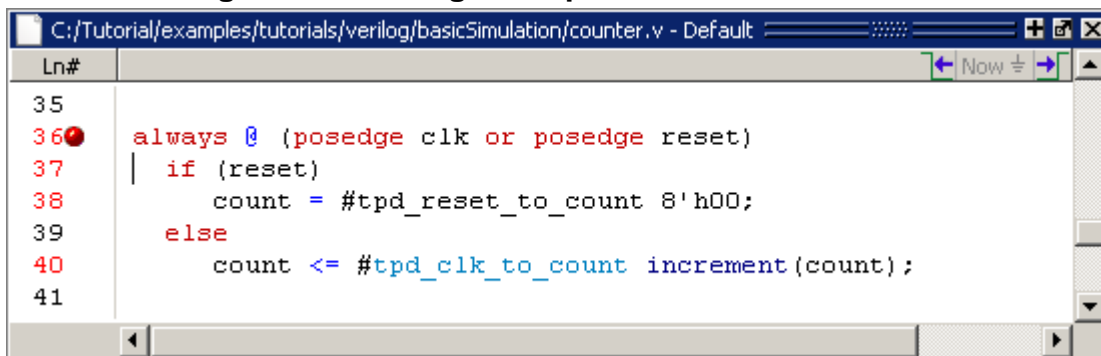
## Set Breakpoints and Step through the Source

Next you will take a brief look at one interactive debugging feature of the ModelSim environment. You will set a breakpoint in the Source window, run the simulation, and then step through the design under test. Breakpoints can be set only on executable lines, which are indicated with red line numbers.

1. Open *counter.v* in the Source window.
  - a. Select **View > Files** to open the Files window.
  - b. Click the + sign next to the *sim* filename to see the contents of *vsim.wlf* dataset.
  - c. Double-click *counter.v* (or *counter.vhd* if you are simulating the VHDL files) to open the file in the Source window.
2. Set a breakpoint on line 36 of *counter.v* (or, line 39 of *counter.vhd* for VHDL).
  - a. Scroll to line 36 and click in the Ln# (line number) column next to the line number.

A red ball appears in the line number column at line number 36 (Figure 3-9), indicating that a breakpoint has been set.

**Figure 3-9. Setting Breakpoint in Source Window**

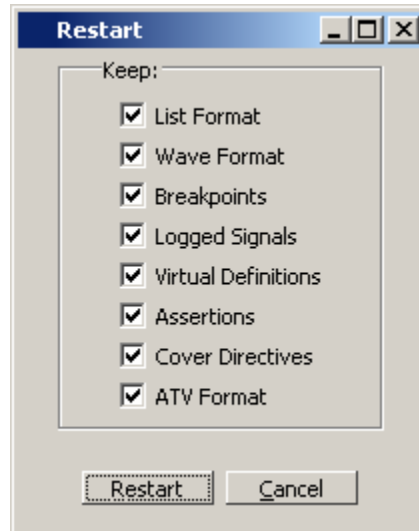


3. Disable, enable, and delete the breakpoint.
  - a. Click the red ball to disable the breakpoint. It will become a black ball.
  - b. Click the black ball again to re-enable the breakpoint. It will become a red ball.
  - c. Click the red ball with your right mouse button and select **Remove Breakpoint 36**.
  - d. Click in the line number column next to line number 36 again to re-create the breakpoint.
4. Restart the simulation.
  - a. Click the Restart icon to reload the design elements and reset the simulation time to zero.



The Restart dialog that appears gives you options on what to retain during the restart (Figure 3-10).

**Figure 3-10. Setting Restart Functions**

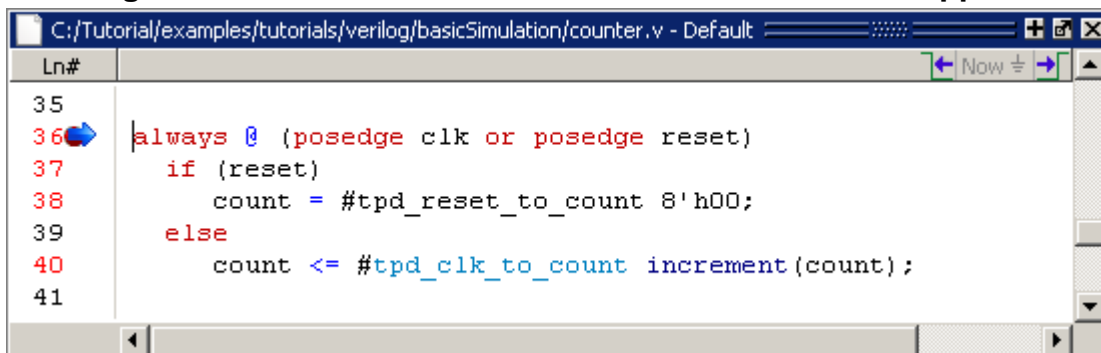


- b. Click the **Restart** button in the Restart dialog.
- c. Click the Run -All icon.

The simulation runs until the breakpoint is hit. When the simulation hits the breakpoint, it stops running, highlights the line with a blue arrow in the Source view (Figure 3-11), and issues a Break message in the Transcript window.



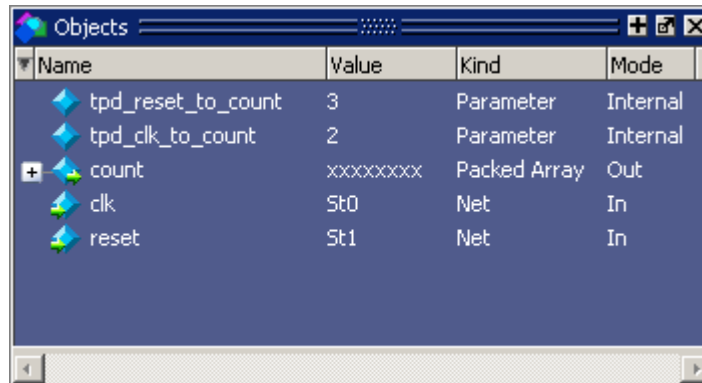
**Figure 3-11. Blue Arrow Indicates Where Simulation Stopped.**



When a breakpoint is reached, typically you want to know one or more signal values. You have several options for checking values:

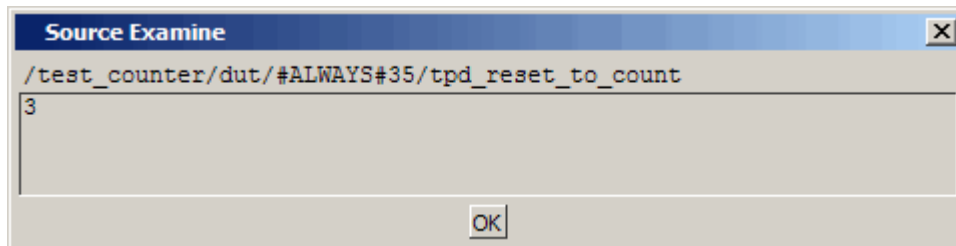
- look at the values shown in the Objects window (Figure 3-12)

**Figure 3-12. Values Shown in Objects Window**



- set your mouse pointer over a variable in the Source window and a yellow box will appear with the variable name and the value of that variable at the time of the selected cursor in the Wave window
- highlight a signal, parameter, or variable in the Source window, right-click it, and select **Examine** from the pop-up menu to display the variable and its current value in a Source Examine window (Figure 3-13)

**Figure 3-13. Parameter Name and Value in Source Examine Window**



- use the **examine** command at the VSIM> prompt to output a variable value to the Transcript window (i.e., `examine count`)
5. Try out the step commands.
- a. Click the Step Into icon on the Step toolbar.



This single-steps the debugger.

Experiment on your own. Set and clear breakpoints and use the Step, Step Over, and Continue Run commands until you feel comfortable with their operation.

## Lesson Wrap-Up

This concludes this lesson. Before continuing we need to end the current simulation.

1. Select **Simulate > End Simulation**.
2. Click **Yes** when prompted to confirm that you wish to quit simulating.







### Introduction

In this lesson you will practice creating a project.

At a minimum, projects contain a work library and a session state that is stored in an *.mpf* file. A project may also consist of:

- HDL source files or references to source files
- other files such as READMEs or other project documentation
- local libraries
- references to global libraries

### Design Files for this Lesson

The sample design for this lesson is a simple 8-bit, binary up-counter with an associated test bench. The pathnames are as follows:

**Verilog** – *<install\_dir>/examples/tutorials/verilog/projects/counter.v* and *tcounter.v*

**VHDL** – *<install\_dir>/examples/tutorials/vhdl/projects/counter.vhd* and *tcounter.vhd*

This lesson uses the Verilog files *tcounter.v* and *counter.v*. If you have a VHDL license, use *tcounter.vhd* and *counter.vhd* instead.

### Related Reading

User's Manual Chapter: [Projects](#).

## Create a New Project

1. Create a new directory and copy the design files for this lesson into it.

Start by creating a new directory for this exercise (in case other users will be working with these lessons).

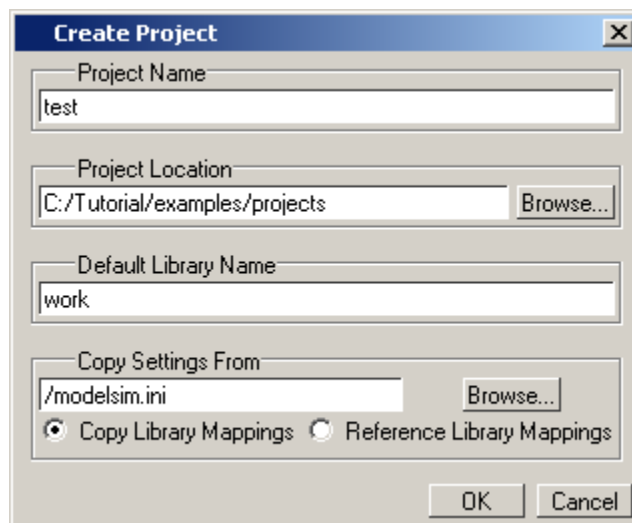
**Verilog:** Copy *counter.v* and *tcounter.v* files from *<install\_dir>/examples/tutorials/verilog/projects* to the new directory.

**VHDL:** Copy *counter.vhd* and *tcounter.vhd* files from *<install\_dir>/examples/tutorials/vhdl/projects* to the new directory.

2. If you just finished the previous lesson, ModelSim should already be running. If not, start ModelSim.
  - a. Type **vsim** at a UNIX shell prompt or use the ModelSim icon in Windows.
  - b. Select **File > Change Directory** and change to the directory you created in step 1.
3. Create a new project.
  - a. Select **File > New > Project** (Main window) from the menu bar.

This opens the Create Project dialog where you can enter a Project Name, Project Location (i.e., directory), and Default Library Name (Figure 4-1). You can also reference library settings from a selected .ini file or copy them directly into the project. The default library is where compiled design units will reside.
  - b. Type **test** in the Project Name field.
  - c. Click the **Browse** button for the Project Location field to select a directory where the project file will be stored.
  - d. Leave the Default Library Name set to *work*.
  - e. Click **OK**.

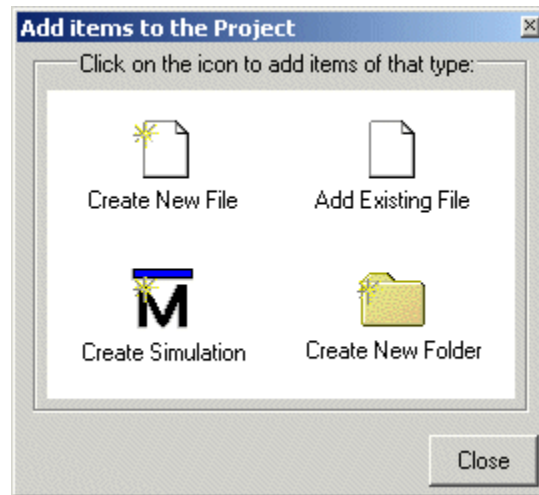
**Figure 4-1. Create Project Dialog - Project Lab**



## Add Objects to the Project

Once you click OK to accept the new project settings, a blank Project window and the “Add items to the Project” dialog will appear (Figure 4-2). From the dialog you can create a new design file, add an existing file, add a folder for organization purposes, or create a simulation configuration (discussed below).

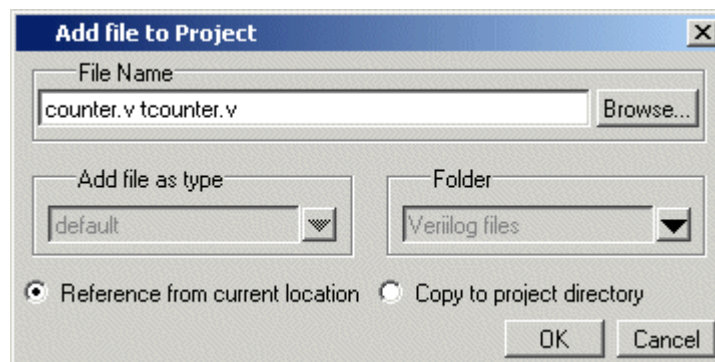
**Figure 4-2. Adding New Items to a Project**



1. Add two existing files.
  - a. Click **Add Existing File**.

This opens the Add file to Project dialog (Figure 4-3). This dialog lets you browse to find files, specify the file type, specify a folder to which the file will be added, and identify whether to leave the file in its current location or to copy it to the project directory.

**Figure 4-3. Add file to Project Dialog**



- b. Click the **Browse** button for the File Name field. This opens the “Select files to add to project” dialog and displays the contents of the current directory.
  - c. **Verilog:** Select *counter.v* and *tcounter.v* and click **Open**.  
**VHDL:** Select *counter.vhd* and *tcounter.vhd* and click **Open**.

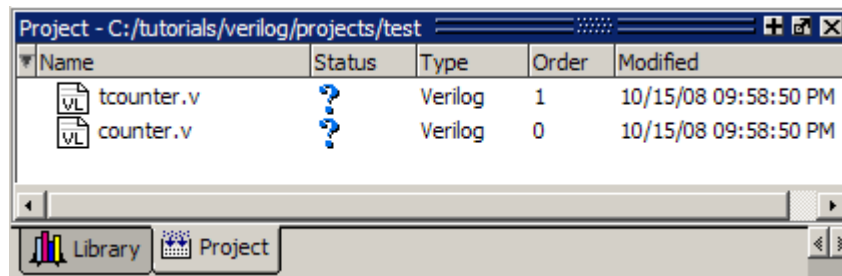
This closes the “Select files to add to project” dialog and displays the selected files in the “Add file to Project” dialog (Figure 4-3).

- d. Click **OK** to add the files to the project.

- e. Click **Close** to dismiss the Add items to the Project dialog.

You should now see two files listed in the Project window (Figure 4-4). Question-mark icons in the Status column indicate that the file has not been compiled or that the source file has changed since the last successful compile. The other columns identify file type (e.g., Verilog or VHDL), compilation order, and modified date.

**Figure 4-4. Newly Added Project Files Display a '?' for Status**



## Changing Compile Order (VHDL)

By default ModelSim performs default binding of VHDL designs when you load the design with `vsim`. However, you can elect to perform default binding at compile time. (For details, refer to the section [Default Binding](#) in the User's Manual.) If you elect to do default binding at compile, then the compile order is important. Follow these steps to change compilation order within a project.

1. Change the compile order.
  - a. Select **Compile > Compile Order**.

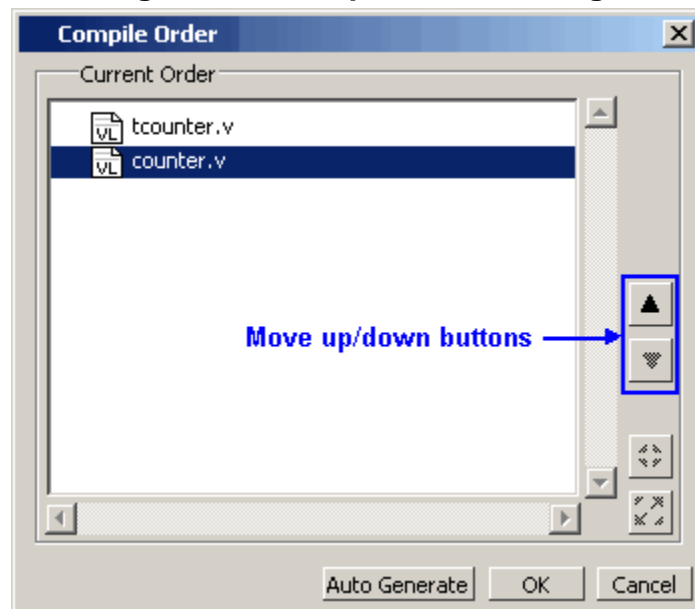
This opens the Compile Order dialog box.

- b. Click the **Auto Generate** button.

ModelSim determines the compile order by making multiple passes over the files. It starts compiling from the top; if a file fails to compile due to dependencies, it moves that file to the bottom and then recompiles it after compiling the rest of the files. It continues in this manner until all files compile successfully or until a file(s) can't be compiled for reasons other than dependency.

Alternatively, you can select a file and use the Move Up and Move Down buttons to put the files in the correct order (Figure 4-5).

**Figure 4-5. Compile Order Dialog**



- c. Click **OK** to close the Compile Order dialog.

## Compile the Design

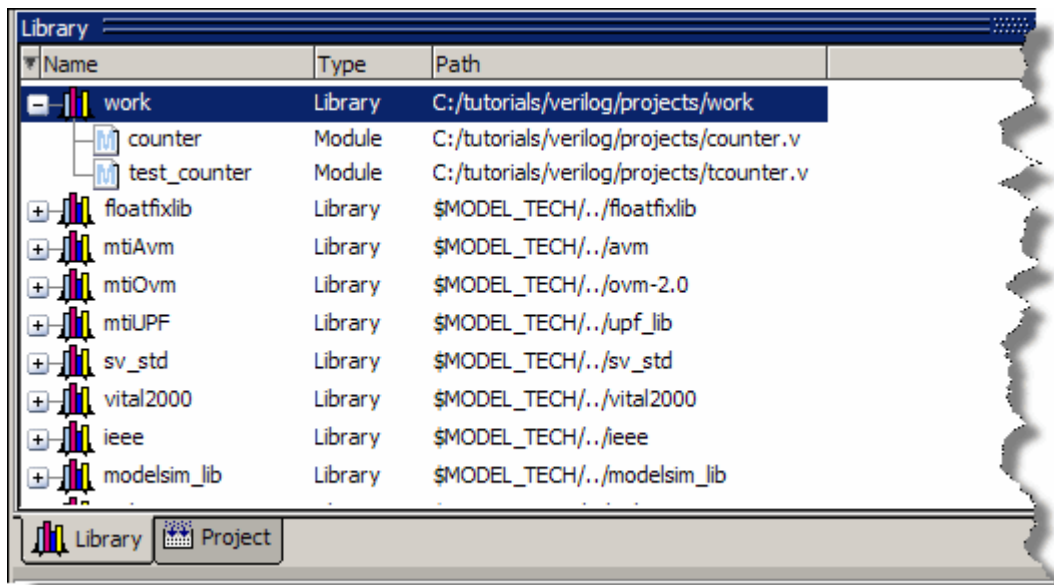
1. Compile the files.
  - a. Right-click either *counter.v* or *tcounter.v* in the Project window and select **Compile** > **Compile All** from the pop-up menu.

ModelSim compiles both files and changes the symbol in the Status column to a green check mark. A check mark means the compile succeeded. If compile fails, the symbol will be a red 'X', and you will see an error message in the Transcript window.

2. View the design units.
  - a. Click the **Library** tab (Figure 4-6).
  - b. Click the '+' icon next to the *work* library.

You should see two compiled design units, their types (modules in this case), and the path to the underlying source files.

Figure 4-6. Library Window with Expanded Library



## Optimize for Design Visibility

1. Use the **vopt** command to optimize the design with full visibility into all design units.
  - a. Enter the following command at the QuestaSim> prompt in the Transcript window:  
**vopt +acc test\_counter -o testcounter\_opt**  
  
The **+acc** switch provides visibility into the design for debugging purposes.  
  
The **-o** switch allows you designate the name of the optimized design file (testcounter\_opt).

### Note



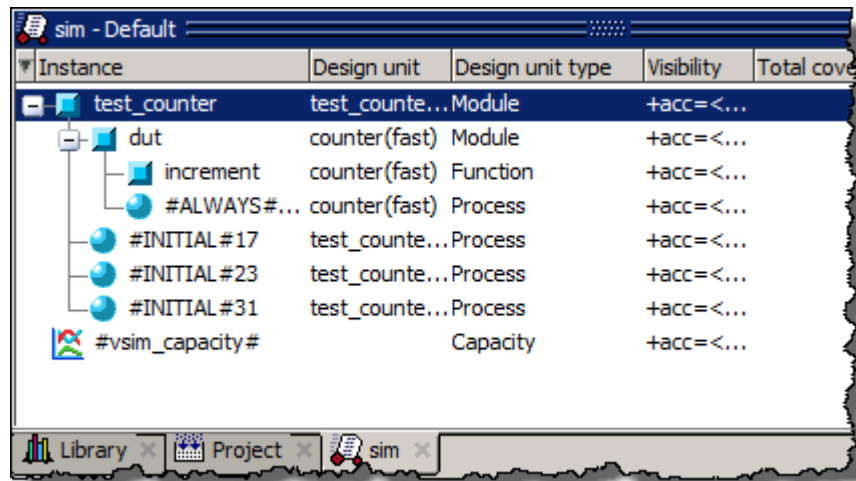
You must provide a name for the optimized design file when you use the vopt command.

## Load the Design

1. Load the *test\_counter* design unit.
  - a. Use the optimized design name to load the design with the **vsim** command:  
**vsim testcounter\_opt**  
  
The Structure (sim) window appears as part of the tab group with the Library and Project windows (Figure 4-7).



**Figure 4-7. Structure(sim) window for a Loaded Design**



At this point you would typically run the simulation and analyze or debug your design like you did in the previous lesson. For now, you'll continue working with the project. However, first you need to end the simulation that started when you loaded *test\_counter*.

2. End the simulation.
  - a. Select **Simulate > End Simulation**.
  - b. Click **Yes**.

## Organizing Projects with Folders

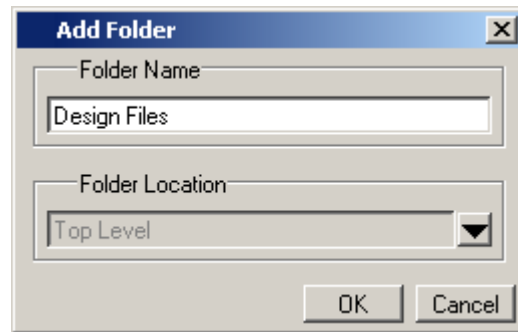
If you have a lot of files to add to a project, you may want to organize them in folders. You can create folders either before or after adding your files. If you create a folder before adding files, you can specify in which folder you want a file placed at the time you add the file (see Folder field in [Figure 4-3](#)). If you create a folder after adding files, you edit the file properties to move it to that folder.

### Add Folders

As shown previously in [Figure 4-2](#), the Add items to the Project dialog has an option for adding folders. If you have already closed that dialog, you can use a menu command to add a folder.

1. Add a new folder.
  - a. Right-click in the Projects window and select **Add to Project > Folder**.
  - b. Type **Design Files** in the **Folder Name** field ([Figure 4-8](#)).

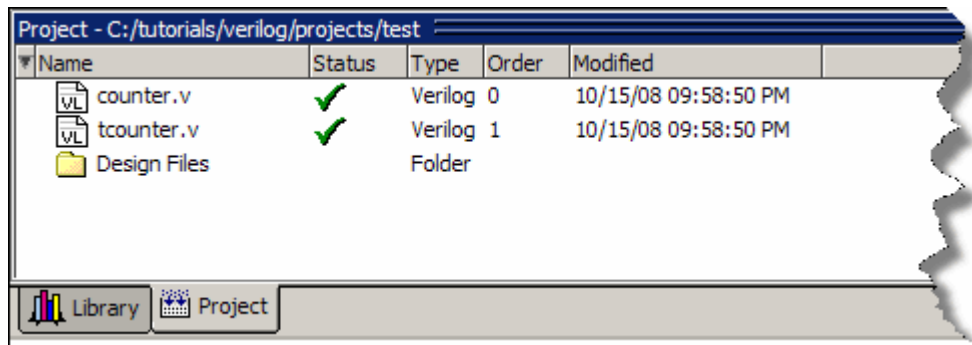
**Figure 4-8. Adding New Folder to Project**



- c. Click **OK**.

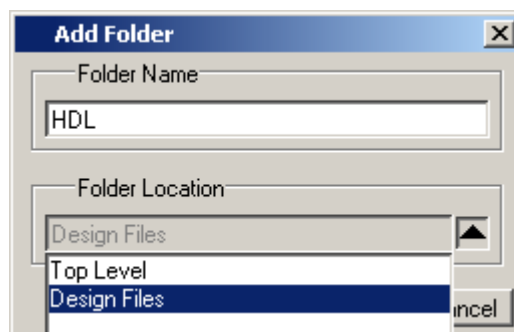
The new Design Files folder is displayed in the Project window ([Figure 4-9](#)).

**Figure 4-9. A Folder Within a Project**



2. Add a sub-folder.
  - a. Right-click anywhere in the Project window and select **Add to Project > Folder**.
  - b. Type **HDL** in the **Folder Name** field ([Figure 4-10](#)).

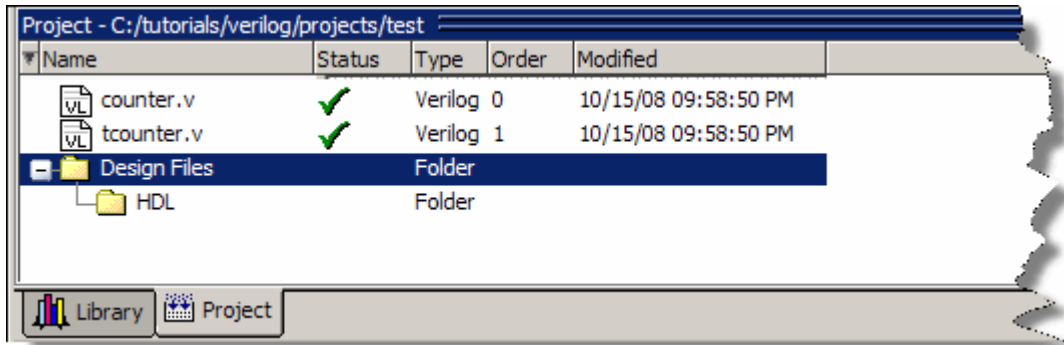
**Figure 4-10. Creating Subfolder**



- c. Click the **Folder Location** drop-down arrow and select *Design Files*.
- d. Click **OK**.

A '+' icon appears next to the *Design Files* folder in the Project window (Figure 4-11).

**Figure 4-11. A folder with a Sub-folder**



- e. Click the '+' icon to see the *HDL* sub-folder.

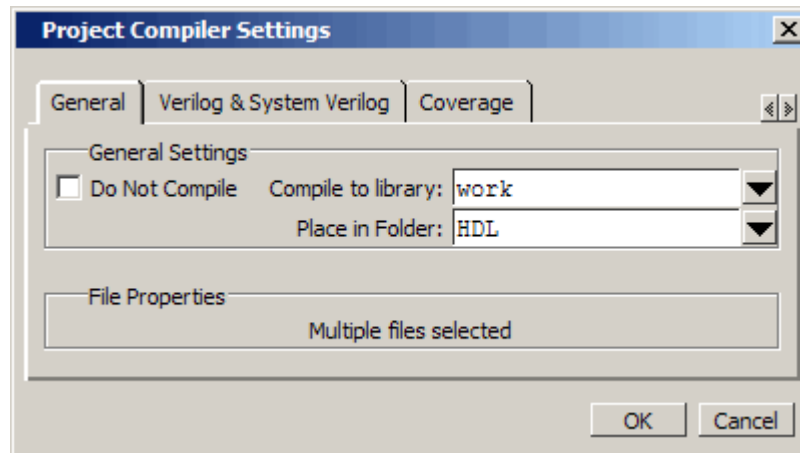
## Moving Files to Folders

If you don't place files into a folder when you first add the files to the project, you can move them into a folder using the properties dialog.

1. Move *tcounter.v* and *counter.v* to the *HDL* folder.
  - a. Select both *counter.v* and *tcounter.v* in the Project window.
  - b. Right-click either file and select **Properties**.

This opens the Project Compiler Settings dialog (Figure 4-12), which allows you to set a variety of options on your design files.

**Figure 4-12. Changing File Location via the Project Compiler Settings Dialog**



- c. Click the **Place In Folder** drop-down arrow and select *HDL*.

- d. Click **OK**.

The selected files are moved into the HDL folder. Click the '+' icon next to the HDL folder to see the files.

The files are now marked with a '?' in the Status column because you moved the files. The project no longer knows if the previous compilation is still valid.

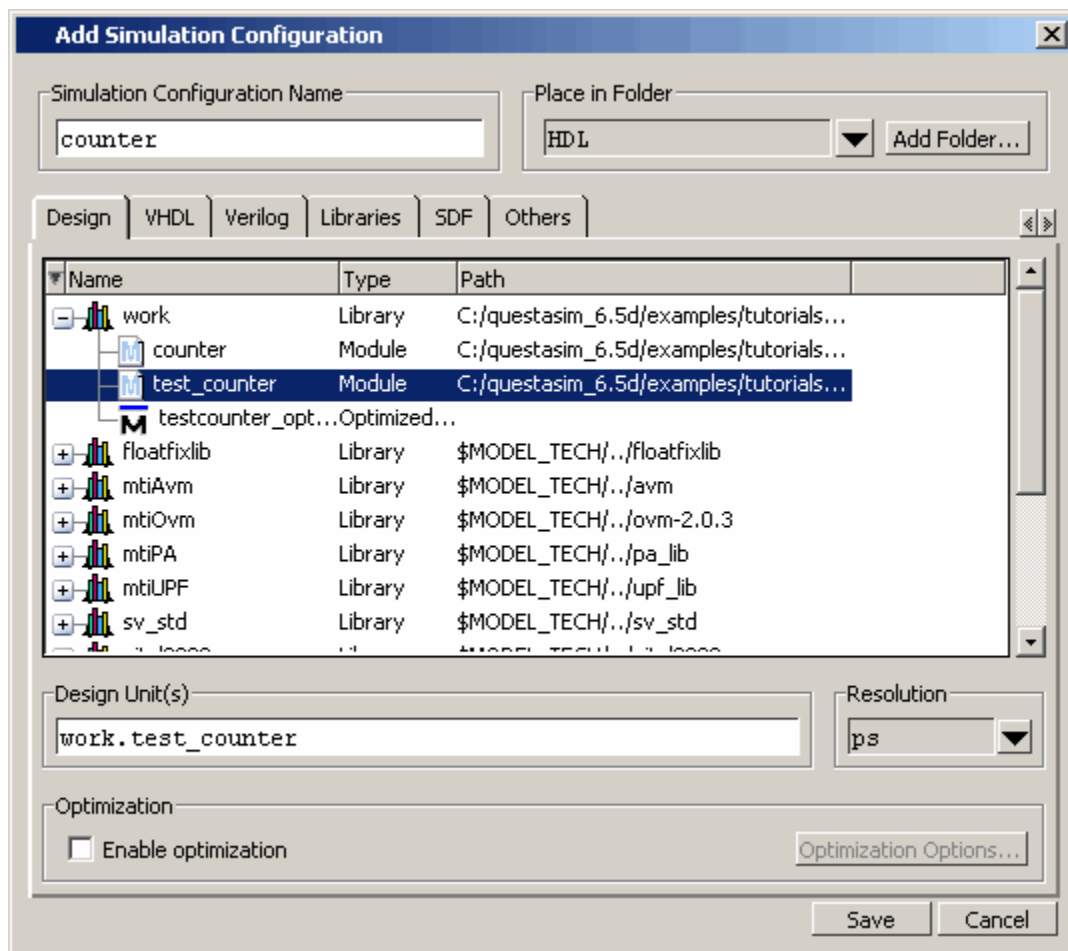
## Simulation Configurations

A Simulation Configuration associates a design unit(s) and its simulation options. For example, let's say that every time you load *tcounter.v* you want to set the simulator resolution to picoseconds (ps) and enable event order hazard checking. Ordinarily, you would have to specify those options each time you load the design. With a Simulation Configuration, you specify options for a design and then save a "configuration" that associates the design and its options. The configuration is then listed in the Project window and you can double-click it to load *tcounter.v* along with its options.

1. Create a new Simulation Configuration.
  - a. Right-click in the Project window and select **Add to Project > Simulation Configuration** from the popup menu.

This opens the Add Simulation Configuration dialog ([Figure 4-13](#)). The tabs in this dialog present several simulation options. You may want to explore the tabs to see what is available. You can consult the ModelSim User's Manual to get a description of each option.

**Figure 4-13. Simulation Configuration Dialog**



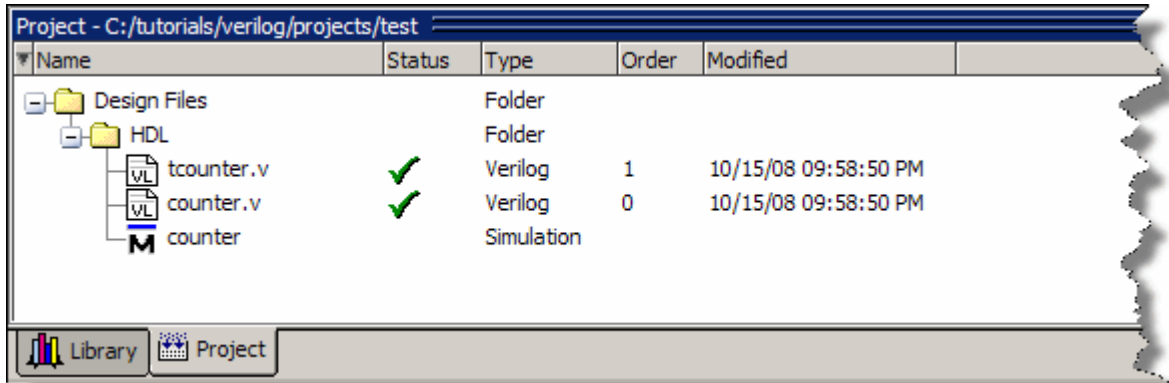
- b. Type **counter** in the **Simulation Configuration Name** field.
- c. Select **HDL** from the **Place in Folder** drop-down.
- d. Click the '+' icon next to the *work* library and select *test\_counter*.
- e. Click the **Resolution** drop-down and select *ps*.
- f. Uncheck the **Enable optimization** selection box.
- g. For Verilog, click the Verilog tab and check **Enable hazard checking (-hazards)**.
- h. Click **Save**.

The files *tcounter.v* and *counter.v* show question mark icons in the status column because they have changed location since they were last compiled and need to be recompiled.

- i. Select one of the files, *tcounter.v* or *counter.v*.
- j. Select **Compile > Compile All**.

The Project window now shows a Simulation Configuration named *counter* in the HDL folder (Figure 4-14).

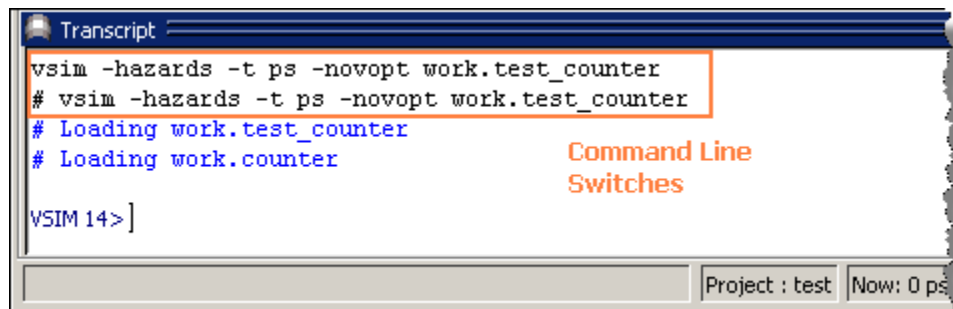
**Figure 4-14. A Simulation Configuration in the Project window**



2. Load the Simulation Configuration.
  - a. Double-click the *counter* Simulation Configuration in the Project window.

In the Transcript window of the Main window, the **vsim** (the ModelSim simulator) invocation shows the **-hazards** and **-t ps** switches (Figure 4-15). These are the command-line equivalents of the options you specified in the Simulate dialog.

**Figure 4-15. Transcript Shows Options for Simulation Configurations**



## Lesson Wrap-Up

This concludes this lesson. Before continuing you need to end the current simulation and close the current project.

1. Select **Simulate > End Simulation**. Click Yes.
2. In the Project window, right-click and select **Close Project**.

If you do not close the project, it will open automatically the next time you start ModelSim.

# Chapter 5

## Working With Multiple Libraries

---

### Introduction

In this lesson you will practice working with multiple libraries. You might have multiple libraries to organize your design, to access IP from a third-party source, or to share common parts between simulations.

You will start the lesson by creating a resource library that contains the *counter* design unit. Next, you will create a project and compile the test bench into it. Finally, you will link to the library containing the counter and then run the simulation.

### Design Files for this Lesson

The sample design for this lesson is a simple 8-bit, binary up-counter with an associated test bench. The pathnames are as follows:

**Verilog** – `<install_dir>/examples/tutorials/verilog/libraries/counter.v` and `tcounter.v`

**VHDL** – `<install_dir>/examples/tutorials/vhdl/libraries/counter.vhd` and `tcounter.vhd`

This lesson uses the Verilog files *tcounter.v* and *counter.v* in the examples. If you have a VHDL license, use *tcounter.vhd* and *counter.vhd* instead.

### Related Reading

User's Manual Chapter: [Design Libraries](#).

## Creating the Resource Library

Before creating the resource library, make sure the *modelsim.ini* in your install directory is “Read Only.” This will prevent permanent mapping of resource libraries to the master *modelsim.ini* file. See [Permanently Mapping VHDL Resource Libraries](#).

1. Create a directory for the resource library.

Create a new directory called *resource\_library*. Copy *counter.v* from `<install_dir>/examples/tutorials/verilog/libraries` to the new directory.

2. Create a directory for the test bench.

Create a new directory called *testbench* that will hold the test bench and project files. Copy *tcounter.v* from *<install\_dir>/examples/tutorials/verilog/libraries* to the new directory.

You are creating two directories in this lesson to mimic the situation where you receive a resource library from a third-party. As noted earlier, we will link to the resource library in the first directory later in the lesson.

3. Start ModelSim and change to the *resource\_library* directory.

If you just finished the previous lesson, ModelSim should already be running. If not, start ModelSim.

- a. Type **vsim** at a UNIX shell prompt or use the ModelSim icon in Windows.

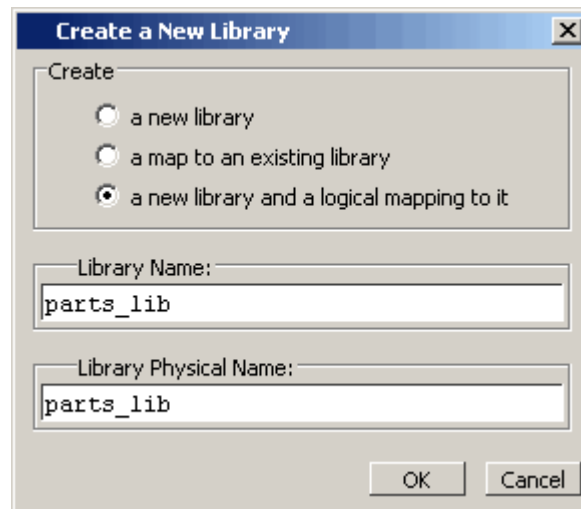
If the Welcome to ModelSim dialog appears, click **Close**.

- b. Select **File > Change Directory** and change to the *resource\_library* directory you created in step 1.

4. Create the resource library.

- a. Select **File > New > Library**.
  - b. Type **parts\_lib** in the Library Name field (Figure 5-1).

**Figure 5-1. Creating New Resource Library**



The Library Physical Name field is filled out automatically.

Once you click OK, ModelSim creates a directory for the library, lists it in the Library window, and modifies the *modelsim.ini* file to record this new library for the future.

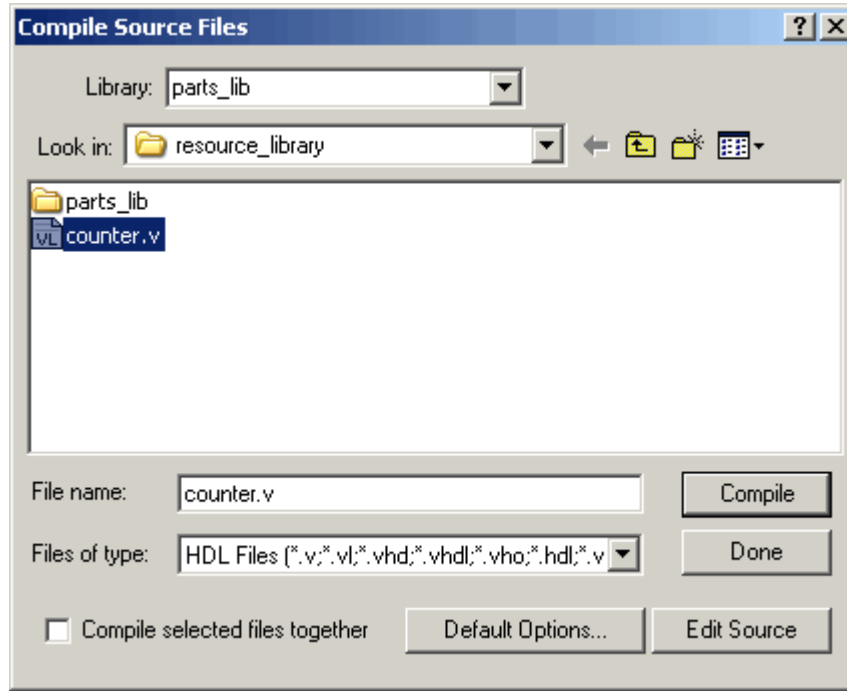
5. Compile the counter into the resource library.



- a. Click the Compile icon on the Main window toolbar.
- b. Select the *parts\_lib* library from the Library list (Figure 5-2).



**Figure 5-2. Compiling into the Resource Library**



- c. Double-click *counter.v* to compile it.
- d. Click **Done**.

You now have a resource library containing a compiled version of the *counter* design unit.

6. Change to the *testbench* directory.
  - a. Select **File > Change Directory** and change to the *testbench* directory you created in step 2.

## Creating the Project

Now you will create a project that contains *tcounter.v*, the counter's test bench.

1. Create the project.
  - a. Select **File > New > Project**.
  - b. Type **counter** in the Project Name field.
  - c. Do not change the Project Location field or the Default Library Name field. (The default library name is *work*.)

- d. Make sure “Copy Library Mappings” is selected. The default *modelsim.ini* file will be used.
    - e. Click **OK**.
  2. Add the test bench to the project.
    - a. Click **Add Existing File** in the Add items to the Project dialog.
    - b. Click the **Browse** button and select *tcounter.v* in the “Select files to add to project” dialog.
    - c. Click **Open**.
    - d. Click **OK**.
    - e. Click **Close** to dismiss the “Add items to the Project” dialog.

The *tcounter.v* file is listed in the Project window.
  3. Compile the test bench.
    - a. Right-click *tcounter.v* and select **Compile > Compile Selected**.

## Linking to the Resource Library

To wrap up this part of the lesson, you will link to the *parts\_lib* library you created earlier. But first, try optimizing the test bench without the link and see what happens.

ModelSim responds differently for Verilog and VHDL in this situation.

## Verilog

### Optimize the Verilog Design for Debug Visibility

1. Use the **vopt** command to optimize with full debug visibility into all design units.
  - a. Enter the following command at the QuestaSim> prompt in the Transcript window:  
**vopt +acc test\_counter -o testcounter\_opt**

The **+acc** switch provides visibility into the design for debugging purposes.

The **-o** switch allows you designate the name of the optimized design file (testcounter\_opt).

---

#### Note



You must provide a name for the optimized design file when you use the vopt command.

---

The Main window Transcript reports an error loading the design because the *counter* module is not defined.

- b. Type **quit -sim** to quit the simulation.

The process for linking to a resource library differs between Verilog and VHDL. If you are using Verilog, follow the steps in [Linking to a Resource Library](#). If you are using VHDL, follow the steps in [Permanently Mapping VHDL Resource Libraries](#) one page later.

## VHDL

### Optimize the VHDL Design for Debug Visibility

1. Use the **vopt** command to optimize with full debug visibility into all design units.
  - a. Enter the following command at the QuestaSim> prompt in the Transcript window:

**vopt +acc test\_counter -o testcounter\_opt**

The **+acc** switch provides visibility into the design for debugging purposes.

The **-o** switch allows you designate the name of the optimized design file (testcounter\_opt).

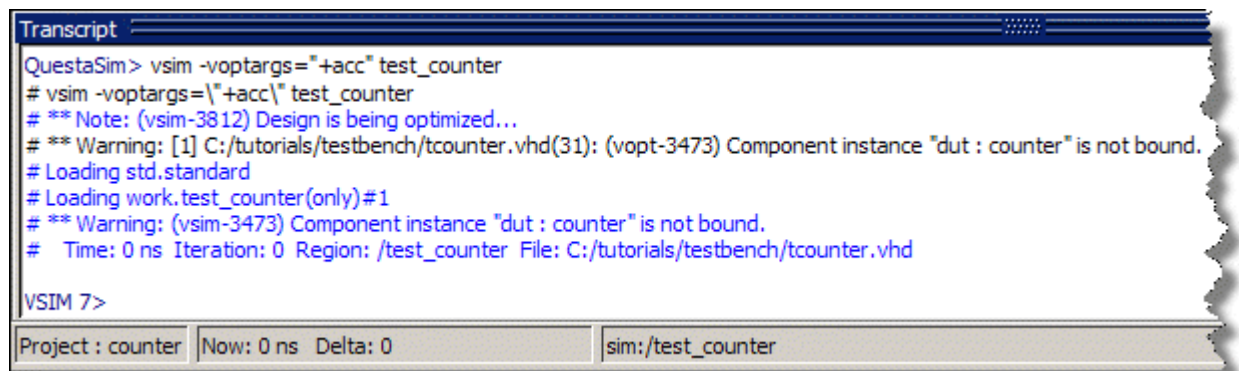
#### Note



You must provide a name for the optimized design file when you use the vopt command.

The Main window Transcript reports a warning ([Figure 5-3](#)). When you see a message that contains text like "Warning: (vsim-3473)", you can view more detail by using the **verror** command.

**Figure 5-3. VHDL Simulation Warning Reported in Main Window**




- b. Type **verror 3473** at the VSIM> prompt.

The expanded error message tells you that a component ('dut' in this case) has not been explicitly bound and no default binding can be found.

- c. Type **quit -sim** to quit the simulation.

## Linking to a Resource Library

Linking to a resource library requires that you specify a "search library" when you invoke the simulator.

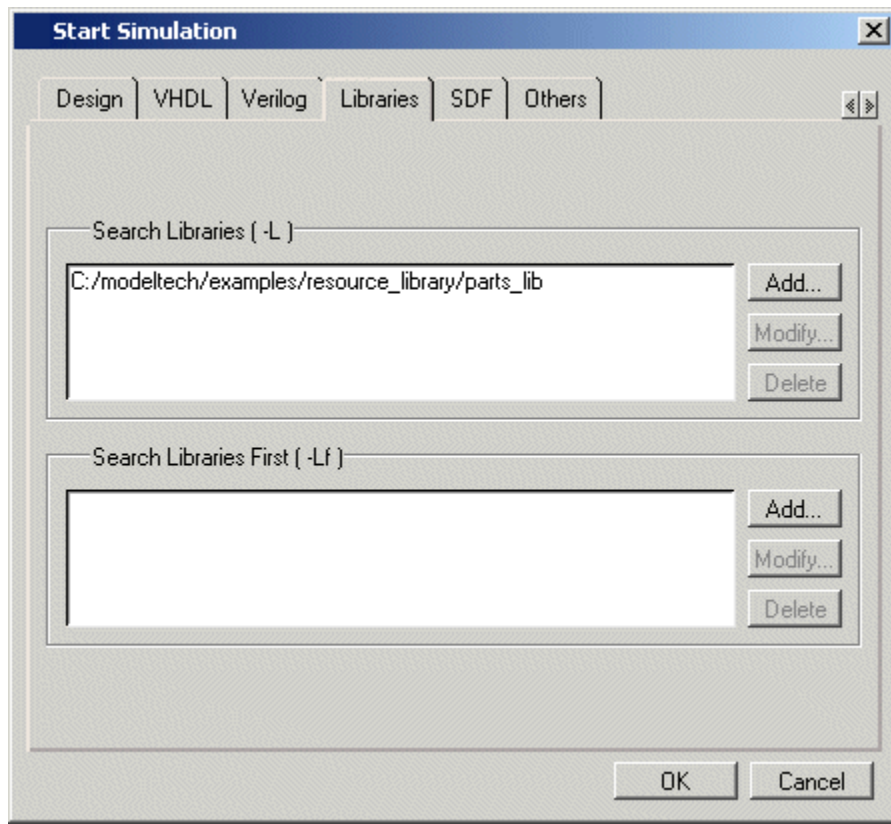
1. Specify a search library during simulation.
  - a. Click the Simulate icon on the Main window toolbar. 
  - b. Click the '+' icon next to the *work* library and select *test\_counter*.
  - c. Uncheck the Enable optimization selection box.
  - d. Click the Libraries tab.
  - e. Click the Add button next to the Search Libraries field and browse to *parts\_lib* in the *resource\_library* directory you created earlier in the lesson.
  - f. Click OK.

The dialog should have *parts\_lib* listed in the Search Libraries field ([Figure 5-4](#)).

- g. Click OK.

The design loads without errors.

**Figure 5-4. Specifying a Search Library in the Simulate Dialog**



## Permanently Mapping VHDL Resource Libraries

If you reference particular VHDL resource libraries in every VHDL project or simulation, you may want to permanently map the libraries. Doing this requires that you edit the master *modelsim.ini* file in the installation directory. Though you won't actually practice it in this tutorial, here are the steps for editing the file:

1. Locate the *modelsim.ini* file in the ModelSim installation directory (*<install\_dir>/modeltech/modelsim.ini*).
2. IMPORTANT - Make a backup copy of the file.
3. Change the file attributes of *modelsim.ini* so it is no longer "read-only."
4. Open the file and enter your library mappings in the [Library] section. For example:  

```
parts_lib = C:/libraries/parts_lib
```
5. Save the file.
6. Change the file attributes so the file is "read-only" again.

## Lesson Wrap-Up

This concludes this lesson. Before continuing we need to end the current simulation and close the project.

1. Select **Simulate > End Simulation**. Click **Yes**.
2. Select the Project window to make it active.
3. Select **File > Close**. Click **OK**.

# Chapter 6

## Simulating SystemC Designs

---

### Introduction

ModelSim treats SystemC as just another design language. With only a few exceptions in the current release, you can simulate and debug your SystemC designs the same way you do HDL designs.

#### Note



The functionality described in this lesson requires a systemc license feature in your ModelSim license file. Please contact your Mentor Graphics sales representative if you currently do not have such a feature.

---

### Design Files for this Lesson

There are two sample designs for this lesson. The first is a very basic design, called "basic", containing only SystemC code. The second design is a ring buffer where the test bench and top-level chip are implemented in SystemC and the lower-level modules are written in HDL.

The pathnames to the files are as follows:

**SystemC** – *<install\_dir>/examples/systemc/sc\_basic*

**SystemC/Verilog** – *<install\_dir>/examples/systemc/sc\_vlog*

**SystemC/VHDL** – *<install\_dir>/examples/systemc/sc\_vhdl*

This lesson uses the SystemC/Verilog version of the ringbuf design in the examples. If you have a VHDL license, use the VHDL version instead. There is also a mixed version of the design, but the instructions here do not account for the slight differences in that version.

### Related Reading

User's Manual Chapters: [SystemC Simulation](#), [Mixed-Language Simulation](#), and [C Debug](#).

Reference Manual command: [sccom](#).

## Setting up the Environment

SystemC is a licensed feature. You need the *systemc* license feature in your ModelSim license file to simulate SystemC designs. Please contact your Mentor Graphics sales representatives if you currently do not have such a feature.

The table below shows the supported operating systems for SystemC and the corresponding required versions of a C compiler

**Table 6-1. Supported Platforms for SystemC**

Platform/OS	Supported compiler versions	32-bit support	64-bit support
Intel and AMD x86-based architectures (32- and 64-bit) SUSE Linux Enterprise Server 9.0, 9.1, 10, 11 Red Hat Enterprise Linux 3, 4, 5	gcc 4.0.2, gcc 4.1.2, gcc 4.3.3 VCO is linux (32-bit binary) VCO is linux_x86_64 (64-bit binary)	yes	yes
Solaris 8, 9, and 10	gcc 4.1.2	yes	no
Solaris 10 on x86	gcc 4.1.2	yes	yes
Windows <sup>1</sup> XP, Vista and 7	Minimalist GNU for Windows (MinGW) gcc 4.2.1	yes	no

1. SystemC supported on this platform with gcc-4.2.1-mingw32vc9.

For a complete list of supported platforms and SystemC compilers see the [Supported Platforms](#) section of the Installation and Licensing Guide. Also, refer to [SystemC Simulation](#) in the *ModelSim User's Manual* for further details.

## Preparing an OSCI SystemC design

For an OpenSystemC Initiative (OSCI) compliant SystemC design to run on ModelSim, you must first:

- Replace **sc\_main()** with an **SC\_MODULE**, potentially adding a process to contain any test bench code.
- Replace **sc\_start()** by using the [run](#) command in the GUI.
- Remove calls to **sc\_initialize()**.
- Export the top level SystemC design unit(s) using the **SC\_MODULE\_EXPORT** macro.

In order to maintain portability between OSCI and ModelSim simulations, we recommend that you preserve the original code by using **#ifdef** to add the ModelSim-specific information. When the design is analyzed, [sccom](#) recognizes the **MTI\_SYSTEMC** preprocessing directive and handles the code appropriately.



For more information on these modifications, refer to [Modifying SystemC Source Code](#) in the User's Manual.

1. Create a new directory and copy the tutorial files into it.

Start by creating a new directory for this exercise (in case other users will be working with these lessons). Create the directory, then copy all files from `<install_dir>/examples/systemc/sc_basic` into the new directory.

2. Start ModelSim and change to the exercise directory.

If you just finished the previous lesson, ModelSim should already be running. If not, start ModelSim.

- a. Type `vsim` at a UNIX shell prompt or use the ModelSim icon in Windows.

If the Welcome to ModelSim dialog appears, click **Close**.

- b. Select **File > Change Directory** and change to the directory you created in step 1.

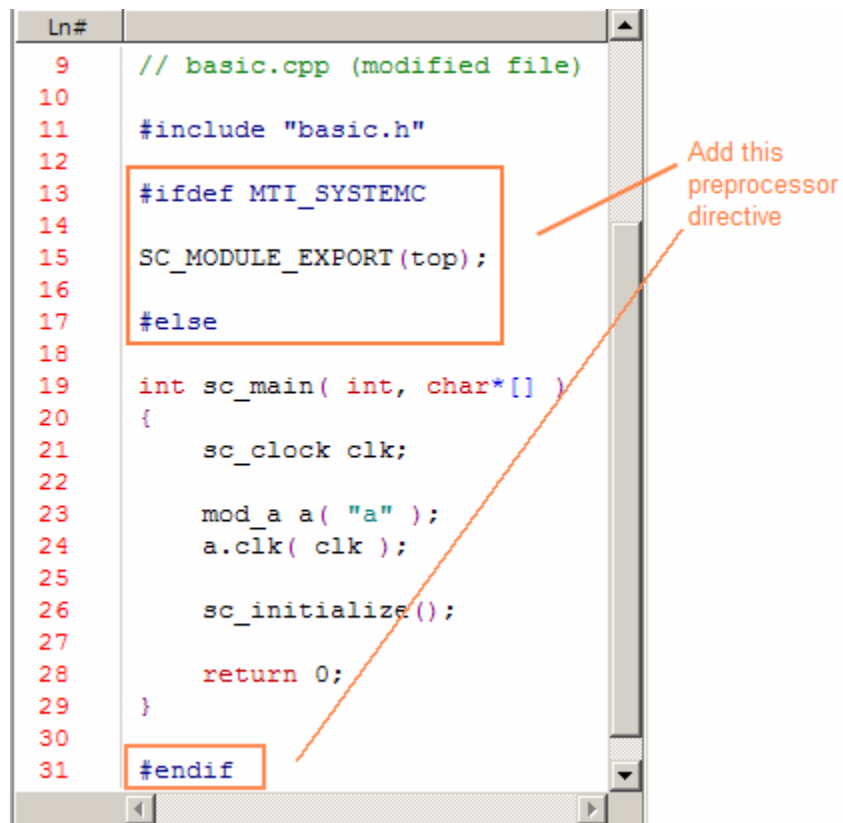
3. Use a text editor to view and edit the `basic_orig.cpp` file. To use ModelSim's editor, from the Main Menu select **File > Open**. Change the files of type to C/C++ files then double-click `basic_orig.cpp`.

- a. If you are using ModelSim's editor, right-click in the source code view of the `basic_orig.cpp` file and uncheck the Read Only option in the popup menu.

- b. Using the `#ifdef MTI_SYSTEMC` preprocessor directive, add the `SC_MODULE_EXPORT(top);` to the design as shown in [Figure 6-1](#).

- c. Save the file as `basic.cpp`.

**Figure 6-1. The SystemC File After Modifications.**

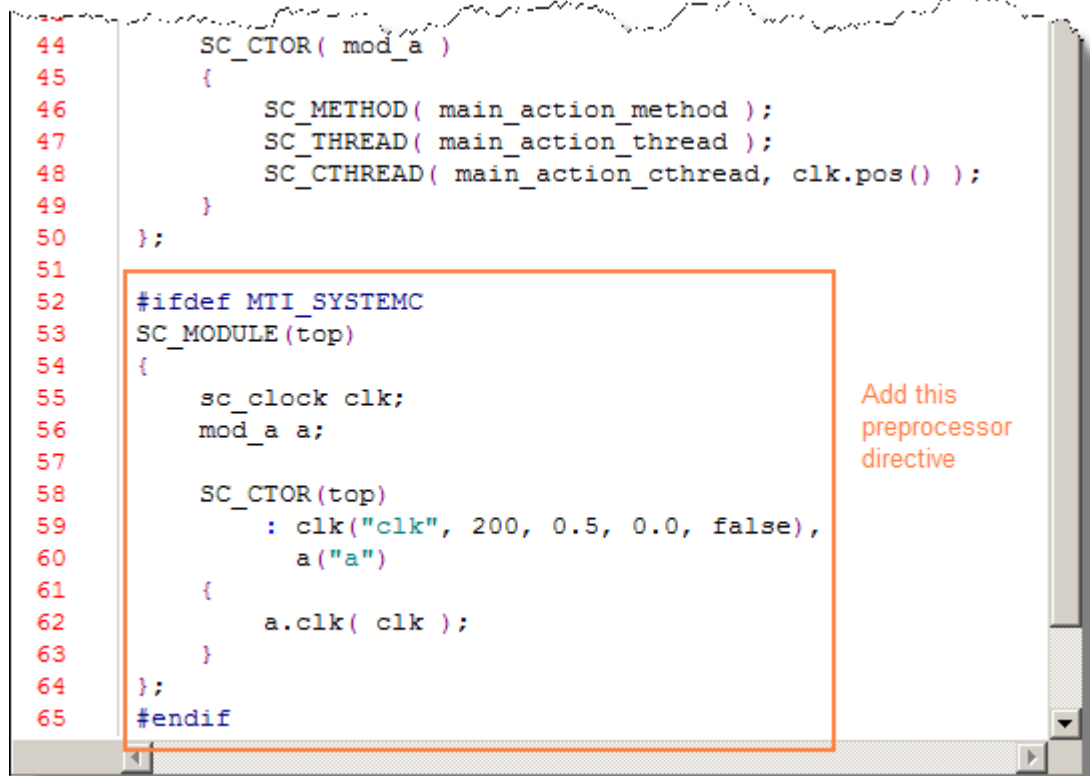


A correctly modified copy of the *basic.cpp* is also available in the *sc\_basic/gold* directory.

1. Edit the *basic\_orig.h* header file as shown in [Figure 6-2](#).
  - a. If you are using ModelSim's editor, right-click in the source code view of the *basic\_orig.h* file and uncheck the Read Only option in the popup menu.
  - b. Add a ModelSim specific SC\_MODULE (top) as shown in lines 52 through 65 of [Figure 6-2](#).

The declarations that were in *sc\_main* are placed here in the header file, in SC\_MODULE (top). This creates a top level module above *mod\_a*, which allows the tool's automatic name binding feature to properly associate the primitive channels with their names.

Figure 6-2. Editing the SystemC Header File.



- c. Save the file as *basic.h*.

A correctly modified copy of the *basic.h* is also available in the *sc\_basic/gold* directory.

You have now made all the edits that are required for preparing the design for compilation.

## Compiling a SystemC-only Design

With the edits complete, you are ready to compile the design. Designs that contain only SystemC code are compiled with [sccom](#).

1. Create a work library.
  - a. Type **vlib work** at the ModelSim> prompt in the Transcript window.
2. Compile and link all SystemC files.
  - a. Type **sccom -g basic.cpp** at the ModelSim> prompt.  
The **-g** argument compiles the design for debug.
  - b. Type **sccom -link** at the ModelSim> prompt to perform the final link on the SystemC objects.

You have successfully compiled and linked the design. The successful compilation verifies that all the necessary file modifications have been entered correctly.

In the next exercise you will compile and load a design that includes both SystemC and HDL code.

## Mixed SystemC and HDL Example

In this next example, you have a SystemC test bench that instantiates an HDL module. In order for the SystemC test bench to interface properly with the HDL module, you must create a stub module, a foreign module declaration. You will use the [scgenmod](#) utility to create the foreign module declaration. Finally, you will link the created C object files using **sccom -link**.

1. Create a new exercise directory and copy the tutorial files into it.

Start by creating a new directory for this exercise (in case other users will be working with these lessons). Create the directory, then copy all files from `<install_dir>/examples/systemc/sc_vlog` into the new directory.

If you have a VHDL license, copy the files in `<install_dir>/examples/systemc/sc_vhdl` instead.

2. Start ModelSim and change to the exercise directory.

If you just finished the previous lesson, ModelSim should already be running. If not, start ModelSim.

- a. Type **vsim** at a command shell prompt.

If the Welcome to ModelSim dialog appears, click **Close**.

- b. Select **File > Change Directory** and change to the directory you created in step 1.

3. Set the working library.

- a. Type **vlib work** in the ModelSim Transcript window to create the working library.

4. Compile the design.

- a. **Verilog:**

Type **vlog \*.v** in the ModelSim Transcript window to compile all Verilog source files.

**VHDL:**

Type **vcom -93 \*.vhd** in the ModelSim Transcript window to compile all VHDL source files.

5. Create the foreign module declaration (SystemC stub) for the Verilog module *ringbuf*.

a. **Verilog:**

Type `scgenmod -map "scalar=bool" ringbuf > ringbuf.h` at the ModelSim> prompt.

The `-map "scalar=bool"` argument is used to generate boolean scalar port types inside the foreign module declaration. See [scgenmod](#) for more information.

**VHDL:**

Type `scgenmod ringbuf > ringbuf.h` at the ModelSim> prompt.

The output is redirected to the file *ringbuf.h* (Figure 6-3).

**Figure 6-3. The ringbuf.h File.**

```

1  #ifndef _SCGENMOD_ringbuf_
2  #define _SCGENMOD_ringbuf_
3
4  #include "systemc.h"
5
6  class ringbuf : public sc_foreign_module
7  {
8  public:
9      sc_in<bool> clock;
10     sc_in<bool> reset;
11     sc_in<bool> txda;
12     sc_out<bool> rxda;
13     sc_out<bool> txc;
14     sc_out<bool> outstrobe;
15
16
17     ringbuf(sc_module_name nm, const char* hdl_name,
18           int num_generics, const char** generic_list)
19       : sc_foreign_module(nm),
20         clock("clock"),
21         reset("reset"),
22         txda("txda"),
23         rxda("rxda"),
24         txc("txc"),
25         outstrobe("outstrobe")
26     {
27         elaborate_foreign_module(hdl_name, num_generics, generic_list);
28     }
29     ~ringbuf()
30     {}
31
32 };
33
34 #endif
35
```

The *test\_ringbuf.h* file is included in *test\_ringbuf.cpp*, as shown in [Figure 6-4](#).

Figure 6-4. The test\_ringbuf.cpp File

```
8  ..
9  // test_ringbuf.cpp
10
11  #include "test_ringbuf.h"
12  #include <iostream>
13
14
15  SC_MODULE_EXPORT(test_ringbuf);
16
```

6. Compile and link all SystemC files, including the generated *ringbuf.h*.

- a. Type **sccom -g test\_ringbuf.cpp** at the ModelSim> prompt.

The *test\_ringbuf.cpp* file contains an include statement for *test\_ringbuf.h* and a required `SC_MODULE_EXPORT(top)` statement, which informs ModelSim that the top-level module is SystemC.

- b. Type **sccom -link** at the ModelSim> prompt to perform the final link on the SystemC objects.

7. Optimize the design with full debug visibility.

- a. Enter the following command at the ModelSim> prompt:

**vopt +acc test\_ringbuf -o test\_ringbuf\_opt**

The **+acc** switch for the **vopt** command provides full visibility into the design for debugging purposes.

The **-o** switch designates the name of the optimized design (*test\_ringbuf\_opt*).

---

**Note**



You must provide a name for the optimized design file when you use the **vopt** command.

---

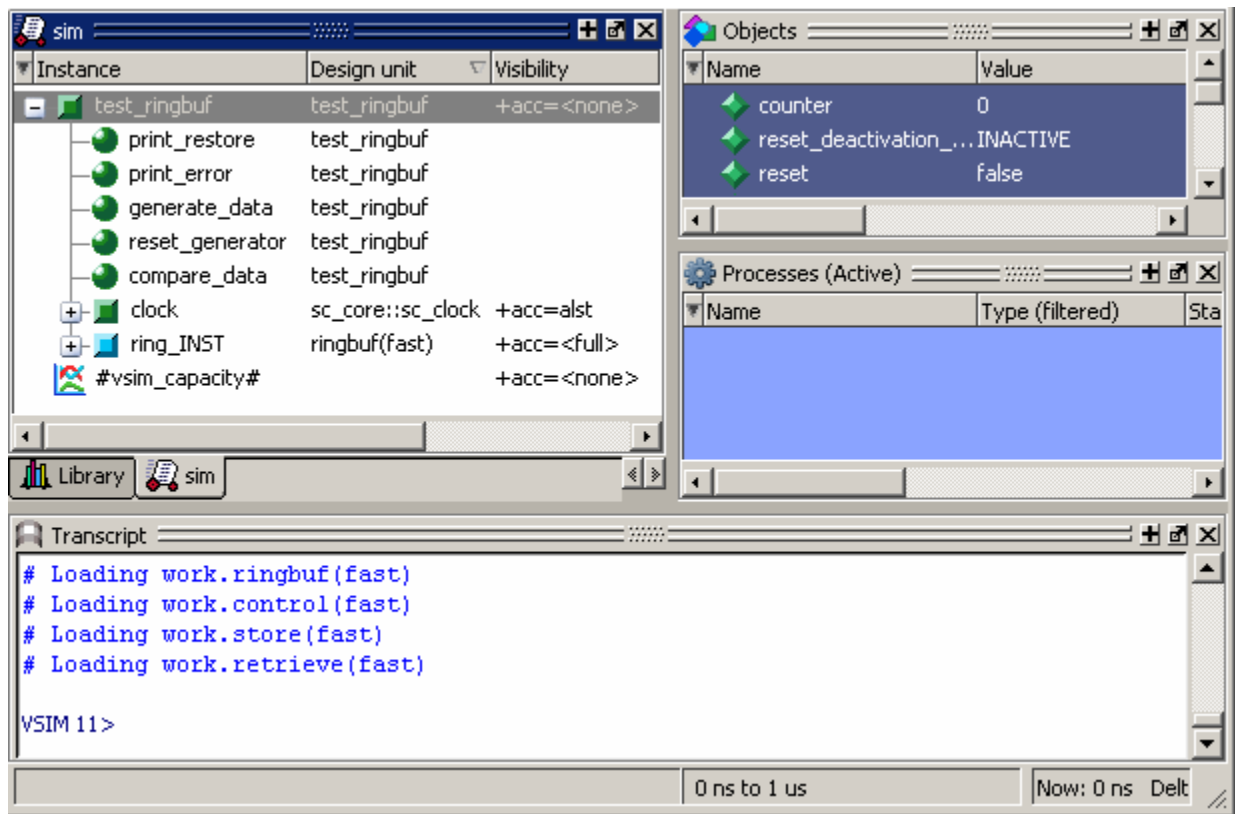
8. Load the design.

- a. Load the design using the optimized design name.

**vsim test\_ringbuf\_opt**

9. Make sure the Objects window is open and the Processes window is open in “Active” mode, as shown in [Figure 6-5](#). To open or close these windows, use the **View** menu.

Figure 6-5. The test\_ringbuf Design



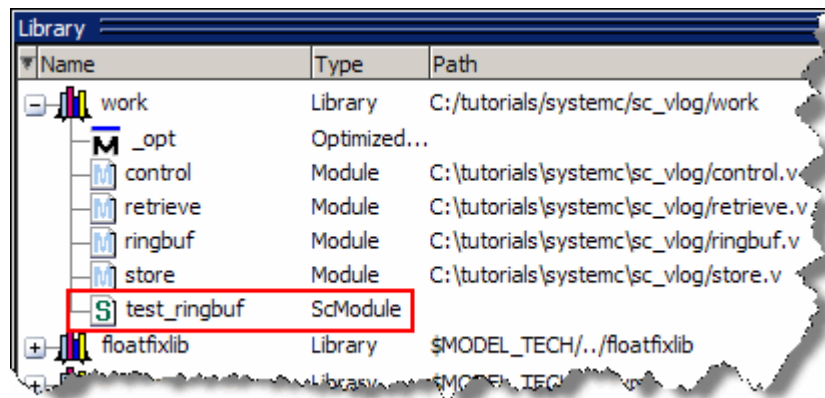
## Viewing SystemC Objects in the GUI

SystemC objects are denoted in the ModelSim GUI with a green 'S' in the Library window and a green square, circle, or diamond icon elsewhere.

1. View objects in the Library window.
  - a. Click on the Library tab and expand the work library.

SystemC objects have a green 'S' next to their names ([Figure 6-6](#)).

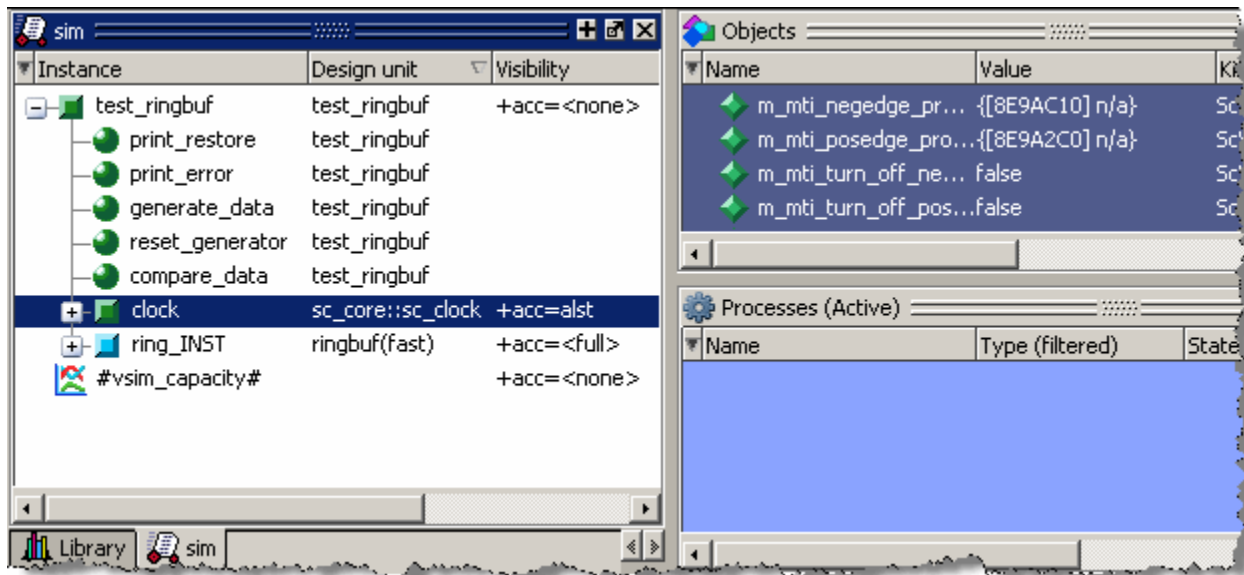
Figure 6-6. SystemC Objects in the work Library



2. Observe window linkages.
  - a. Click on the Structure window (sim) tab to make it active.
  - b. Select the *clock* instance in the Structure window (Figure 6-7).

The Objects window updates to show the associated SystemC or HDL objects.

Figure 6-7. SystemC Objects in Structure (sim) and Objects Windows



3. Add objects to the Wave window.
  - a. In the Structure window, right-click *test\_ringbuf* and select **Add Wave** from the popup menu.



## Setting Breakpoints and Stepping in the Source Window

As with HDL files, you can set breakpoints and step through SystemC files in the Source window. In the case of SystemC, ModelSim uses C Debug, an interface to the open-source **gdb** debugger. Refer to the [C Debug](#) chapter in the User's Manual for complete details.

1. Before we set a breakpoint, we must disable the Auto Lib Step Out feature, which is on by default. With Auto Lib Step Out, if you try to step into a standard C++ or SystemC header file (`<install_dir>/include/systemc`), ModelSim will automatically do a step-out.

- a. Select **Tools > C Debug > Allow lib step** from the Main menus.

2. Set a breakpoint.

- a. Double-click *test\_ringbuf* in the Structure window to open the source file.

- b. In the Source window:

**Verilog:** scroll to the area around line 150 of *test\_ringbuf.h*.

**VHDL:** scroll to the area around line 155 of *test\_ringbuf.h*.

- c. Click in the line number column next to the red line number of the line containing (shown in [Figure 6-8](#)):

**Verilog:** `bool var_dataerror_newval = actual.read()...`

**VHDL:** `sc_logic var_dataerror_newval = acutal.read ...`

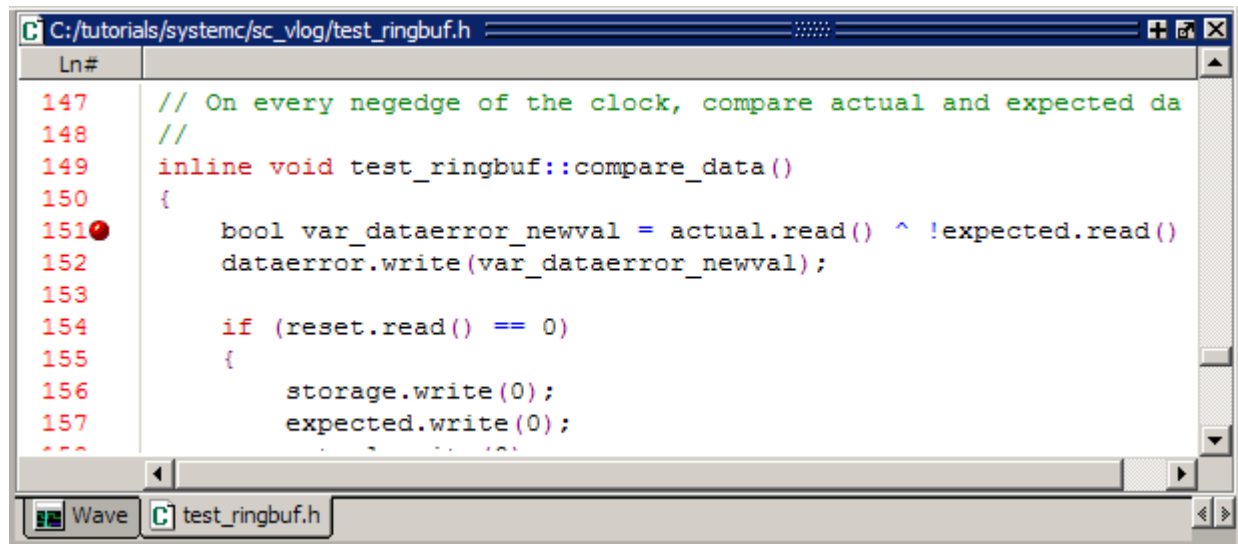
### Note



ModelSim recognizes that the file contains SystemC code and automatically launches C Debug. There will be a slight delay while C Debug opens before the breakpoint appears.

Once the debugger is running, ModelSim places a solid red ball next to the line number ([Figure 6-8](#)).

Figure 6-8. Active Breakpoint in a SystemC File

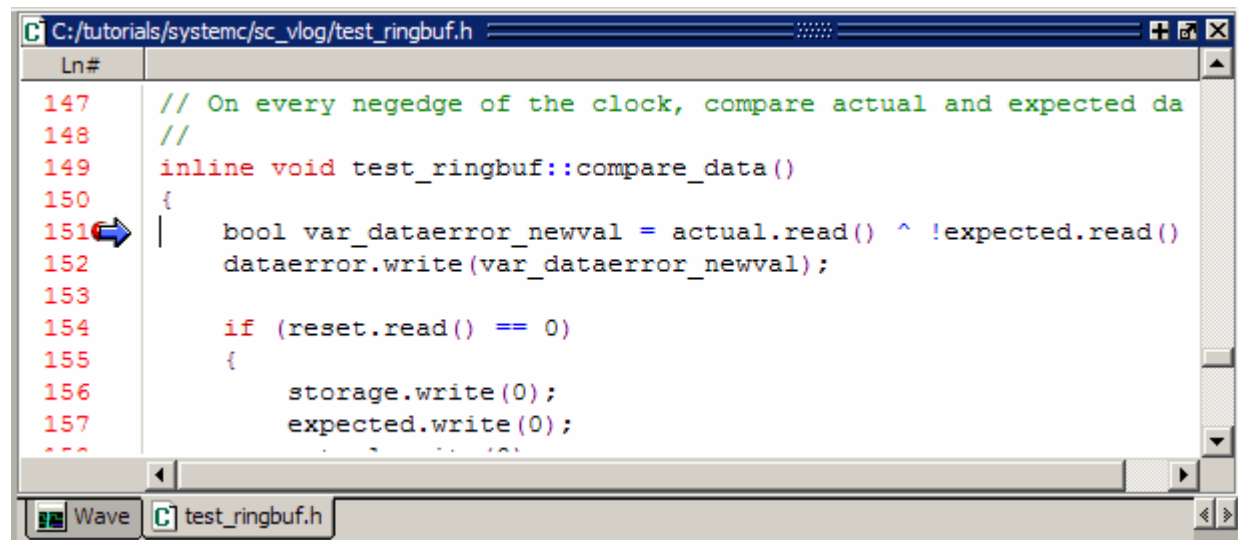


3. Run and step through the code.
  - a. Type **run 500** at the VSIM> prompt.

When the simulation hits the breakpoint it stops running, highlights the line with a blue arrow in the Source window (Figure 6-9), and issues a message like this in the Transcript:

```
# C breakpoint c.1
# test_ringbuf::compare_data (this=0x27c4d08) at test_ringbuf.h:151
```

Figure 6-9. Simulation Stopped at Breakpoint

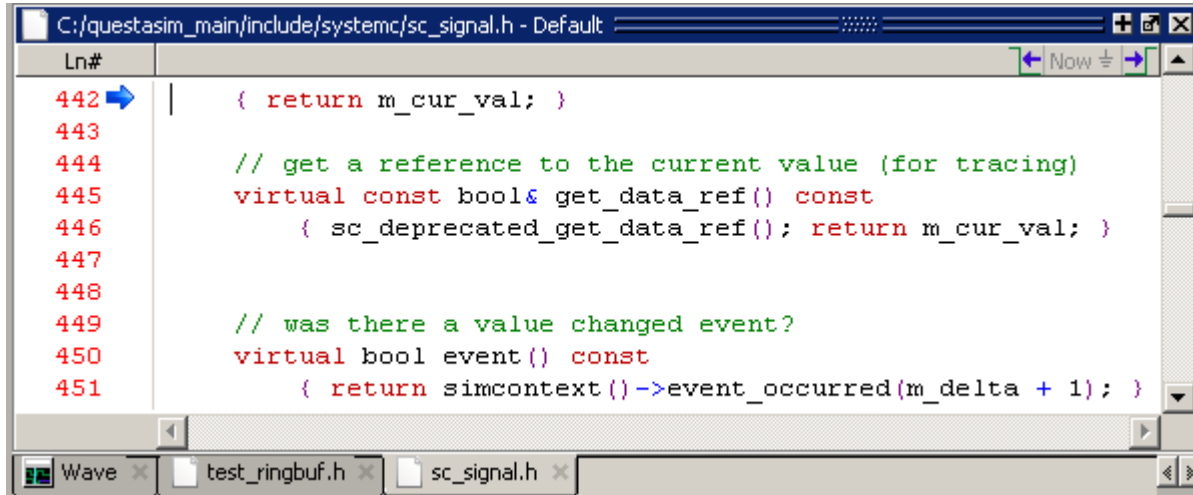


- b. Click the Step icon on the Step Into toolbar.



This steps the simulation to the next statement. Because the next statement is a function call, ModelSim steps into the function, which is in a separate file — *sc\_signal.h* (Figure 6-10).

**Figure 6-10. Stepping into a Separate File**



- c. Click the Continue Run icon in the toolbar.



The breakpoint in *test\_ringbuf.h* is hit again.

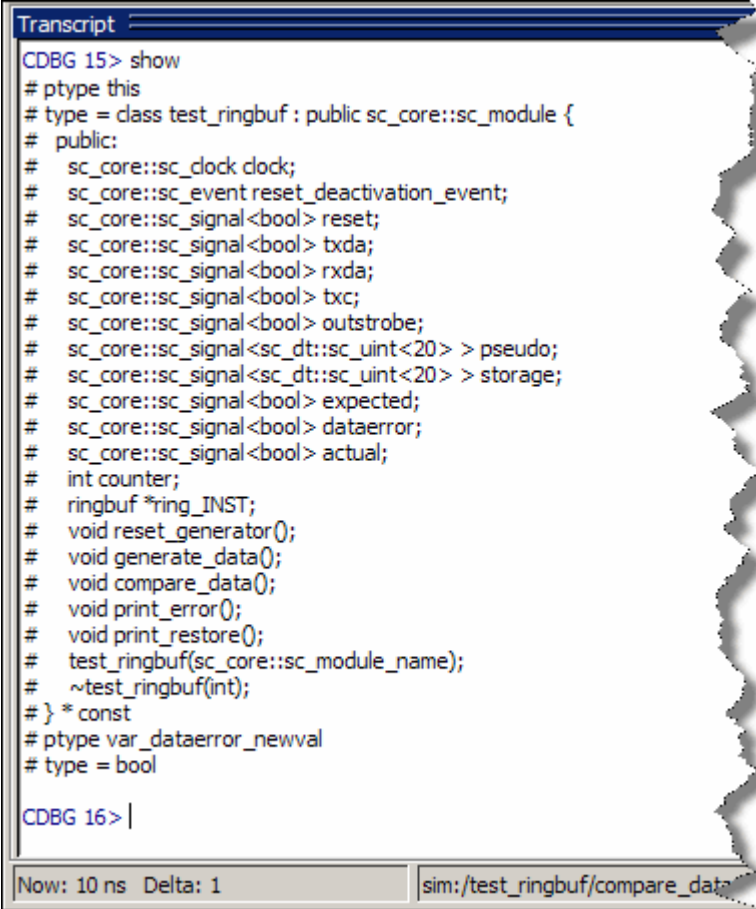
## Examining SystemC Objects and Variables

To examine the value of a SystemC object or variable, you can use the **examine** command or view the value in the Objects window.

1. View the value and type of an *sc\_signal*.
  - a. Enter the **show** command at the **CDBG >** prompt to display a list of all design objects, including their types, in the Transcript.

In this list, you'll see that the type for *dataerror* is "boolean" (*sc\_logic* for VHDL) and *counter* is "int" (Figure 6-11).

Figure 6-11. Output of show Command



```
Transcript
CDBG 15> show
# ptype this
# type = class test_ringbuf : public sc_core::sc_module {
# public:
#   sc_core::sc_clock clock;
#   sc_core::sc_event reset_deactivation_event;
#   sc_core::sc_signal<bool> reset;
#   sc_core::sc_signal<bool> txda;
#   sc_core::sc_signal<bool> rxda;
#   sc_core::sc_signal<bool> txc;
#   sc_core::sc_signal<bool> outstrobe;
#   sc_core::sc_signal<sc_dt::sc_uint<20> > pseudo;
#   sc_core::sc_signal<sc_dt::sc_uint<20> > storage;
#   sc_core::sc_signal<bool> expected;
#   sc_core::sc_signal<bool> dataerror;
#   sc_core::sc_signal<bool> actual;
#   int counter;
#   ringbuf *ring_INST;
#   void reset_generator();
#   void generate_data();
#   void compare_data();
#   void print_error();
#   void print_restore();
#   test_ringbuf(sc_core::sc_module_name);
#   ~test_ringbuf(int);
# } * const
# ptype var_dataerror_newval
# type = bool

CDBG 16> |

Now: 10 ns Delta: 1    sim:/test_ringbuf/compare_data
```

- b. Enter the **examine dataerror** command at the CDBG > prompt.

The value returned is "true".

2. View the value of a SystemC variable.

- a. Enter the **examine counter** command at the CDBG > prompt to view the value of this variable.

The value returned is "-1".

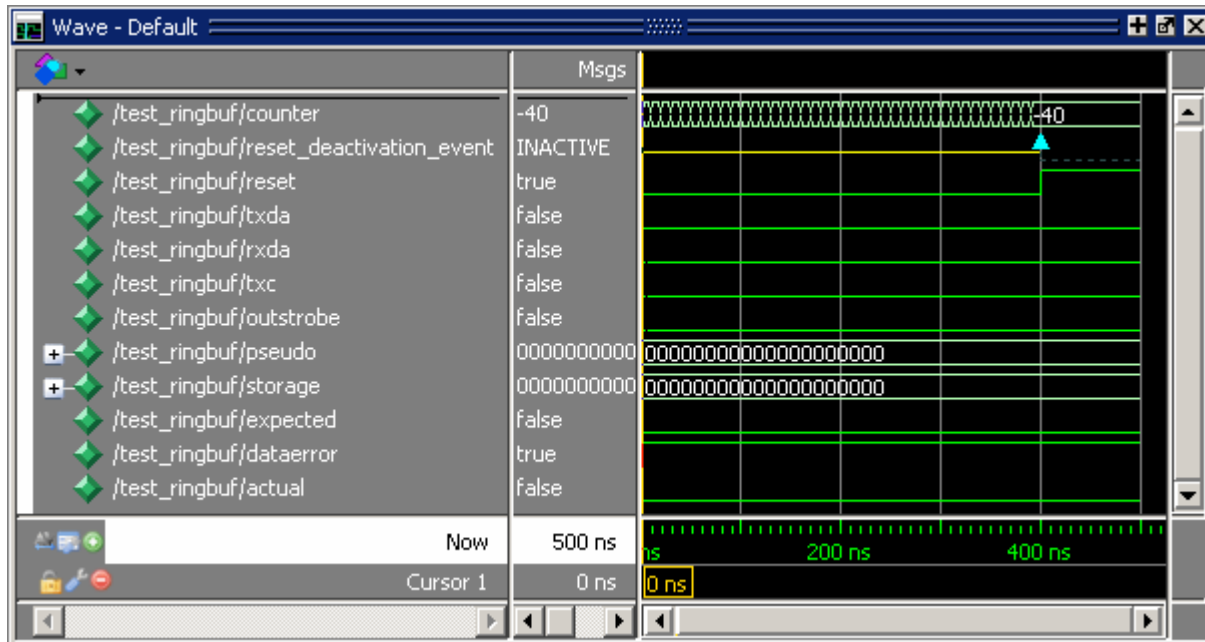
## Removing a Breakpoint

1. Return to the Source window for test\_ringbuf.h and right-click the red ball in the line number column. Select **Remove Breakpoint** from the popup menu.
2. Click the Continue Run button again.

The simulation runs for 500 ns and waves are drawn in the Wave window (Figure 6-12).

If you are using the VHDL version, you might see warnings in the Main window transcript. These warnings are related to VHDL value conversion routines and can be ignored.

**Figure 6-12. SystemC Primitive Channels in the Wave Window**



## Lesson Wrap-up

This concludes the lesson. Before continuing we need to quit the C debugger and end the current simulation.

1. Select **Tools > C Debug > Quit C Debug**.
2. Select **Simulate > End Simulation**. Click **Yes** when prompted to confirm that you wish to quit simulating.



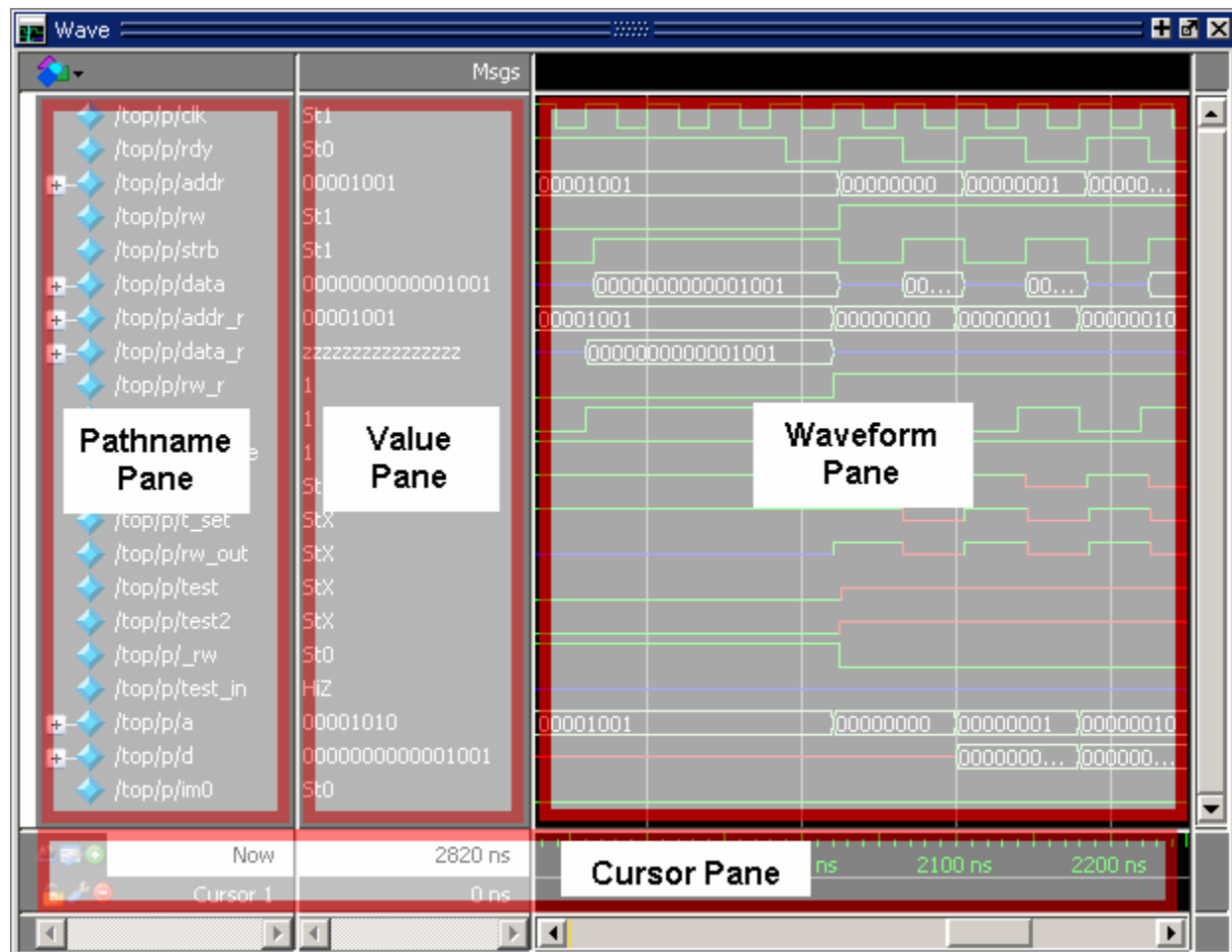
# Chapter 7

## Analyzing Waveforms

### Introduction

The Wave window allows you to view the results of your simulation as HDL waveforms and their values. The Wave window is divided into a number of panes (Figure 7-1). You can resize the pathnames pane, the values pane, and the waveform pane by clicking and dragging the bar between any two panes.

Figure 7-1. Panes of the Wave Window



### Related Reading

User's Manual sections: [Wave Window](#) and [Recording Simulation Results With Datasets](#)

## Loading a Design

For the examples in this lesson, we will use the design simulated in [Basic Simulation](#).

1. If you just finished the previous lesson, ModelSim should already be running. If not, start ModelSim.
  - a. Type **vsim** at a UNIX shell prompt or use the ModelSim icon in Windows.  
If the Welcome to ModelSim dialog appears, click **Close**.

2. Load the design.
  - a. Select **File > Change Directory** and open the directory you created in the “Basic Simulation” lesson.

The *work* library should already exist.

- b. Use the optimized design name to load the design with vsim.

**vsim testcounter\_opt**

ModelSim loads the design and opens a Structure (sim) window.

## Add Objects to the Wave Window

ModelSim offers several methods for adding objects to the Wave window. In this exercise, you will try different methods.

1. Add objects from the Objects window.
  - a. Open an Objects window by selecting **View > Objects**.
  - b. Select an item in the Objects window, right-click, and then select **Add > To Wave > Signals in Region**.

ModelSim opens a Wave window and displays signals in the region.

- c. Place the cursor over an object and click the middle mouse button to place an object in the Wave window.
  - d. Select a group of objects then click the middle mouse button while the cursor is placed over the group.
2. Undock the Wave window.

By default ModelSim opens the Wave window in the right side of the Main window. You can change the default via the Preferences dialog (**Tools > Edit Preferences**). Refer to the [Simulator GUI Preferences](#) section in the User’s Manual for more information.

- a. Click the undock icon on the Wave window.





The Wave window becomes a standalone, un-docked window. Resize the window as needed.

3. Add objects using drag-and-drop.

You can drag an object to the Wave window from many other windows (e.g., Structure, Objects, and Locals).

a. In the Wave window, select **Edit > Select All** and then **Edit > Delete**.

b. Drag an instance from the Structure (sim) window to the Wave window.

ModelSim adds the objects for that instance to the Wave window.

c. Drag a signal from the Objects window to the Wave window.

d. In the Wave window, select **Edit > Select All** and then **Edit > Delete**.

4. Add objects using the [add wave](#) command.

a. Type the following at the VSIM> prompt.

**add wave \***

ModelSim adds all objects from the current region.

b. Run the simulation for 500 ns so you can see waveforms.

## Zooming the Waveform Display

There are numerous methods for zooming the Waveform display.

1. Zoom the display using various techniques.

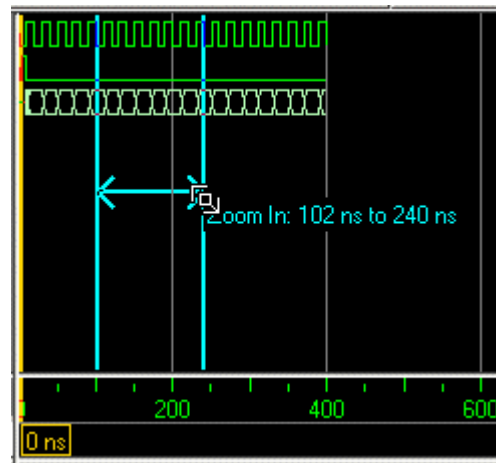
a. Click the Zoom Mode icon on the Wave window toolbar.



b. In the waveform display, click and drag down and to the right.

You should see blue vertical lines and numbers defining an area to zoom in ([Figure 7-2](#)).

Figure 7-2. Zooming in with the Mouse Pointer



- c. Select **View > Zoom > Zoom Last**.

The waveform display restores the previous display range.

- d. Click the Zoom In icon a few times.



- e. In the waveform display, click and drag up and to the right.

You should see a blue line and numbers defining an area to zoom out.

- f. Select **View > Zoom > Zoom Full**.

## Using Cursors in the Wave Window

Cursors mark simulation time in the Wave window. When ModelSim first draws the Wave window, it places one cursor at time zero. Clicking anywhere in the waveform display brings that cursor to the mouse location.

You can also:

- add additional cursors;
- name, lock, and delete cursors;
- use cursors to measure time intervals; and
- use cursors to find transitions.

First, dock the Wave window in the Main window by clicking the dock icon.



## Working with a Single Cursor

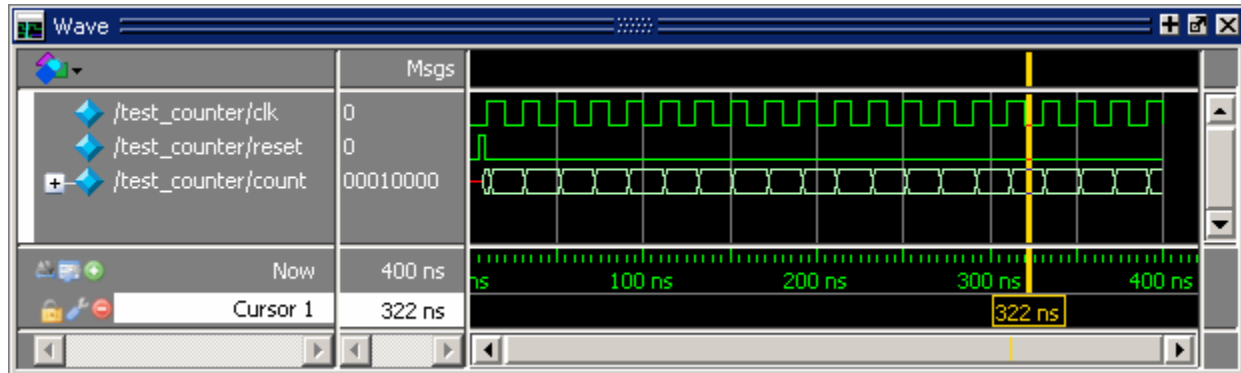
1. Position the cursor by clicking and dragging.

- a. Click the Select Mode icon on the Wave window toolbar.
- b. Click anywhere in the waveform pane.



A cursor is inserted at the time where you clicked ([Figure 7-3](#)).

**Figure 7-3. Working with a Single Cursor in the Wave Window**



- c. Drag the cursor and observe the value pane.

The signal values change as you move the cursor. This is perhaps the easiest way to examine the value of a signal at a particular time.

- d. In the waveform pane, drag the cursor to the right of a transition with the mouse positioned over a waveform.

The cursor "snaps" to the nearest transition to the left. Cursors "snap" to a waveform edge if you click or drag a cursor to within ten pixels of a waveform edge. You can set the snap distance in the Window Preferences dialog (select **Tools > Window Preferences**).

- e. In the cursor pane, drag the cursor to the right of a transition ([Figure 7-3](#)).

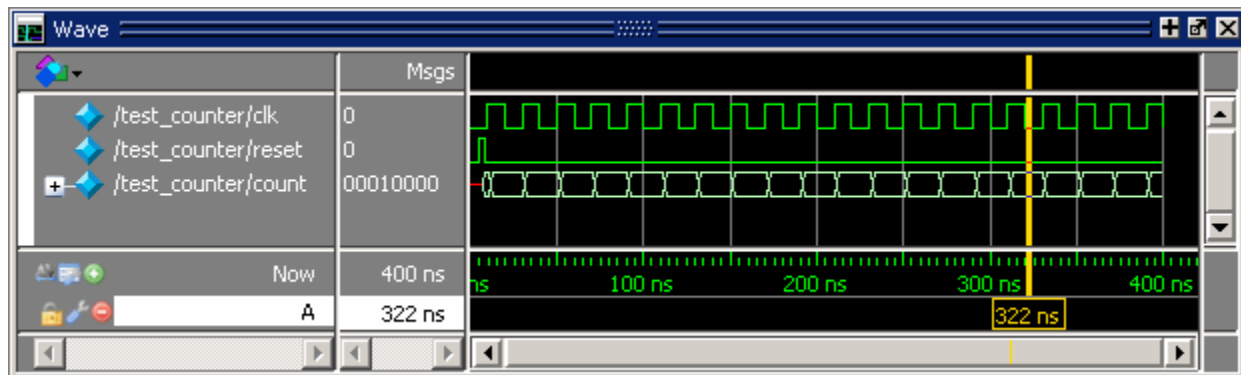
The cursor doesn't snap to a transition if you drag in the cursor pane.

## 2. Rename the cursor.

- a. Right-click "Cursor 1" in the cursor pane, and select and delete the text.
- b. Type **A** and press Enter.

The cursor name changes to "A" ([Figure 7-4](#)).

Figure 7-4. Renaming a Cursor



3. Jump the cursor to the next or previous transition.

a. Click signal *count* in the pathname pane.

b. Click the Find Next Transition icon on the Wave window toolbar.



The cursor jumps to the next transition on the selected signal.

c. Click the Find Previous Transition icon on the Wave window toolbar.



The cursor jumps to the previous transition on the selected signal.

## Working with Multiple Cursors

1. Add a second cursor.

a. Click the Insert Cursor icon on the Wave window toolbar.

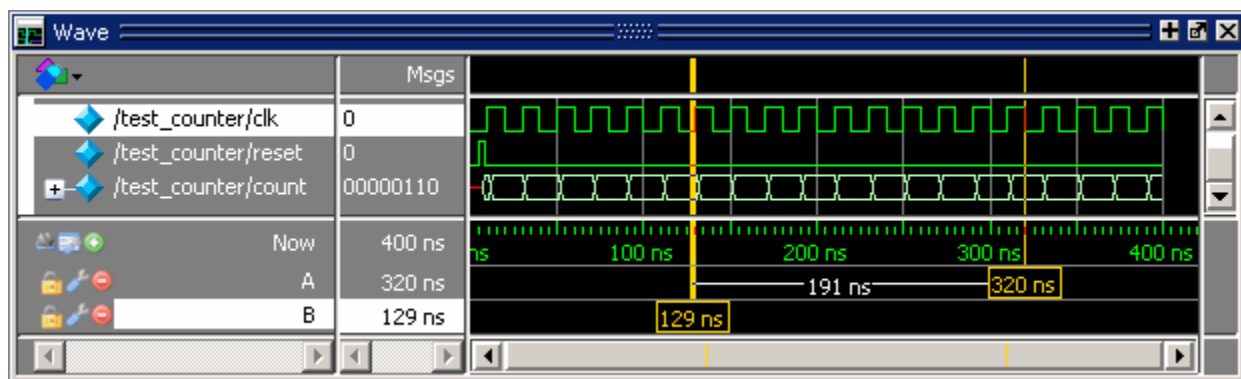


b. Right-click the name of the new cursor and delete the text.

c. Type **B** and press Enter.

d. Drag cursor *B* and watch the interval measurement change dynamically (Figure 7-5).

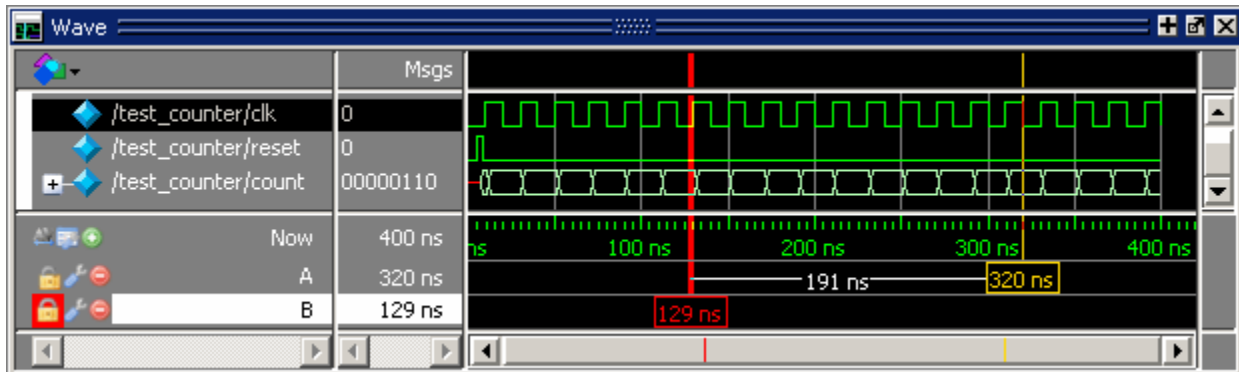
Figure 7-5. Interval Measurement Between Two Cursors



2. Lock cursor *B*.
  - a. Right-click the yellow box associated with cursor *B* (at 56 ns).
  - b. Select **Lock B** from the popup menu.

The cursor color changes to red and you can no longer drag the cursor (Figure 7-6).

**Figure 7-6. A Locked Cursor in the Wave Window**



3. Delete cursor *B*.
  - a. Right-click cursor *B* (the red box at 56 ns) and select **Delete B**.

## Saving and Reusing the Window Format

If you close the Wave window, any configurations you made to the window (e.g., signals added, cursors set, etc.) are discarded. However, you can use the Save Format command to capture the current Wave window display and signal preferences to a *.do* file. You open the *.do* file later to recreate the Wave window as it appeared when the file was created.

Format files are design-specific; use them only with the design you were simulating when they were created.

1. Save a format file.
  - a. In the Wave window, select **File > Save Format**.
  - b. In the Pathname field of the Save Format dialog, leave the file name set to *wave.do* and click **OK**.
  - c. Close the Wave window.
2. Load a format file.
  - a. In the Main window, select **View > Wave**.
  - b. Undock the window.

All signals and cursor(s) that you had set are gone.

- c. In the Wave window, select **File > Load**.
- d. In the Open Format dialog, select *wave.do* and click **Open**.

ModelSim restores the window to its previous state.

- e. Close the Wave window when you are finished by selecting **File > Close Window**.

## Lesson Wrap-Up

This concludes this lesson. Before continuing we need to end the current simulation.

1. Select **Simulate > End Simulation**. Click Yes.

# Chapter 8

## Creating Stimulus With Waveform Editor

---

### Introduction

The Waveform Editor creates stimulus for your design via interactive manipulation of waveforms. You can then run the simulation with these edited waveforms or export them to a stimulus file for later use.

In this lesson you will do the following:

- Create a new directory and copy the *counter* design unit into it.
- Load the *counter* design unit without a test bench.
- Create waves via a wizard.
- Edit waves interactively in the Wave window.
- Export the waves to an HDL test bench and extended VCD file.
- Run the simulation.
- Re-simulate using the exported test bench and VCD file.

### Related Reading

User's Manual Sections: [Generating Stimulus with Waveform Editor](#) and [Wave Window](#).

### Design Files for this Lesson

The sample design for this lesson is a simple 8-bit, binary up-counter that was used in [Basic Simulation](#). The pathnames are as follows:

**Verilog** - `<install_dir>/examples/tutorials/verilog/basicSimulation`

**VHDL** - `<install_dir>/examples/tutorials/vhdl/basicSimulation`

This lesson uses the Verilog version in the examples. If you have a VHDL license, use the VHDL version instead. When necessary, we distinguish between the Verilog and VHDL versions of the design.

## Compile and Load the Design

### Note



You can also use the Waveform Editor prior to loading a design. Refer to the section [Using Waveform Editor Prior to Loading a Design](#) in the User Manual for more information.

---

1. Create a new Directory and copy the tutorial files into it.

Start by creating a new directory for this exercise (in case other users will be working with these lessons). Create the directory and copy the file *counter.v* from *<install\_dir>/examples/tutorials/verilog/basicSimulation* to the new directory.

If you have a VHDL license, copy the file *counter.vhd* from *<install\_dir>/examples/tutorials/vhdl/basicSimulation* to the new directory.

2. Start ModelSim and change to the directory you created for this lesson in step 1.

If you just finished the previous lesson, ModelSim should already be running. If not, start ModelSim.

- a. Type **vsim** at a UNIX shell prompt or use the ModelSim icon in Windows.

If the Welcome to ModelSim dialog appears, click **Close**.

- b. Select **File > Change Directory** and change to the directory you created in step 1.

3. Create the working library and compile the design.

- a. Type **vlib work** at the ModelSim> prompt.

- b. Compile the design file:

#### Verilog:

Type **vlog counter.v** at the ModelSim> prompt.

#### VHDL:

Type **vcom counter.vhd** at the ModelSim> prompt.

4. Load the design unit.

- a. Type **vsim -novopt counter** at the ModelSim> prompt.

5. Open a Wave window.

- a. Select **View > Wave** from the Main window menus.

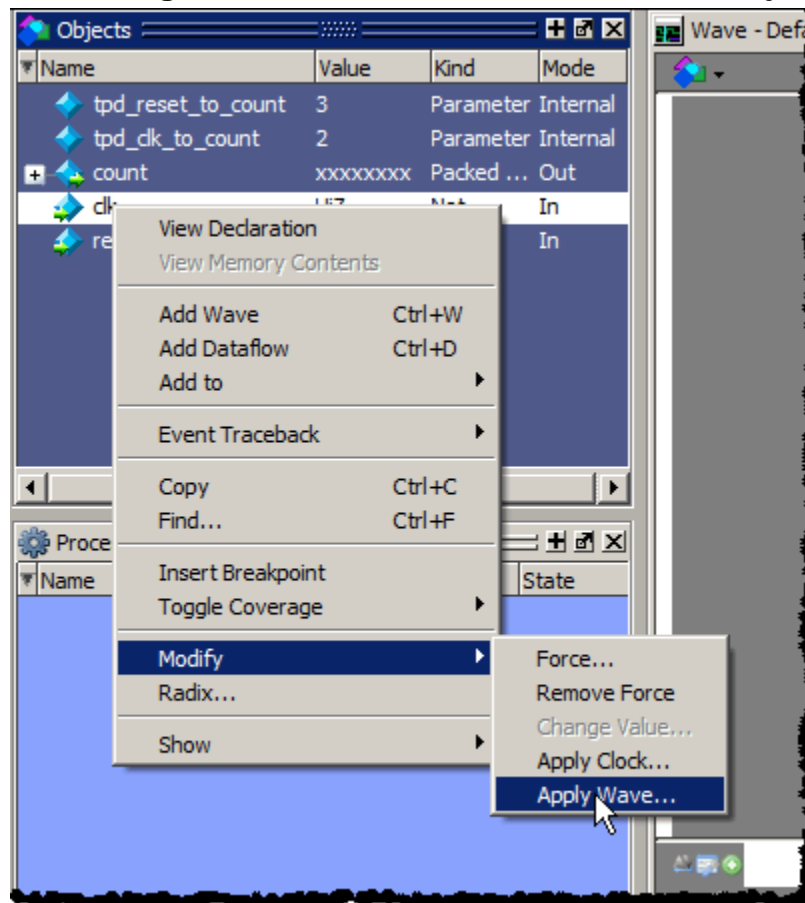


## Create Graphical Stimulus with a Wizard

Waveform Editor includes a Create Pattern Wizard that walks you through the process of creating editable waveforms.

1. Use the Create Pattern Wizard to create a clock pattern.
  - a. In the Objects window, right click the signal *clk* and select **Modify > Apply Wave** (Figure 8-1).

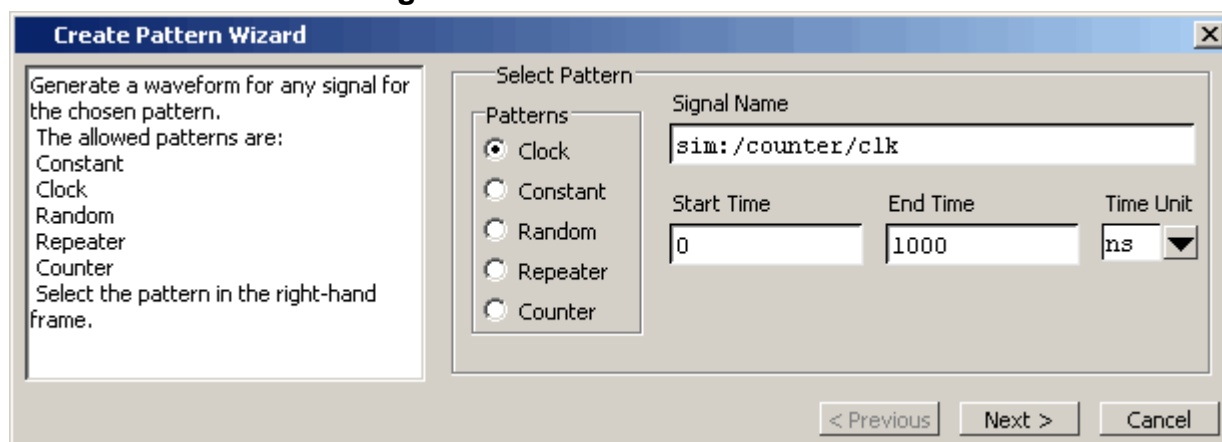
**Figure 8-1. Initiating the Create Pattern Wizard from the Objects Window**



This opens the Create Pattern Wizard dialog where you specify the type of pattern (Clock, Repeater, etc.) and a start and end time.

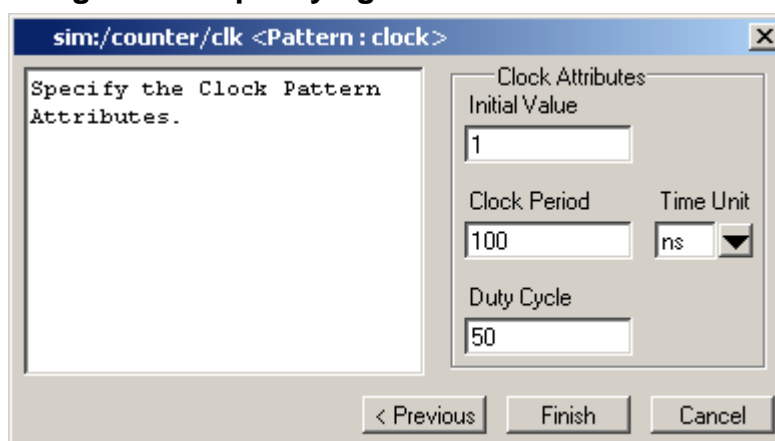
- b. The default pattern is Clock, which is what we need, so click **Next** (Figure 8-2).

Figure 8-2. Create Pattern Wizard



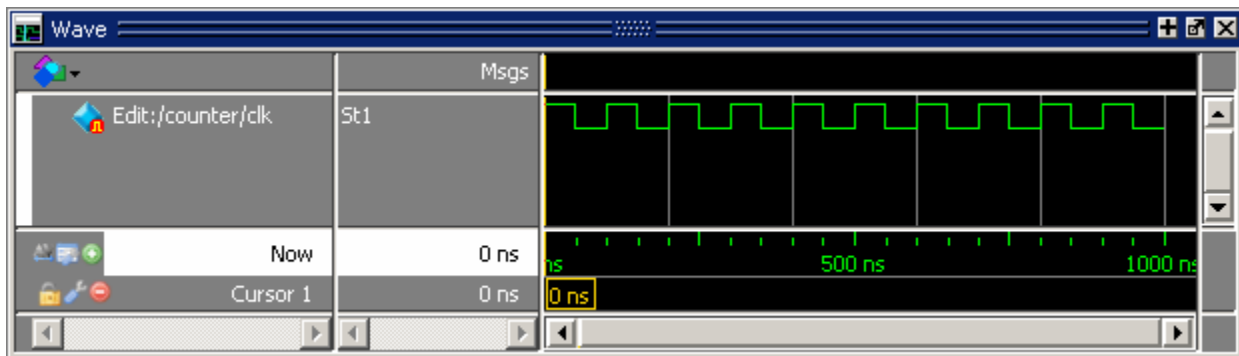
- c. In the second dialog of the wizard, enter **1** for Initial Value. Leave everything else as is and click **Finish** (Figure 8-3).

Figure 8-3. Specifying Clock Pattern Attributes



A generated waveform appears in the Wave window (Figure 8-4). Notice the small red dot on the waveform icon and the prefix "Edit:". These items denote an editable wave. (You may want to undock the Wave window.)

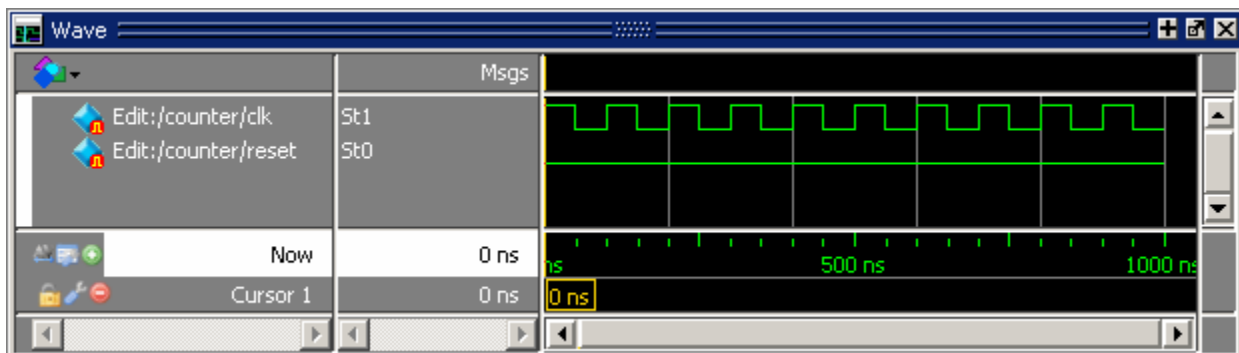
**Figure 8-4. The *clk* Waveform**



2. Create a second wave using the wizard.
  - a. Right-click signal *reset* in the Objects window and select **Modify > Apply Wave** from the popup menu.
  - b. Select **Constant** for the pattern type and click **Next**.
  - c. Enter **0** for the Value and click **Finish**.


A second generated waveform appears in the Wave window (Figure 8-5).


**Figure 8-5. The *reset* Waveform**



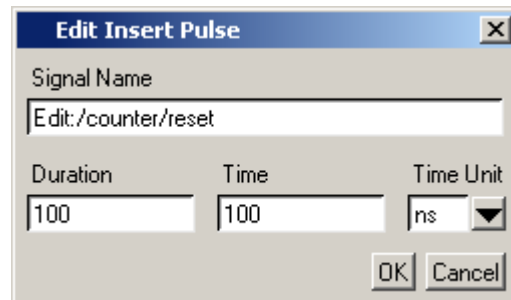
## Edit Waveforms in the Wave Window

Waveform Editor gives you numerous commands for interactively editing waveforms (e.g., invert, mirror, stretch edge, cut, paste, etc.). You can access these commands via the menus, toolbar buttons, or via keyboard and mouse shortcuts. You will try out several commands in this part of the exercise.

1. Insert a pulse on signal *reset*.
  - a. Click the Wave window title bar to make the Wave window active.
  - b. Click the Edit Mode icon in the toolbar. 

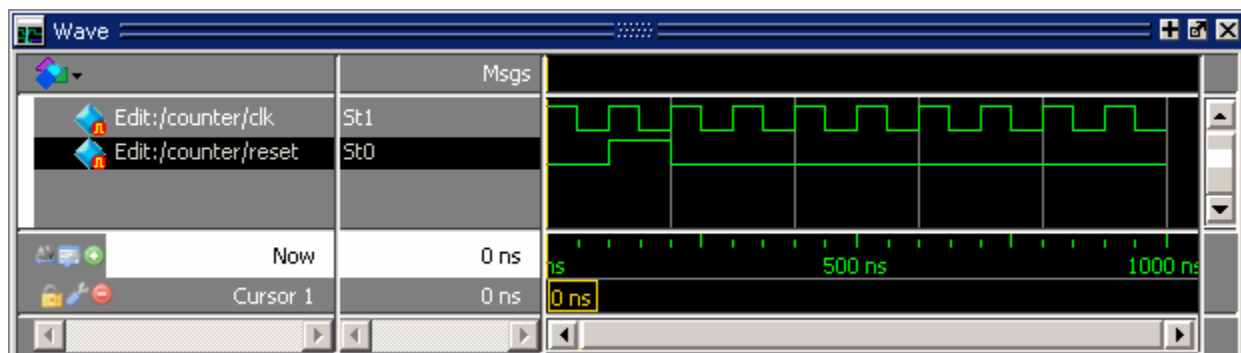
- c. In the Wave window Pathnames column, click the *reset* signal so it is selected.
- d. Click the Insert Pulse icon in the [Wave Edit Toolbar](#). 
- Or, in the Wave window, right-click on the *reset* signal waveform (not the pathname or value) and select **Wave > Wave Editor > Insert Pulse**.
- e. In the Edit Insert Pulse dialog, enter **100** in the Duration field and **100** in the Time field ([Figure 8-6](#)), and click OK.

**Figure 8-6. Edit Insert Pulse Dialog**



Signal *reset* now goes high from 100 ns to 200 ns ([Figure 8-7](#)).

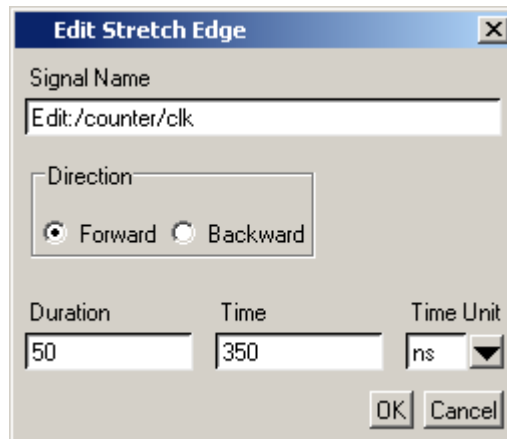
**Figure 8-7. Signal *reset* with an Inserted Pulse**



2. Stretch an edge on signal *clk*.
  - a. Click the signal *clk* waveform just to the right of the transition at 350 ns. The cursor should snap to the transition at 350 ns.
  - b. Right-click that same transition and select **Wave Editor > Stretch Edge** from the popup menu.

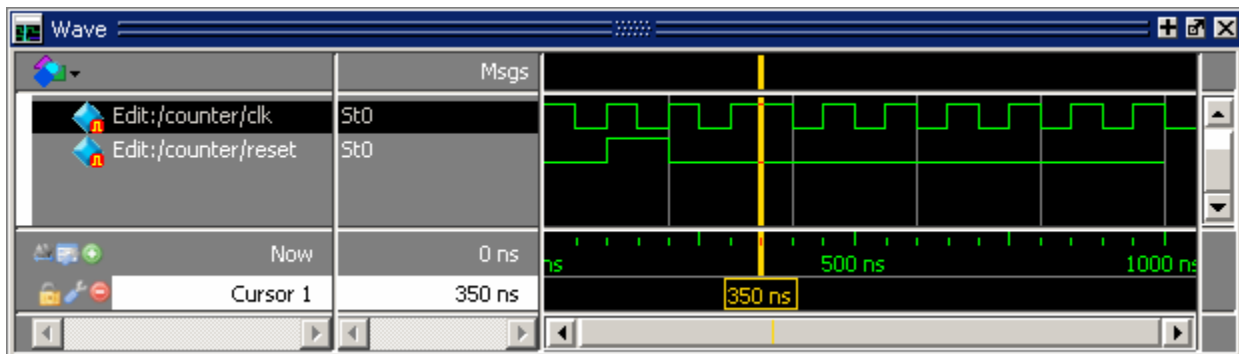
If the command is dimmed out, the cursor probably isn't on the edge at 350 ns.
  - c. In the Edit Stretch Edge dialog, enter 50 for Duration, make sure the Time field shows 350, and then click OK ([Figure 8-8](#)).

**Figure 8-8. Edit Stretch Edge Dialog**



The wave edge stretches so it is high from 300 to 400 ns (Figure 8-9).


**Figure 8-9. Stretching an Edge on the *clk* Signal**



Note the difference between stretching and moving an edge — the Stretch command moves an edge by moving other edges on the waveform (either increasing waveform duration or deleting edges at the beginning of simulation time); the Move command moves an edge but does not move other edges on the waveform. You should see in the Wave window that the waveform for signal *clk* now extends to 1050 ns.

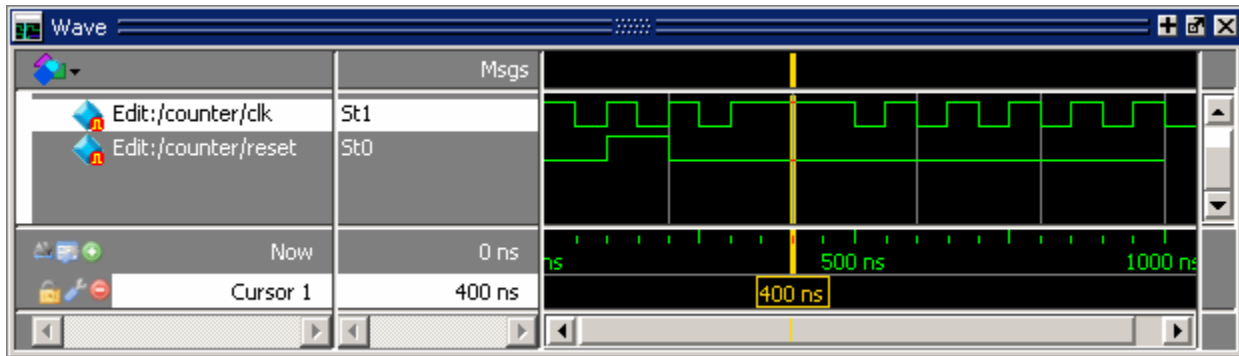
3. Delete an edge.
  - a. Click signal *clk* just to the right of the transition at 400 ns.

The cursor should "snap" to 400 ns.

- b. Click the Delete Edge icon. 

This opens the Edit Delete Edge dialog. The Time is already set to 400 ns. Click **OK**. The edge is deleted and *clk* now stays high until 500 ns (Figure 8-10).

Figure 8-10. Deleting an Edge on the *clk* Signal



4. Undo and redo an edit.

- a. Click the Undo icon.



The Edit Undo dialog opens, allowing you to select the Undo Count - the number of past actions to undo. Click **OK** with the Undo Count set to 1 and the deleted edge at 400 ns reappears in the waveform display.

- b. Reselect the *clk* signal to activate the Redo icon.

- c. Click the Redo icon.



- d. Click **OK** in the Edit Redo dialog.

The edge is deleted again. You can undo and redo any number of editing operations *except* extending all waves and changing drive types. Those two edits cannot be undone.

## Save and Reuse the Wave Commands

You can save the commands that ModelSim used to create the waveforms. You can load this "format" file at a later time to re-create the waves. In this exercise, we will save the commands, quit and reload the simulation, and then open the format file.

1. Save the wave commands to a format file.

- a. Select **File > Close** in the menu bar and you will be prompted to save the wave commands.
- b. Click **Yes**.
- c. Type *wave.do* in the File name field of the Save Commands dialog that opens and then click Save.

This saves a DO file named *waveedit.do* to the current directory and closes the Wave window.

2. Quit and then reload the optimized design.
  - a. In the Main window, select **Simulate > End Simulation**, and click Yes to confirm you want to quit simulating.
  - b. Enter the following command at the ModelSim> prompt.  
**vsim -novopt counter**
3. Open the format file.
  - a. Select **View > Wave** to open the Wave window.
  - b. Select **File > Load** from the menu bar.
  - c. Double-click *wave.do* to open the file.

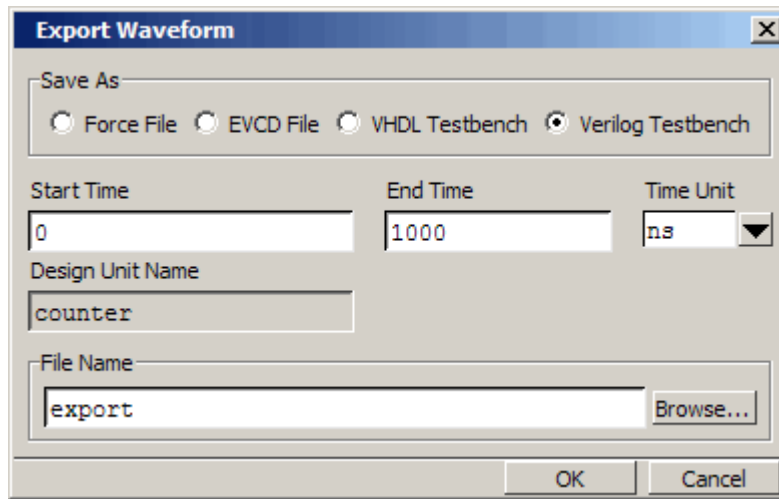
The waves you created earlier in the lesson reappear. If waves do not appear, you probably did not load the *counter* design unit.

## Exporting the Created Waveforms

At this point you can run the simulation or you can export the created waveforms to one of four stimulus file formats. You will run the simulation in a minute but first export the created waveforms so you can use them later in the lesson.

1. Export the created waveforms in an HDL test bench format.
  - a. Select **File > Export > Waveform**.
  - b. Select **Verilog Testbench** (or **VHDL Testbench** if you are using the VHDL sample files).
  - c. Enter **1000** for End Time if necessary.
  - d. Type “export” in the File Name field and click **OK** (Figure 8-11).

**Figure 8-11. The Export Waveform Dialog**



ModelSim creates a file named *export.v* (or *export.vhd*) in the current directory. Later in the lesson we will compile and simulate the file.

2. Export the created waveforms in an extended VCD format.
  - a. Select **File > Export > Waveform**.
  - b. Select **EVCD File**.
  - c. Enter **1000** for End Time if necessary and click OK.

ModelSim creates an extended VCD file named *export.vcd*. We will import this file later in the lesson.

## Run the Simulation

Once you have finished editing the waveforms, you can run the simulation.

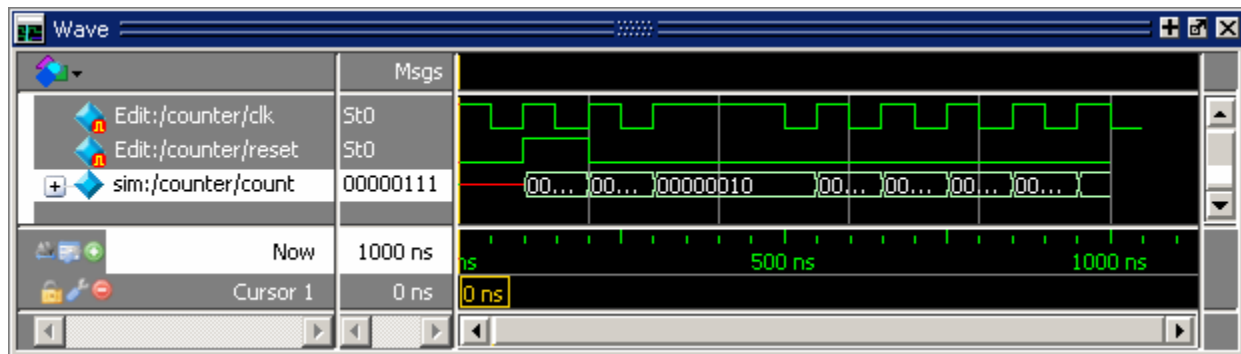
1. Add a design signal.
  - a. In the Objects window, right-click *count* and select **Add Wave**.  
The signal is added to the Wave window.
2. Run the simulation.
  - a. Enter the following command at the ModelSim> prompt.

**run 1000**

The simulation runs for 1000 ns and the waveform is drawn for *sim:/counter/count* (Figure 8-12).



**Figure 8-12. The counter Waveform Reacts to Stimulus Patterns**



Look at the signal transitions for *count* from 300 ns to 500 ns. The transitions occur when *clk* goes high, and you can see that *count* follows the pattern you created when you edited *clk* by stretching and deleting edges.

3. Quit the simulation.
  - a. In the Main window, select **Simulate > End Simulation**, and click Yes to confirm you want to quit simulating. Click **No** if you are asked to save the wave commands.

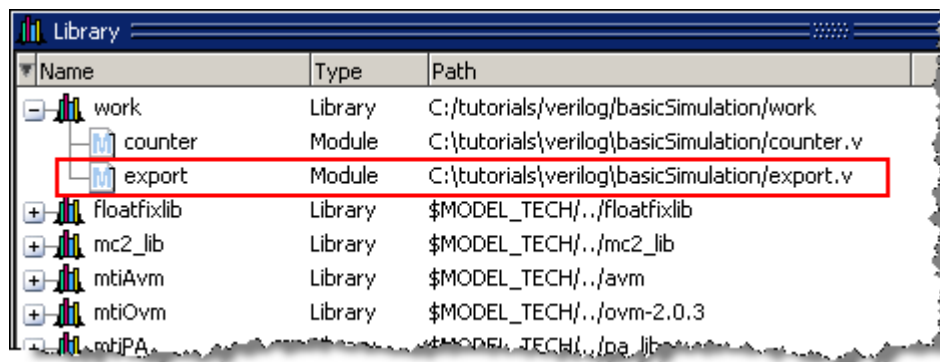
## Simulating with the Test Bench File

Earlier in the lesson you exported the created waveforms to a test bench file. In this exercise you will compile and load the test bench and then run the simulation.

1. Compile and load the test bench.
  - a. At the ModelSim prompt, enter **vlog export.v** (or **vcom export.vhd** if you are working with VHDL files).

You should see a design unit named *export* appear in the work library (Figure 8-13).

**Figure 8-13. The *export* Test Bench Compiled into the work Library**



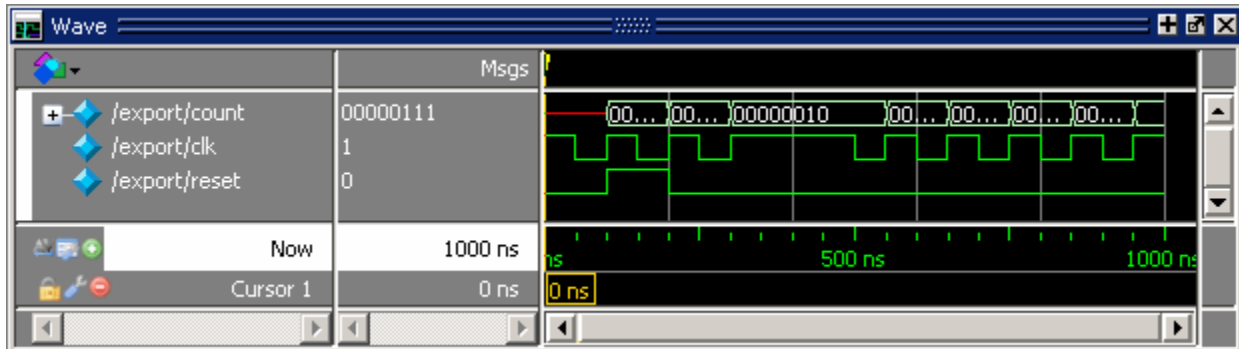
- b. Enter the following command at the ModelSim> prompt.

```
vsim -voptargs="+acc" export
```

2. Add waves and run the design.
  - a. At the VSIM> prompt, type **add wave \***.
  - b. Next type **run 1000**.

The waveforms in the Wave window match those you saw in the last exercise (Figure 8-14).

**Figure 8-14. Waves from Newly Created Test Bench**



3. Quit the simulation.
  - a. At the VSIM> prompt, type **quit -sim**. Click **Yes** to confirm you want to quit simulating.

## Importing an EVCD File

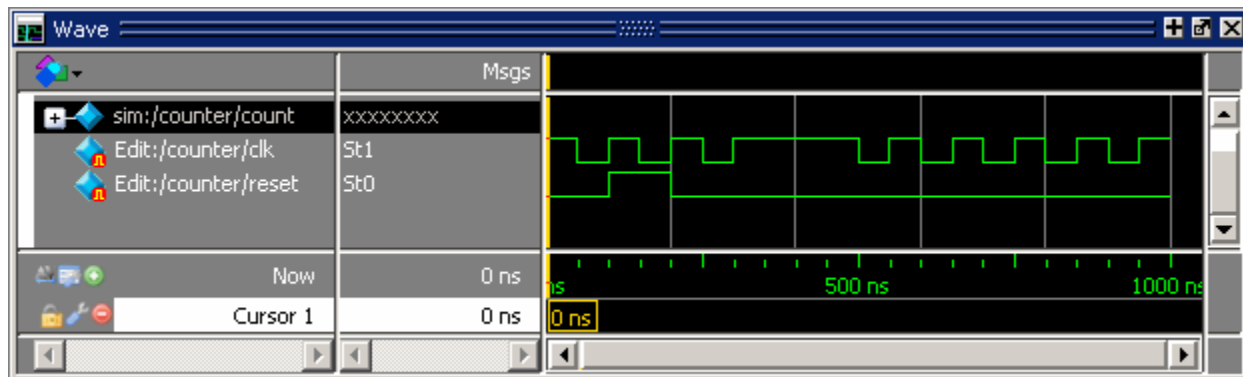
Earlier in the lesson you exported the created waveforms to an extended VCD file. In this exercise you will use that file to stimulate the *counter* design unit.


1. Load the *counter* design unit and add waves.
  - a. Enter the following command at the ModelSim> prompt.

```
vsim -voptargs="+acc" counter
```
  - b. In the Objects window, right-click *count* and select **Add Wave**.
2. Import the VCD file.
  - a. Make sure the Wave window is active, then select **File > Import > EVCD** from the menu bar.
  - b. Double-click *export.vcd*.

The created waveforms draw in the Wave window (Figure 8-15).

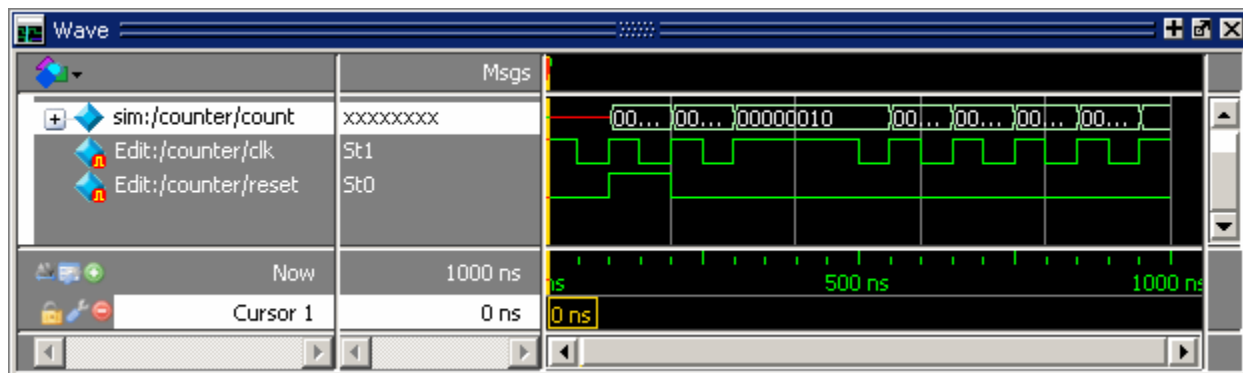
**Figure 8-15. EVCD File Loaded in Wave Window**



- c. Click the Run -All icon. 

The simulation runs for 1000 ns and the waveform is drawn for *sim:/counter/count* (Figure 8-16).

**Figure 8-16. Simulation results with EVCD File**



When you import an EVCD file, signal mapping happens automatically if signal names and widths match. If they do not, you have to manually map the signals. Refer to the section [Signal Mapping and Importing EVCD Files](#) in the User's Manual for more information.

## Lesson Wrap-Up

This concludes this lesson. Before continuing we need to end the current simulation.

1. At the VSIM> prompt, type quit -sim. Click No if you are asked to save the wave commands.



# Chapter 9

## Debugging With The Schematic Window

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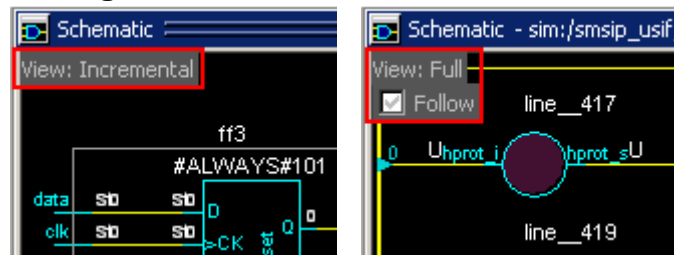
### Introduction

The Schematic window allows you to explore the physical connectivity of your design; to trace events that propagate through the design; and to identify the cause of unexpected outputs. The window displays processes, signals, nets, registers, VHDL architectures, and Verilog modules.

The Schematic window provides two views of the design — a Full View, which is a structural overview of design hierarchy; and an Incremental View, which uses click-and-sprout actions to incrementally add to the selected net's fanout. The Incremental view displays the logical gate equivalent of the RTL portion of the design, making it easier to understand the intent of the design.

A “View” indicator is displayed in the top left corner of the window (Figure 9-1). You can toggle back and forth between views by simply clicking this “View” indicator.

**Figure 9-1. Schematic View Indicator**



The Incremental View is ideal for design debugging. It allows you to explore design connectivity by tracing signal readers/drivers to determine where and why signals change values at various times.

#### Note



The Schematic window will not function without an extended dataflow license. If you attempt to create the debug database (vsim -debugdb) without this license the following error message will appear: “Error: (vsim-3304) You are not authorized to use -debugdb, no extended dataflow license exists.”

### Design Files for this Lesson

The sample design for this lesson is a test bench that verifies a cache module and how it works with primary memory. A processor design unit provides read and write requests.

The pathnames to the files are as follows:

**Verilog** – *<install\_dir>/examples/tutorials/verilog/schematic*

**VHDL** – *<install\_dir>/examples/tutorials/vhdl/schematic*

This lesson uses the Verilog version in the examples. If you have a VHDL license, use the VHDL version instead. When necessary, we distinguish between the Verilog and VHDL versions of the design.

## Related Reading

User's Manual section: [Schematic Window](#).

## Compile and Load the Design

In this exercise you will use a DO file to compile and load the design.

1. Create a new directory and copy the tutorial files into it.

Start by creating a new directory for this exercise (in case other users will be working with these lessons). Create the directory and copy all files from *<install\_dir>/examples/tutorials/verilog/schematic* to the new directory.

If you have a VHDL license, copy the files in *<install\_dir>/examples/tutorials/vhdl/schematic* instead.

2. Start ModelSim and change to the exercise directory.

If you just finished the previous lesson, ModelSim should already be running. If not, start ModelSim.

- a. Type **vsim** at a UNIX shell prompt or use the ModelSim icon in Windows.

If the Welcome to ModelSim dialog appears, click **Close**.

- b. Select **File > Change Directory** and change to the directory you created in step 1.

3. Change your WildcardFilter settings.

Execute the following command:

```
set WildcardFilter "Variable Constant Generic Parameter SpecParam Memory  
Assertion Endpoint ImmediateAssert"
```

With this command, you remove “CellInternal” from the default list of Wildcard filters. This allows all signals in cells to be logged by the simulator so they will be visible in the debug environment.

4. Execute the lesson DO file.

- a. Type **do run.do** at the ModelSim> prompt.

The DO file does the following:

- Creates the working library — `vlib work`
- Compiles the design files — `vlog` or `vcom`
- Optimizes the design — `vopt +acc top -o top_opt`
- Collects combinatorial and sequential logic data — `vdbg top_opt`
- Loads the design into the simulator — `vsim -debugdb top_opt`
- Adds signals to the Wave window — `add wave /top/p/*`
- Logs all signals in the design — `log -r /*`
- Runs the simulation — `run -all`

## Exploring Connectivity

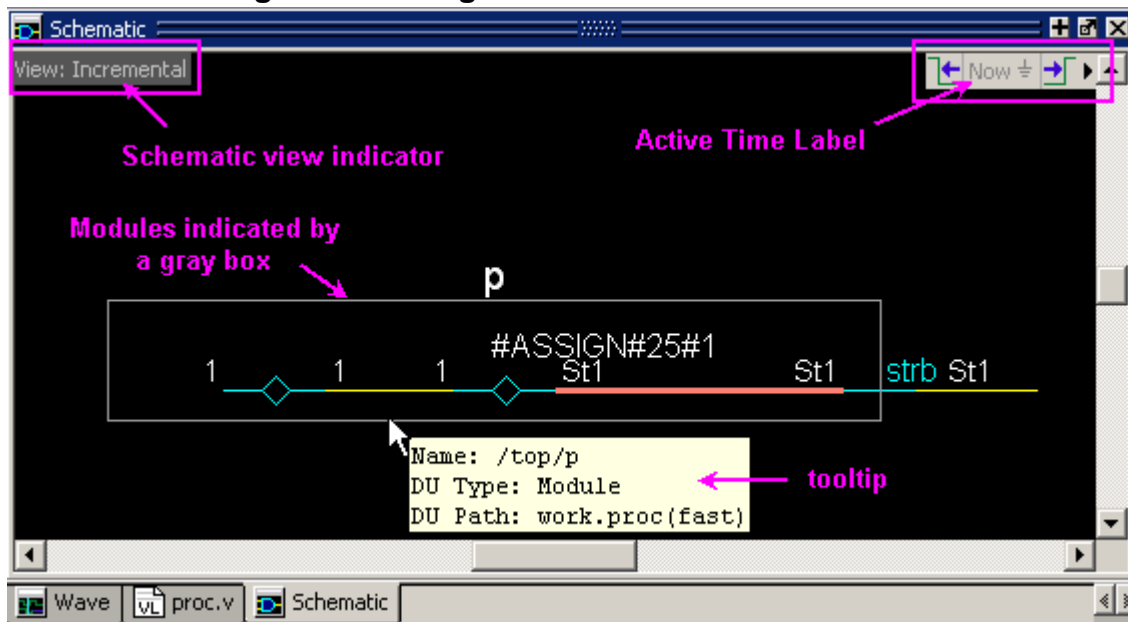
A primary use of the incremental view of the Schematic window is exploring the physical connectivity of your design. You do this by expanding the view from process to process, to display the drivers/receivers of a particular signal, net, register, process, module or architecture.

1. Open the Schematic window.
  - a. Select **View > Schematic** from the menus or use the `view` schematic command at the VSIM prompt in the Transcript window.

The Schematic window opens to the Incremental view.

2. Add a signal to the Schematic window.
  - a. Make sure instance *p* is selected in the Structure (sim) window.
  - b. Drag the *strb* signal from the Objects window to the Schematic window (Figure 9-2).

Figure 9-2. A Signal in the schematic Window



The Incremental view shows the *strb* signal, highlighted in orange. You can display a tooltip - a text information box - as shown in Figure 9-2, by hovering the mouse cursor over any design object in the schematic. In this case, the tooltip shows that the process driving the *strb* signal is #ASSIGN#25#1.

The schematic also shows that the process is a part of module *p*, denoted by the light gray box.

Signal values are displayed at the ends of each signal net. You can toggle signals values on and off with the 'v' key on your keyboard when the Schematic window is active.

3. Find the readers of the *strb* signal.

When you mouse-over any signal pin the mouse cursor will change to a right-pointing arrow, a left-pointing arrow, or a double-headed arrow. If the arrow points to the right, you can double-click the pin to expand the signal fanout to its readers. If the arrow points left, you can double-click to expand the signal fanout to its drivers. Double-clicking a double-headed arrow will expand to drivers and readers.

- a. Place the cursor over the *strb* signal as shown in Figure 9-3, so you see a right pointing arrow indicating readers, and double click.

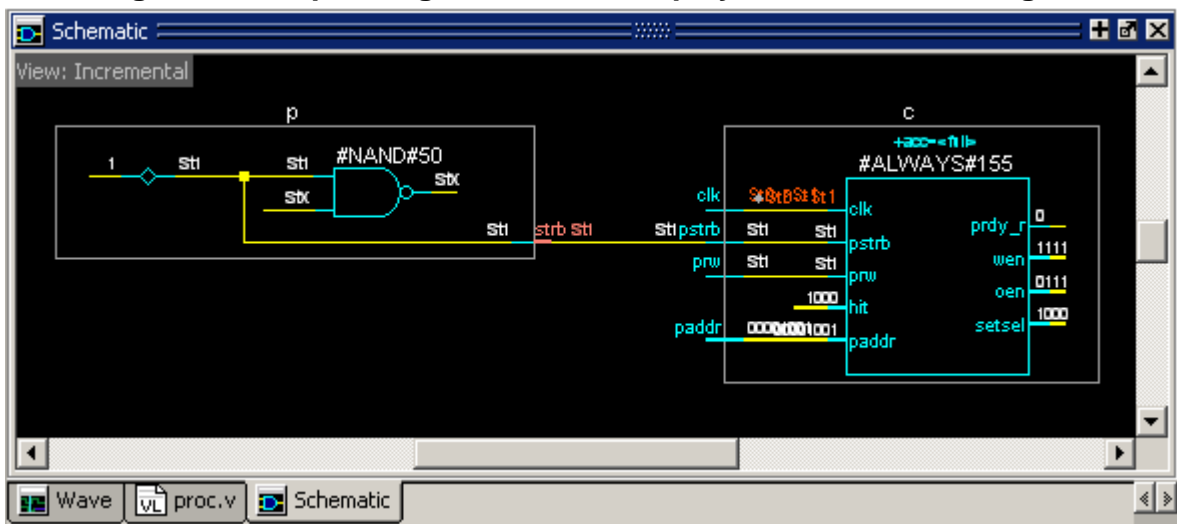


Figure 9-3. Right Pointing Arrow Indicates Readers



This sprouts all readers of *strb* (Figure 9-4).

Figure 9-4. Expanding the View to Display Readers of *strb* Signal



In Figure 9-4, the signal values for the *clk* signal in the *c* module cannot be easily distinguished because the values at each end of the net overlap.

Figure 9-5. Signal Values Overlapped




- b. Click the Regenerate button  to redraw the Schematic with all design elements, signal values, and pin names clearly displayed (Figure 9-6).

Figure 9-6. Signal Values After Regenerate

			#ALWA
clk	St0->St1	St0->St1	clk
St1 pstrb	St1	St1	pstrb
prw	St1	St1	prw

In Figure 9-6, notice the gray dot next to the state of the input *clk* signal for the #ALWAYS#155 process (labeled *line\_84* in the VHDL version). The gray dot indicates an input in the sensitivity list for the process. A change in any input with a gray dot triggers process execution. Inputs without gray dots are read by the process but will not trigger process execution, and are not in the sensitivity list (will not change the output by themselves).

#### Note



Gray dots are only shown on the signals in the sensitivity list of a process that did not synthesize down to gate components. Gates will not have the gray dots because the behavior of their inputs is clearly defined.


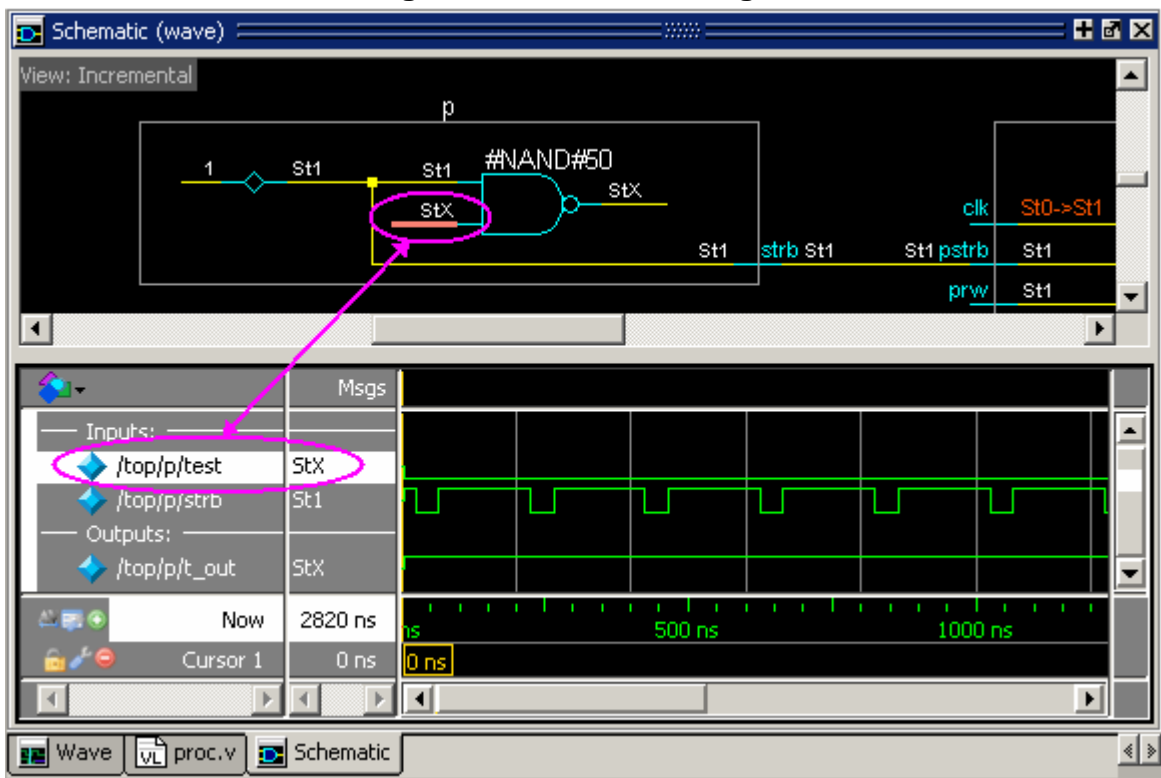
4. Find the drivers of the signal *test* on process #NAND#50 (labeled *line\_71* in the VHDL version).
  - a. Click the **Show Wave** button  to open the Schematic Window's embedded Wave Viewer. You may need to increase the size of the schematic window to see everything
  - b. Select the #NAND#50 gate (labeled *line\_71* in the VHDL version) in the schematic. This loads the wave signals for the inputs and outputs for this gate into the Wave Viewer and highlights the gate.
  - c. Select the signal *test* in the Wave Viewer. This highlights the *test* input in the schematic (Figure 9-7).

Figure 9-7. Select *test* signal

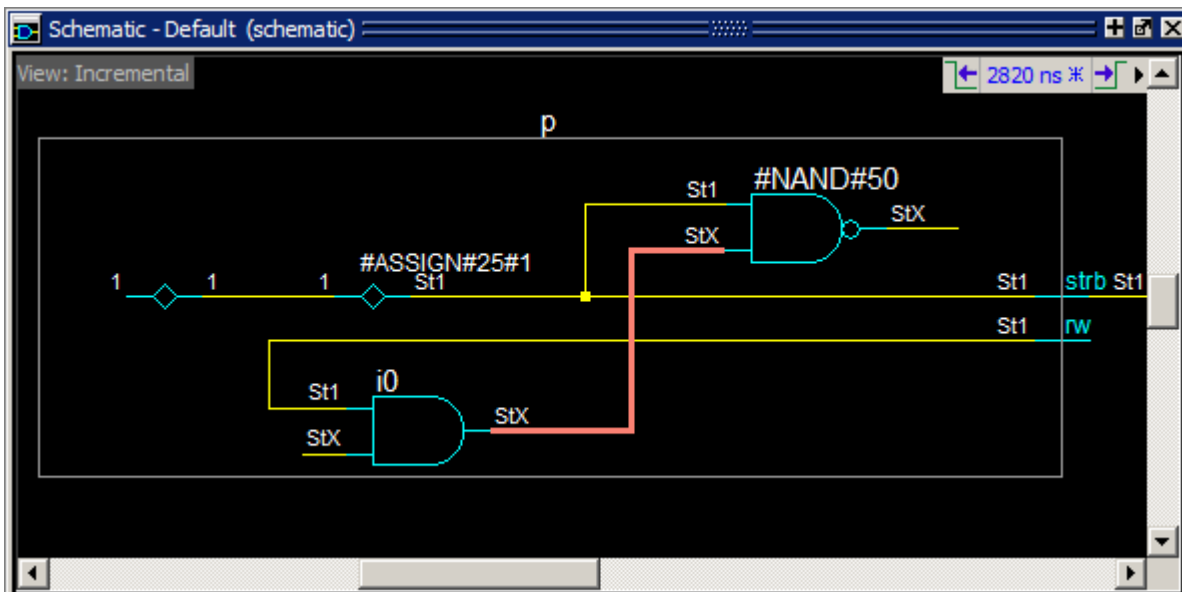


Notice that the title of the Schematic window is “Schematic (wave)” when the embedded Wave Viewer is active and “Schematic (schematic)” when the Incremental View is active. In the next step we have to select a pin in the schematic to make the Incremental View and associated toolbar buttons active.

- d. Select the pin for the highlighted signal – *test* – in the schematic. This makes the schematic view active.
- e. Click the **Expand net to all drivers** icon. This expands the test signal to its driving process - an *i0* NAND gate – which is included in the *p* module (Figure 9-8).

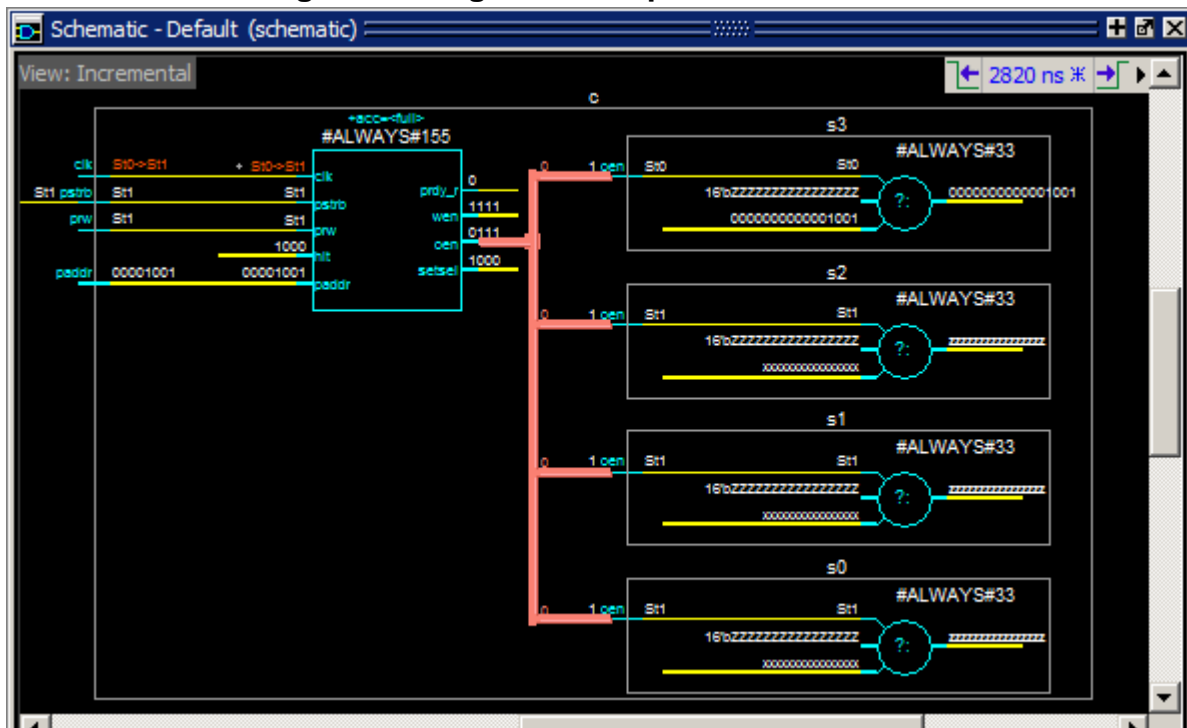


**Figure 9-8. The test Net Expanded to Show All Drivers**



5. Open the readers for signal *oen* on process *#ALWAYS#155* (labeled *line\_84* in the VHDL version).
  - a. Click the *oen* pin to make it active.
  - b. Right-click anywhere in the schematic to open the popup menu and select **Expand Net To > Readers**. Figure [Figure 9-9](#) shows the results.

**Figure 9-9. Signal *oen* Expanded to Readers**



Continue exploring the design with any of the methods discussed above – double-click signal pins, use the toolbar buttons, or use menu selections from the right-click popup menu.

When you are finished, click the **Delete All** button to clear the schematic viewer.



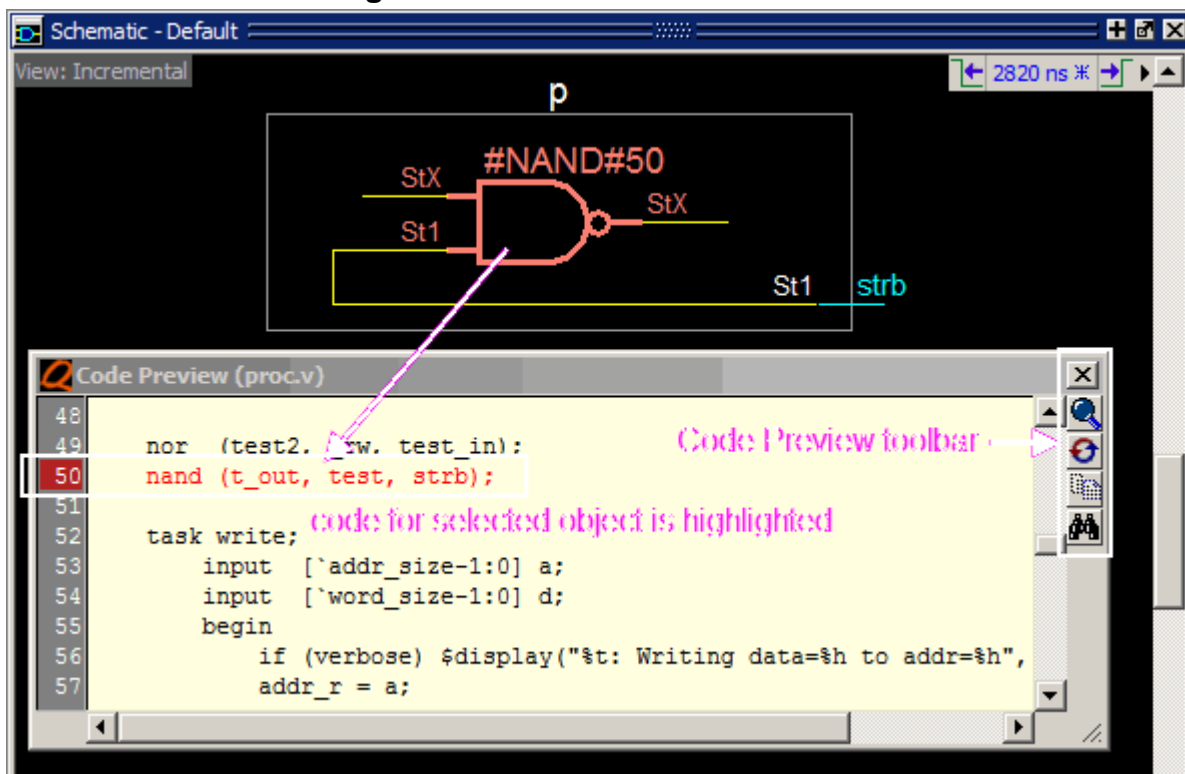
Click the **Show Wave** button  to close the embedded Wave Viewer.

## Viewing Source Code from the Schematic

The Schematic window allows you to display a source code preview of any design object.

1. Add a signal to the Schematic window.
  - a. Make sure instance *p* is selected in the Structure (sim) window.
  - b. Drag signal *t\_out* from the Objects window to the Schematic window.
  - c. Double-click the NAND gate - #NAND#50 - to display a Code Preview window (Figure 9-10). The source code for the selected object is highlighted and centered in the display.

**Figure 9-10. Code Preview Window**



The Code Preview window provides a four-button toolbar that allows you to take the following actions:

- view the source code in a Source Editor
  - recenter the selected code in the Code Preview window if you have scrolled it out of the display
  - copy selected code so it can be pasted elsewhere
  - open the Find toolbar at the bottom of the Code Preview window so you can search for specific code
- d. Experiment with the Code Preview toolbar buttons to see how they work.

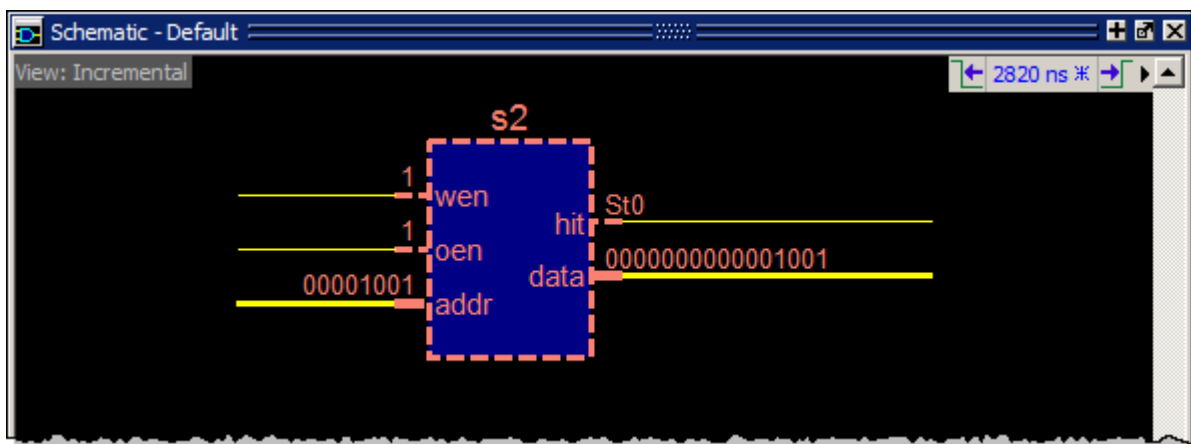
When you are finished, close the Code Preview window and click the **Delete All** button to clear the schematic viewer.

## Unfolding and Folding Instances

Contents of complex instances are folded (hidden) in the Incremental view to maximize screen space and improve the readability of the schematic.

1. Display a folded instance in the Incremental view of the schematic.
  - a. Expand the hierarchy of the *c* module in the Structure window.
  - b. Drag the *s2* module instance (in the *c* module) from the Structure window to the Schematic.

**Figure 9-11. Folded Instance**

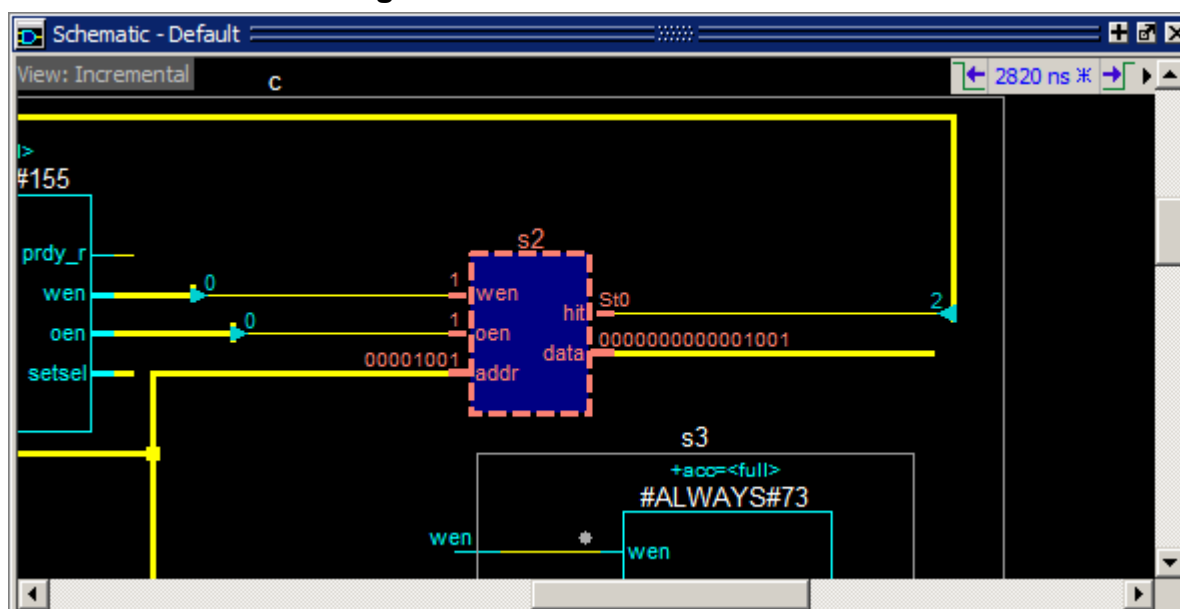


The folded instance is indicated by a dark blue square with dashed borders (Figure 9-11). When you hover the mouse cursor over a folded instance, the tooltip (text box popup) will show that it is **\*\*FOLDED\*\***.

2. Unfold the folded instance.
  - a. Right-click inside the folded instance to open a popup menu.



Figure 9-14. Instance s2 Refolded

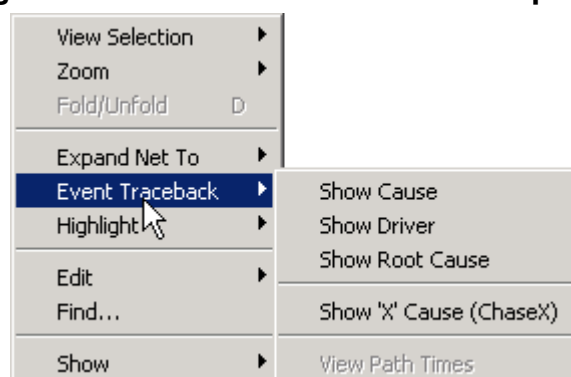


Experiment with other folded instances (s0, s1, s3). When you are finished, click the **Delete All** button to clear the schematic.

## Tracing Events

The Schematic window gives you the ability to trace events to their cause. Event traceback options are available when you right-click anywhere in the Incremental View and select Event Traceback from the popup menu (Figure 9-15).

Figure 9-15. Event Traceback Menu Options



The event trace begins at the current “active time,” which is set:

- by the selected cursor in the Wave window
- by the selected cursor in the Schematic window’s embedded Wave viewer

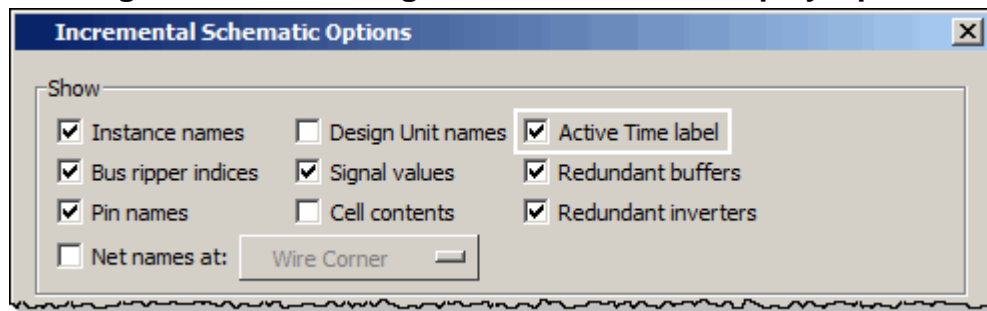


- or with the Active Time label in the Schematic window.

We will use the active time set by the cursor in the embedded Wave viewer. The Active Time label is on by default, the following instructions allow you to turn it off or on in the Incremental View;

1. With the Incremental view active, select **Schematic > Preferences** to open the Incremental Schematic Options dialog.
2. In the Show section of the dialog, click the **Active Time label** box so a checkmark appears, then click the OK button to close the dialog.

**Figure 9-16. Selecting Active Time Label Display Option**



The Active Time label appears in the upper right corner of Incremental view.

**Figure 9-17. Active Time Label in the Incremental View**

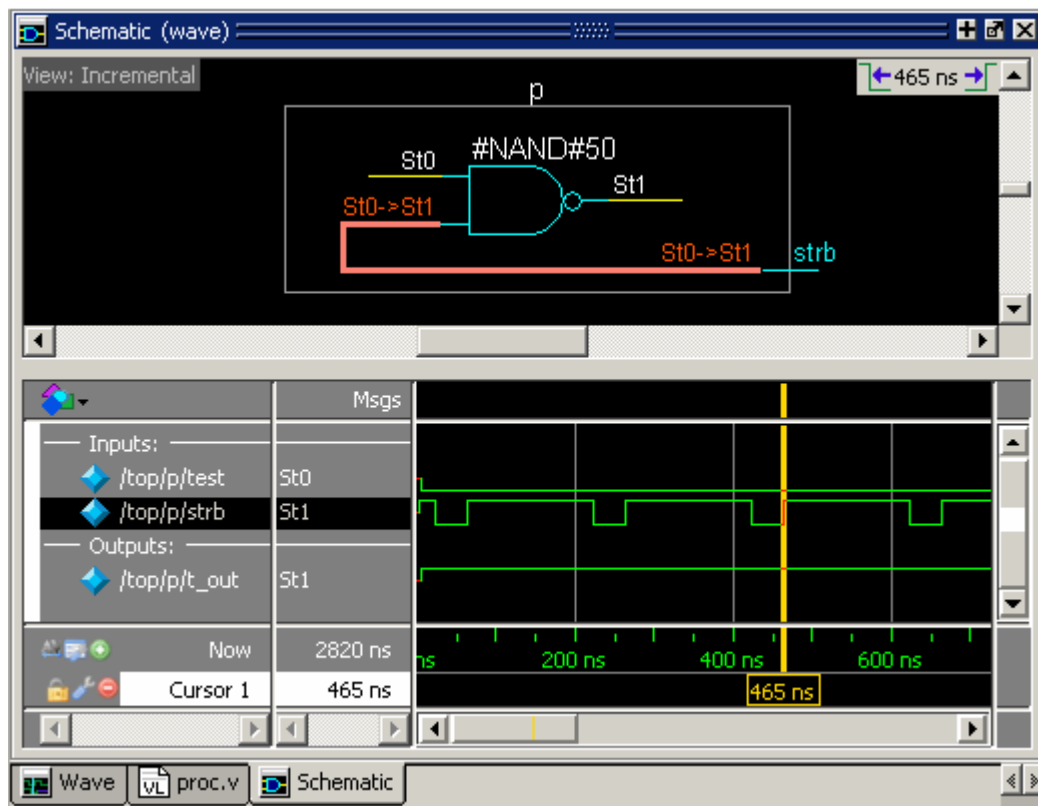


Now we'll trace and event.

1. Add an object to the schematic window.
  - a. Make sure instance *p* is selected in the Structure (sim) window.
  - b. Drag signal *t\_out* from the Objects window to the schematic window.
2. Open the Schematic window's Wave viewer.
  - a. Click the Show Wave button in the toolbar.
3. Show signals for a process in the Schematic window's Wave viewer.
  - a. Select the `#NAND#50` gate (labeled *line\_71* in the VHDL version) in the schematic. This loads the wave signals for the inputs and outputs for this gate into the Wave viewer.

4. Place a cursor in the Wave viewer to designate the Active Time.
  - a. Click the *strb* waveform in the Wave viewer on (or near) the transition at 465 ns. This will highlight the *strb* signal pathname in the Wave viewer and the *strb* signal net in the schematic (Figure 9-18).

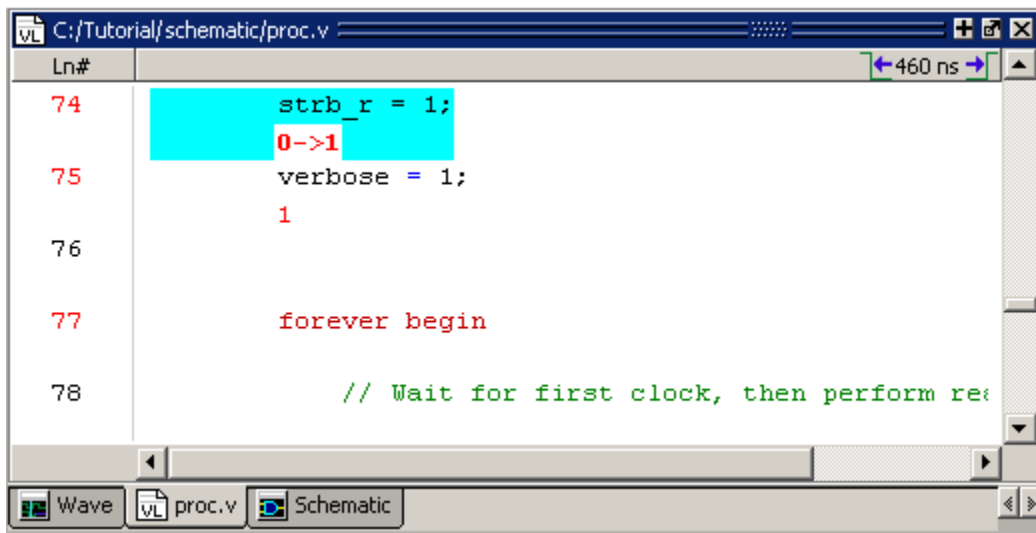
**Figure 9-18. The Embedded Wave Viewer**



Notice that the Active Time label in the upper right corner of the schematic displays the time of the selected cursor - 465 ns.

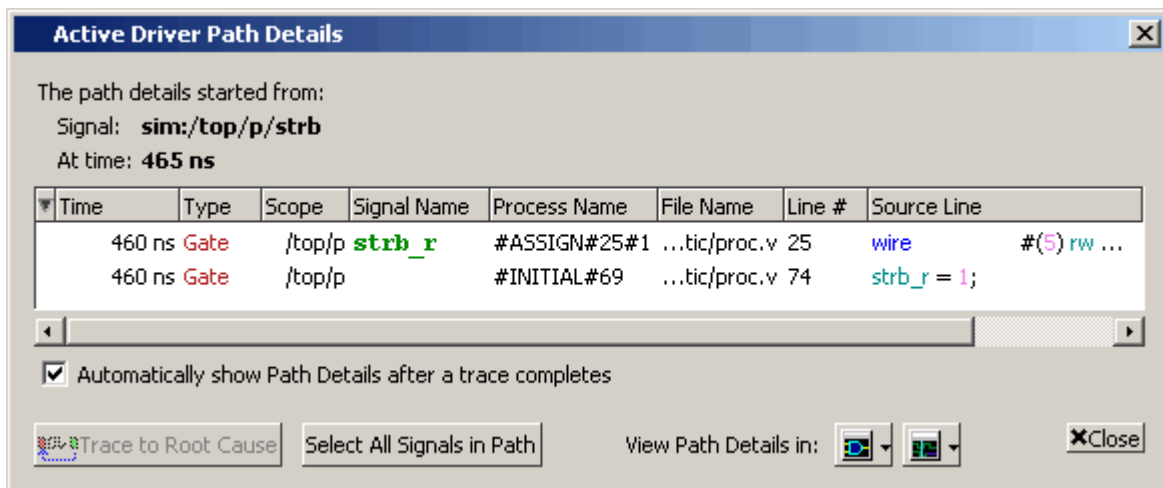
5. Trace to the cause of the event.
  - a. Right-click the highlighted signal in the schematic to open the popup menu.
  - b. Select **Event Traceback > Show Cause**. This will open a Source window where the immediate driving process will be highlighted (Figure 9-19).

**Figure 9-19. Immediate Driving Process in the Source Window**



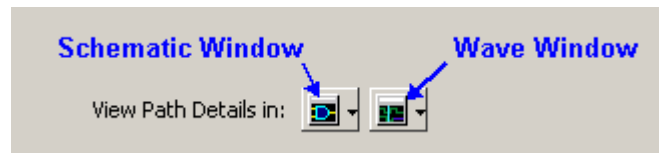
It will also open the Active Driver Path Details window (Figure 9-20). This window displays information about the sequential process(es) that caused the selected event. It shows the selected signal name, the time of each process in the causality path to the first sequential process, and details about the location of the causal process in the code.

**Figure 9-20. Active Driver Path Details Window**



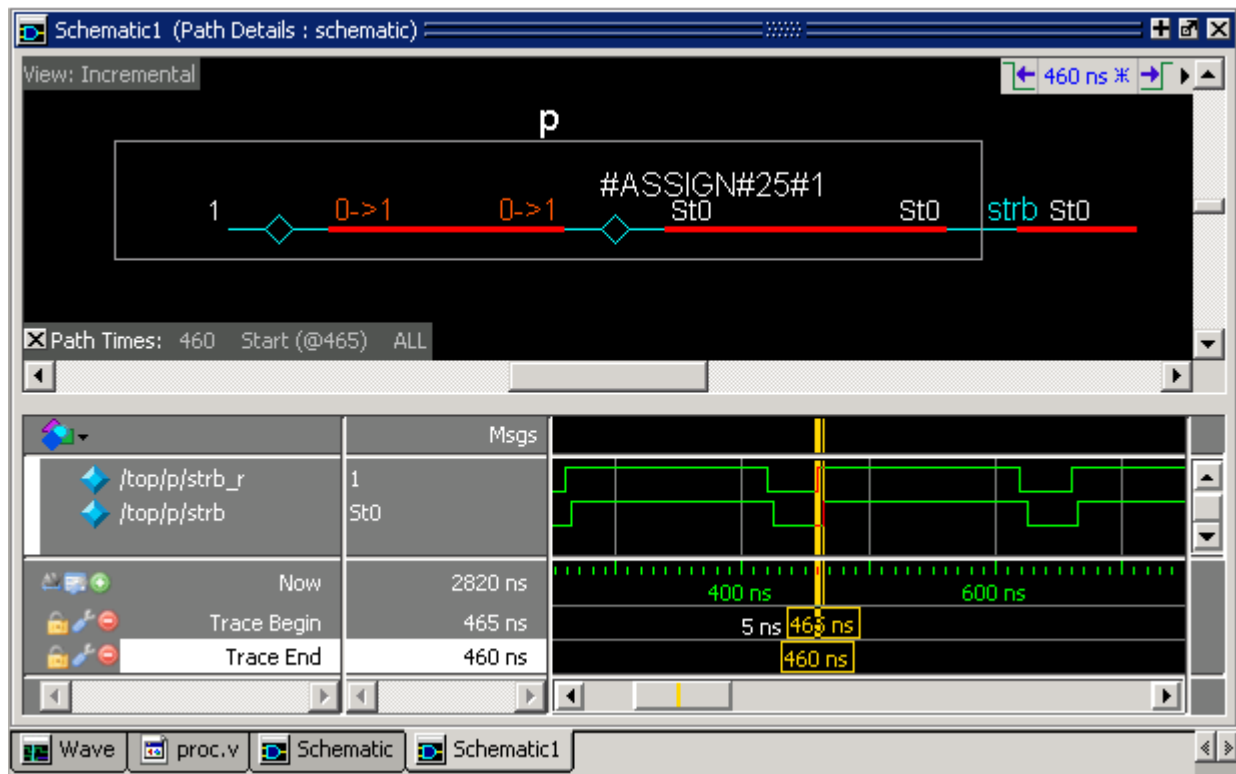
6. View path details for *strb\_r* from the #ASSIGN#25#1 process in the Schematic window.
  - a. Click the top line in the Active Driver Path Details window to select the *strb\_r* signal driver.
  - b. Click the **Schematic Window** button in the View Path Details section of the Active Driver Path Details dialog (Figure 9-21).

**Figure 9-21. Schematic Window Button**



This will open a dedicated Schematic (Path Details) window that displays the path details for the selected driver of the signal (Figure 9-22).

**Figure 9-22. Schematic Path Details Window**



The Wave viewer section of the dedicated Schematic (Path Details) window displays a Trace Begin and a Trace End cursor.

Experiment with tracing other events and viewing path details in the dedicated Schematic and Wave windows.

7. Clear the Schematic window before continuing.
  - a. Close the Active Driver Path Details window.
  - b. Close the Schematic (Path Details) window.
  - c. Select the original Schematic window by clicking the Schematic tab.
  - d. Click the **Delete All** icon to clear the Schematic Viewer.
  - e. Click the **Show Wave** icon to close the Wave view of the schematic window.

## Lesson Wrap-Up

This concludes this lesson. Before continuing we need to end the current simulation.

1. Type **quit -sim** at the VSIM> prompt.

To return the wildcard filter to its factory default settings, enter:

**set WildcardFilter "default"**



# Chapter 10

## Debugging With The Dataflow Window

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### Introduction

The Dataflow window allows you to explore the "physical" connectivity of your design; to trace events that propagate through the design; and to identify the cause of unexpected outputs. The window displays processes; signals, nets, and registers; and interconnect.

---

#### Note



The functionality described in this lesson requires a dataflow license feature in your ModelSim license file. Please contact your Mentor Graphics sales representative if you currently do not have such a feature.

---

### Design Files for this Lesson

The sample design for this lesson is a test bench that verifies a cache module and how it works with primary memory. A processor design unit provides read and write requests.

The pathnames to the files are as follows:

**Verilog** – *<install\_dir>/examples/tutorials/verilog/dataflow*

**VHDL** – *<install\_dir>/examples/tutorials/vhdl/dataflow*

This lesson uses the Verilog version in the examples. If you have a VHDL license, use the VHDL version instead. When necessary, we distinguish between the Verilog and VHDL versions of the design.

### Related Reading

User's Manual Sections: [Debugging with the Dataflow Window](#) and [Dataflow Window](#).

### Compile and Load the Design

In this exercise you will use a DO file to compile and load the design.

1. Create a new directory and copy the tutorial files into it.

Start by creating a new directory for this exercise (in case other users will be working with these lessons). Create the directory and copy all files from *<install\_dir>/examples/tutorials/verilog/dataflow* to the new directory.

If you have a VHDL license, copy the files in  
<install\_dir>/examples/tutorials/vhdl/dataflow instead.

2. Start ModelSim and change to the exercise directory.

If you just finished the previous lesson, ModelSim should already be running. If not, start ModelSim.

- a. Type **vsim** at a UNIX shell prompt or use the ModelSim icon in Windows.

If the Welcome to ModelSim dialog appears, click **Close**.

- b. Select **File > Change Directory** and change to the directory you created in step 1.

3. Change your WildcardFilter settings.

Execute the following command:

```
set WildcardFilter "Variable Constant Generic Parameter SpecParam Memory  
Assertion Endpoint ImmediateAssert"
```

With this command, you remove “CellInternal” from the default list of Wildcard filters. This allows all signals in cells to be logged by the simulator so they will be visible in the debug environment.

4. Execute the lesson DO file.
  - a. Type **do run.do** at the ModelSim> prompt.

The DO file does the following:

- Creates the working library
- Compiles the design files
- Optimizes the design
- Loads the design into the simulator
- Adds signals to the Wave window
- Logs all signals in the design
- Runs the simulation

## Exploring Connectivity

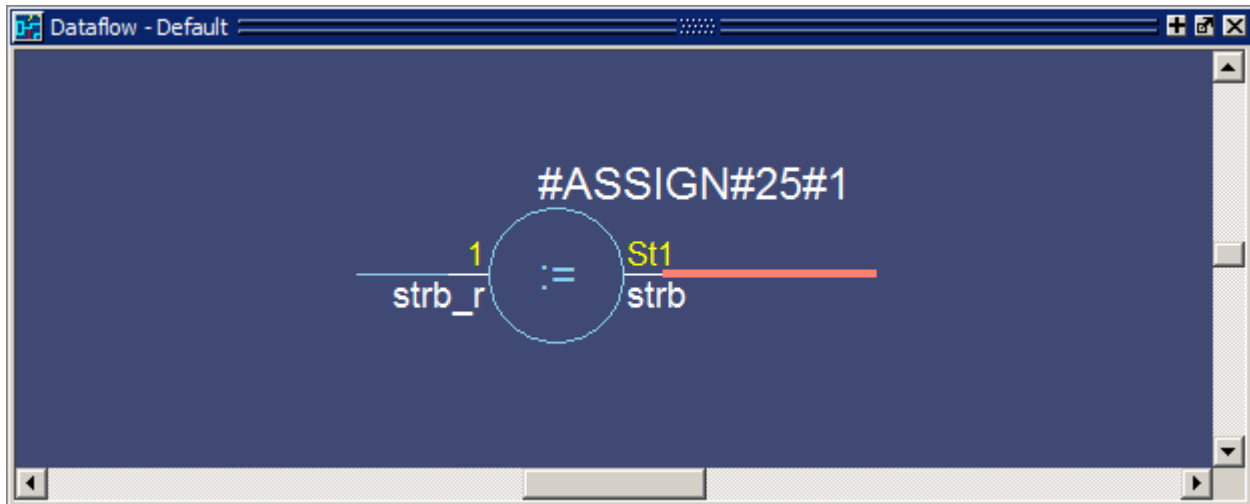
A primary use of the Dataflow window is exploring the "physical" connectivity of your design. You do this by expanding the view from process to process. This allows you to see the drivers/receivers of a particular signal, net, or register.

1. Open the Dataflow window.



- a. Select **View > Dataflow** from the menus or use the **view dataflow** command at the VSIM prompt in the Transcript window.
2. Add a signal to the Dataflow window.
  - a. Make sure instance *p* is selected in the Structure (sim) window.
  - b. Drag signal *strb* from the Objects window to the Dataflow window (Figure 10-1).

**Figure 10-1. A Signal in the Dataflow Window**

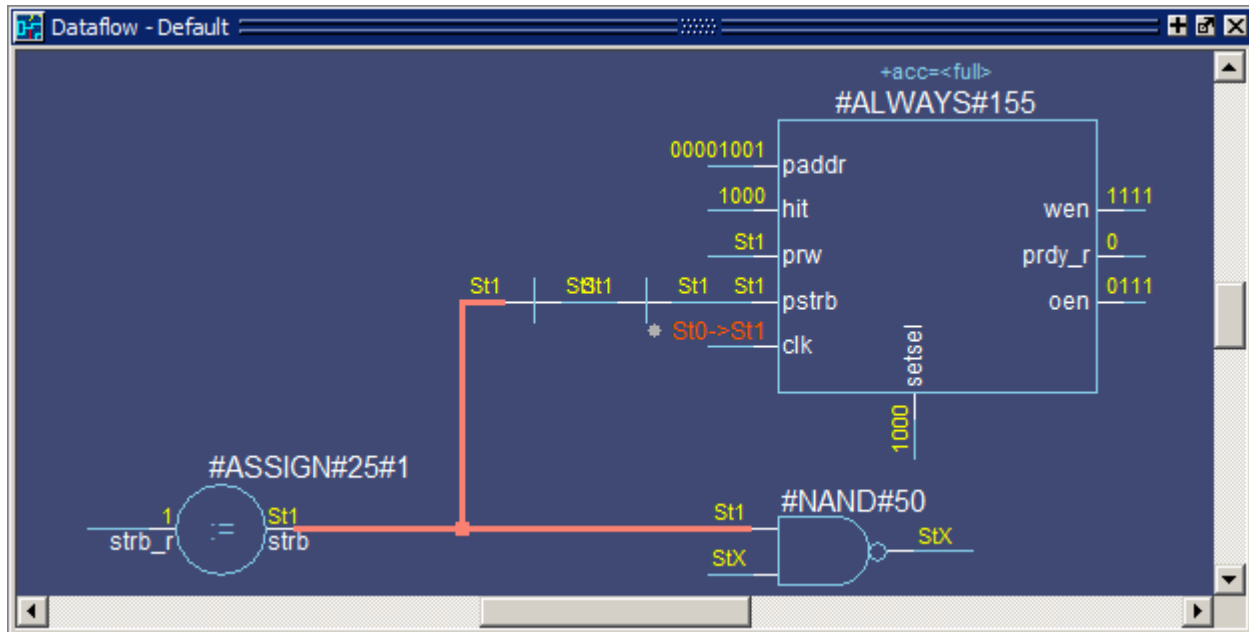


3. Explore the design.
  - a. Click the **Expand net to all readers** icon.



The view expands to display the processes that are connected to *strb* (Figure 10-2).

**Figure 10-2. Expanding the View to Display Connected Processes**



Notice the gray dot next to the state of the input *clk* signal for the #ALWAYS#155 process (labeled *line\_84* in the VHDL version). The gray dot indicates an input that is in the sensitivity list for the process. A change in any input with a gray dot triggers process execution. Inputs without gray dots are read by the process but will not trigger process execution, and are not in the sensitivity list (will not change the output by themselves).


- b. Find the drivers of the signal *test* on process #NAND#50 (labeled *line\_71* in the VHDL version).
  - i. Click the **Show Wave** icon  to open the Wave Viewer. You may need to increase the size of the Dataflow window to see everything
  - ii. Select the #NAND#50 gate (labeled *line\_71* in the VHDL version) in the Dataflow Viewer. This loads the wave signals for the inputs and outputs for this gate into the Wave Viewer and highlights the gate.
  - iii. Select the signal *test* in the Wave Viewer. This highlights the *test* input in the Dataflow Viewer. (Figure 10-3)

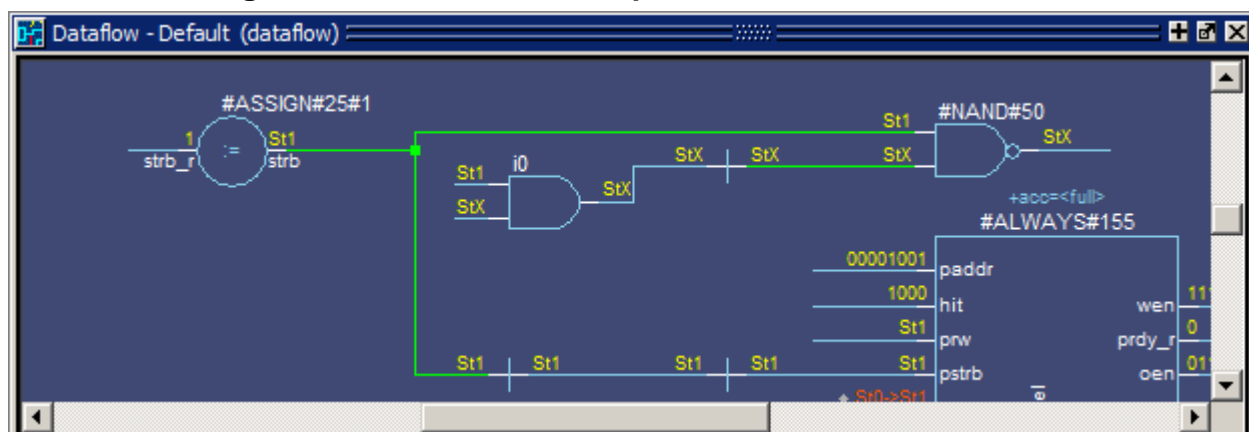
Figure 10-3. Select test signal



- iv. **Select** the highlighted signal in the Dataflow Viewer (this makes the Dataflow Viewer portion of the Dataflow window active) then click the **Expand net to all drivers** icon.



Figure 10-4. The test Net Expanded to Show All Drivers



In Figure 10-4, notice that after you selected the signal *test*, the signal line for *strb* is highlighted in green. This highlighting indicates the path you have traversed in the design.

Select net for the signal *oen* on process *#ALWAYS#155*(labeled *line\_84* in the VHDL version), and click the **Expand net to all readers** icon.



Continue exploring if you wish.

When you are done, click and hold the **Delete Content** button then select **Delete All** to clear the Dataflow Viewer.

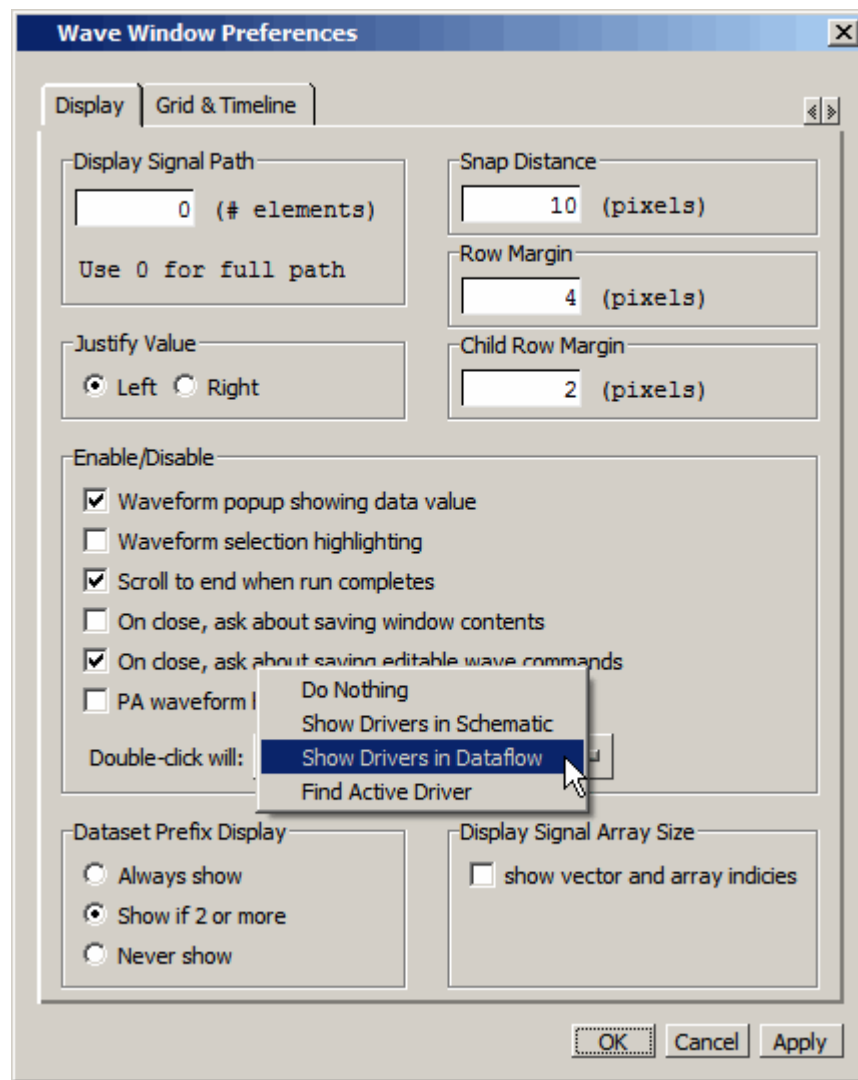



## Tracing Events

Another useful debugging feature is tracing events that contribute to an unexpected output value. Using the Dataflow window's embedded Wave Viewer, you can trace backward from a transition to a process or signal that caused the unexpected output.

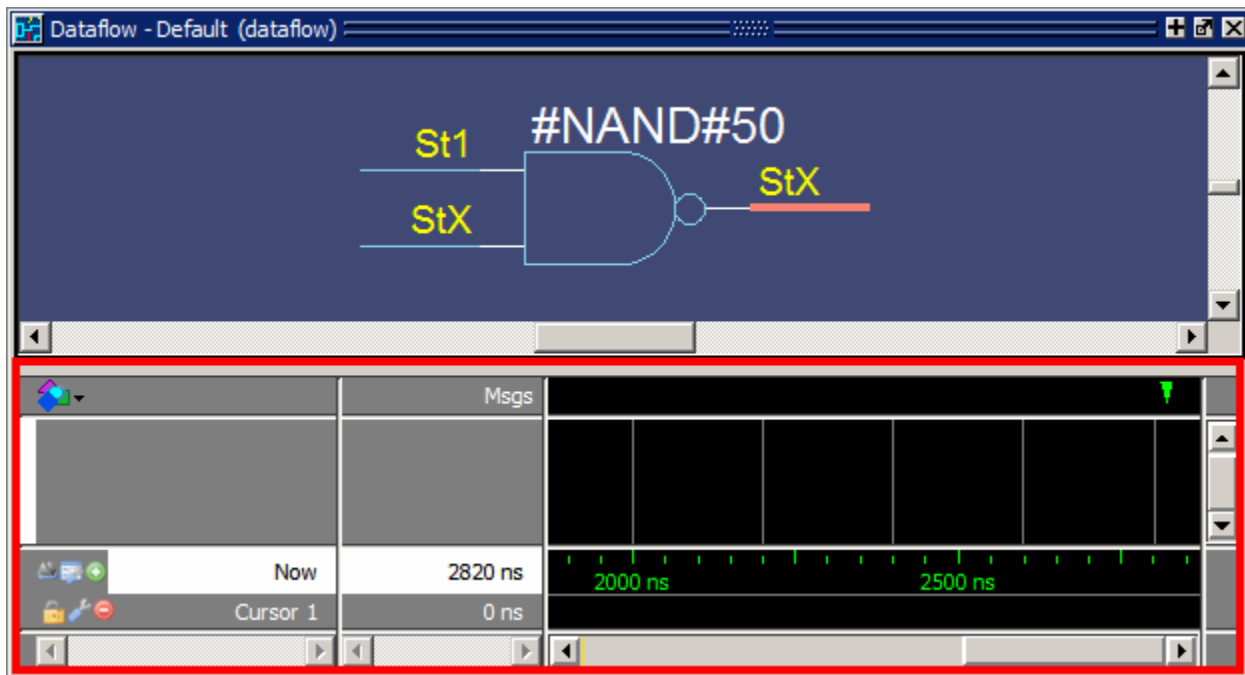
1. Set the default behavior to show drivers in the Dataflow window when double-clicking a signal in the Wave window.
  - a. Click the Wave window tab.
  - b. Select **Wave > Wave Preferences**. This opens the **Wave Window Preferences** dialog.
  - c. Select **Show Drivers in Dataflow Window** in the **Double-click will:** menu then click **OK**. ([Figure 10-5](#))

**Figure 10-5. Wave Window Preferences Dialog**



2. Add an object to the Dataflow window.
  - a. Make sure instance *p* is selected in the Structure (sim) window.
  - b. Drag signal *t\_out* from the Objects window to the Dataflow window.
  - c. Click the **Show Wave** icon  to open the Wave Viewer if it is not already open. You may need to increase the size of the Dataflow window to see everything (Figure 10-6).

**Figure 10-6. The Embedded Wave Viewer**



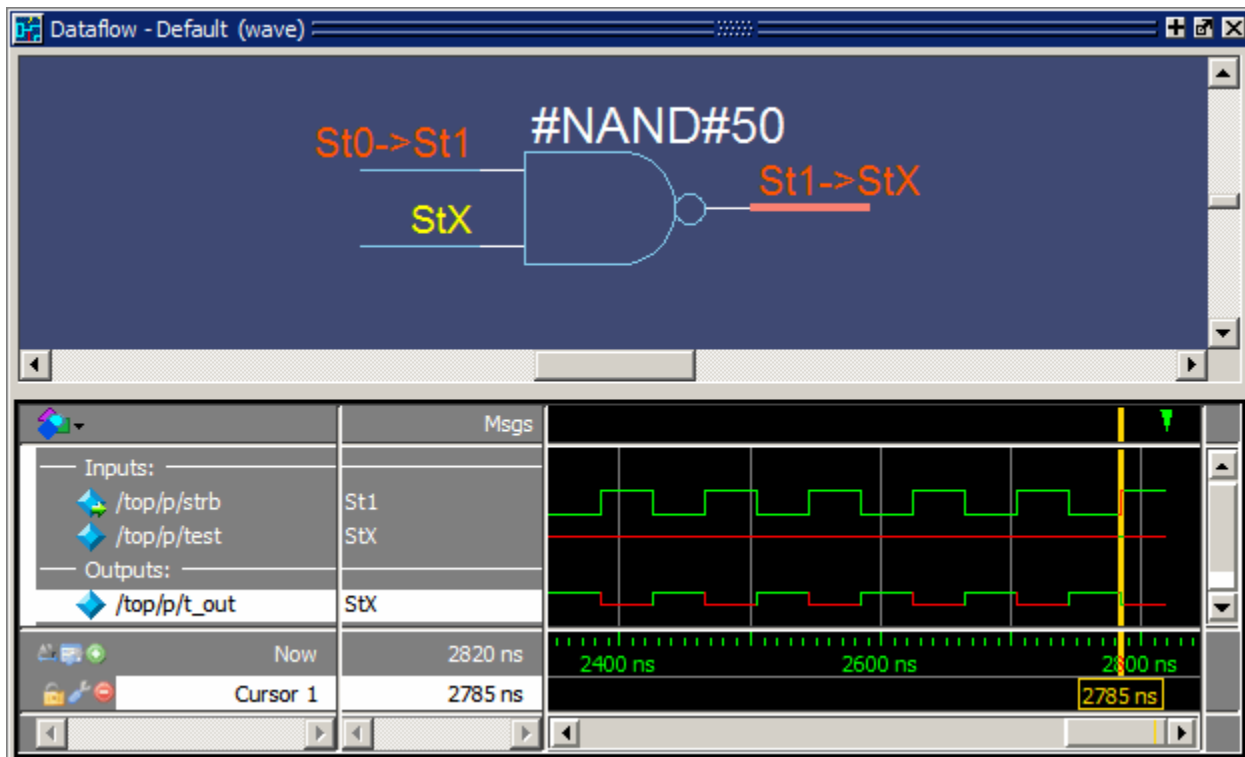
3. Trace the inputs of the nand gate.
  - a. Double-click process `#NAND#50` (labeled *line\_71* in the VHDL version) in the Dataflow Viewer. The active display jumps to the source code view, with a blue arrow pointing to the declaration of the NAND gate (Figure 10-7).

**Figure 10-7. Source Code for the NAND Gate**

```
48  
49     nor (test2, _rw, test_in);  
50     nand (t_out, test, strb);  
51  
52     task write;  
53         input  [`addr_size-1:0] a;  
54         input  [`word_size-1:0] d;  
55     begin
```

- b. Click the Dataflow tab to move back to the Dataflow window. All input and output signals of the process are displayed in the Wave Viewer.
    - c. In the Wave Viewer, scroll to the last transition of signal `t_out`.
    - d. Click just to the right of the last transition of signal `t_out`. The cursor should snap to time 2785 ns. (Figure 10-8)

**Figure 10-8. Signals Added to the Wave Viewer Automatically**



- e. Double-click just to the right of the last transition of signal *t\_out*. The active display will jump, once again, to the source code view. But this time, the signal *t\_out* is highlighted (Figure 10-9).

**Figure 10-9. Source Code with *t\_out* Highlighted**

```

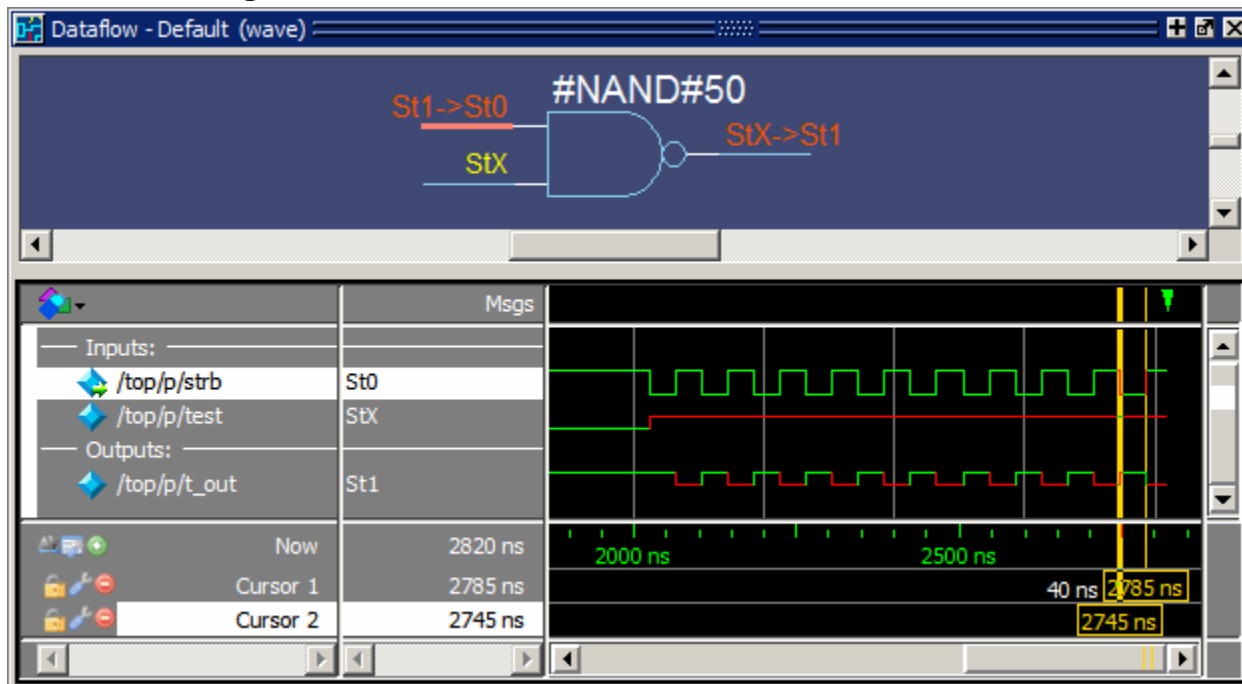
48
49     nor (test2, _rw, test_in);
50     nand (t_out, test, strb);
51
52     task write;
53         input ['addr_size-1:0] a;
54         input ['word_size-1:0] d;
55     begin

```

- f. Click the Dataflow tab to move back to the Dataflow window.
- g. The signal *t\_out* in the Dataflow Viewer should be highlighted. Click on the highlighted signal to make the signal active, then select **Tools > Trace > Trace next event** to trace the first contributing event.

ModelSim adds a cursor to the Wave Viewer to mark the last event - the transition of the strobe to 0 at 2745 ns - which caused the output of St1 on *t\_out* (Figure 10-10).

**Figure 10-10. Cursor in Wave Viewer Marks Last Event**

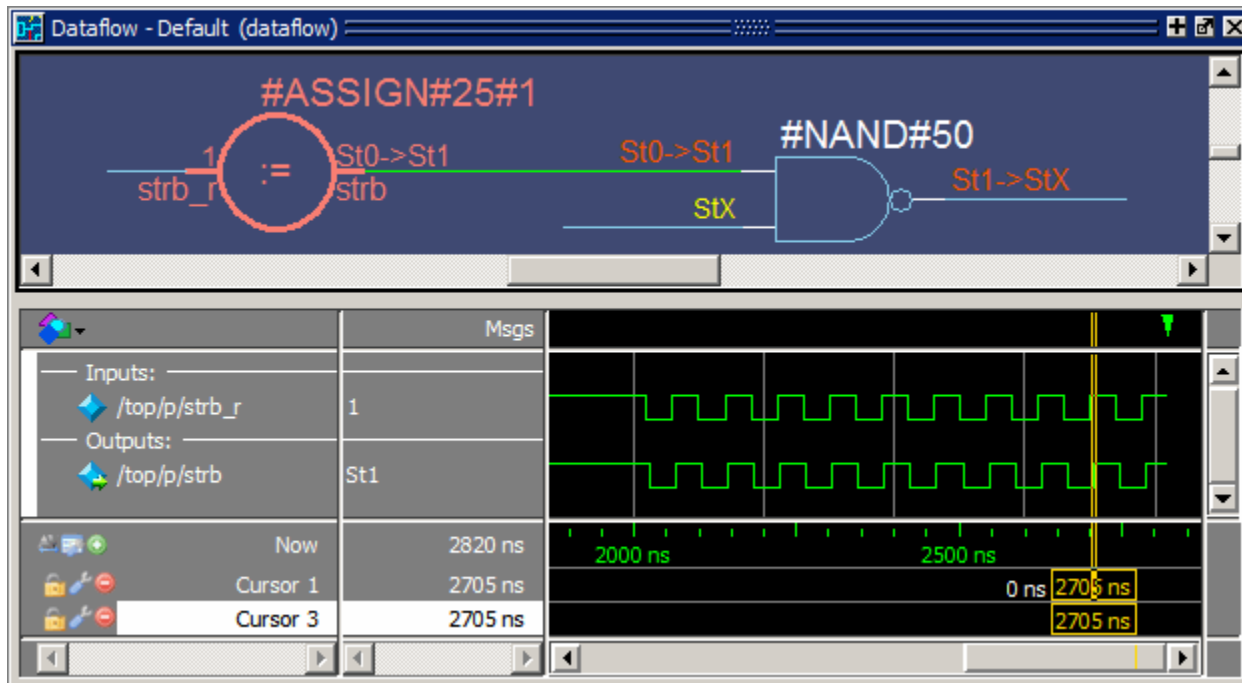


- h. Select **Tools > Trace > Trace next event** two more times and watch the cursor jump to the next event.
- i. Select **Tools > Trace > Trace event set**.

The Dataflow flow diagram sprouts to the preceding process and shows the input driver of the *strb* signal (Figure 10-11). Notice, also, that the Wave Viewer now shows the input and output signals of the newly selected process.



Figure 10-11. Tracing the Event Set



You can continue tracing events through the design in this manner: select **Trace next event** until you get to a transition of interest in the Wave Viewer, and then select **Trace event set** to update the Dataflow flow diagram.

4. When you are finished, select **File > Close Window** to close the Dataflow window.

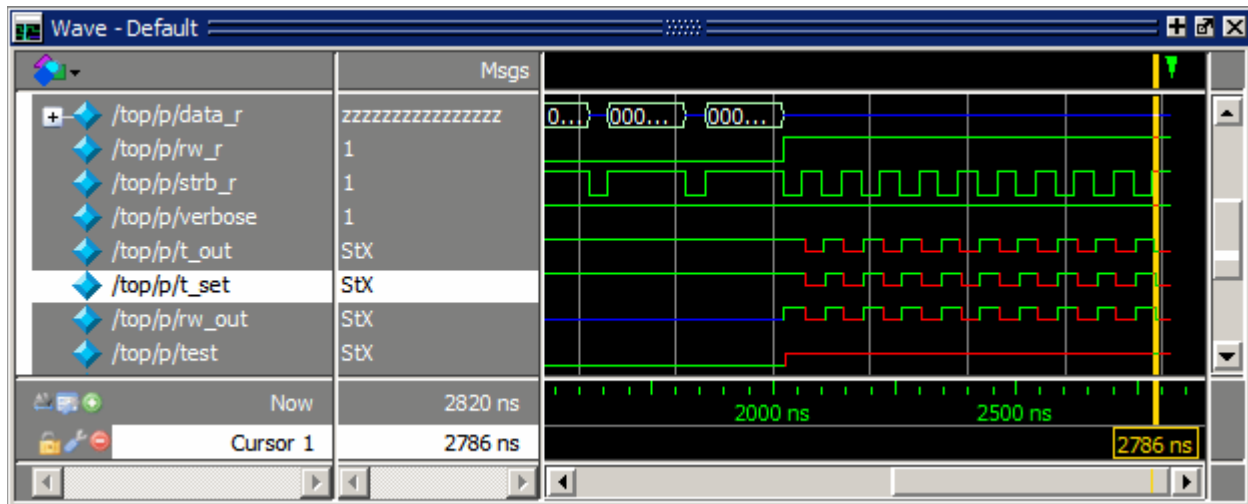
## Tracing an X (Unknown)

The Dataflow window lets you easily track an unknown value (X) as it propagates through the design. The Dataflow window is dynamically linked to the Wave window, so you can view signals in the Wave window and then use the Dataflow window to track the source of a problem. As you traverse your design in the Dataflow window, appropriate signals are added automatically to the Wave window.

1. View *t\_out* in the Wave and Dataflow windows.
  - a. Scroll in the Wave window until you can see */top/p/t\_out*.

*t\_out* goes to an unknown state, StX, at 2065 ns and continues transitioning between 1 and unknown for the rest of the run (Figure 10-12). The red color of the waveform indicates an unknown value.

Figure 10-12. A Signal with Unknown Values



- b. Double-click the `t_out` waveform at the last transition of signal `t_out` at 2785 ns.

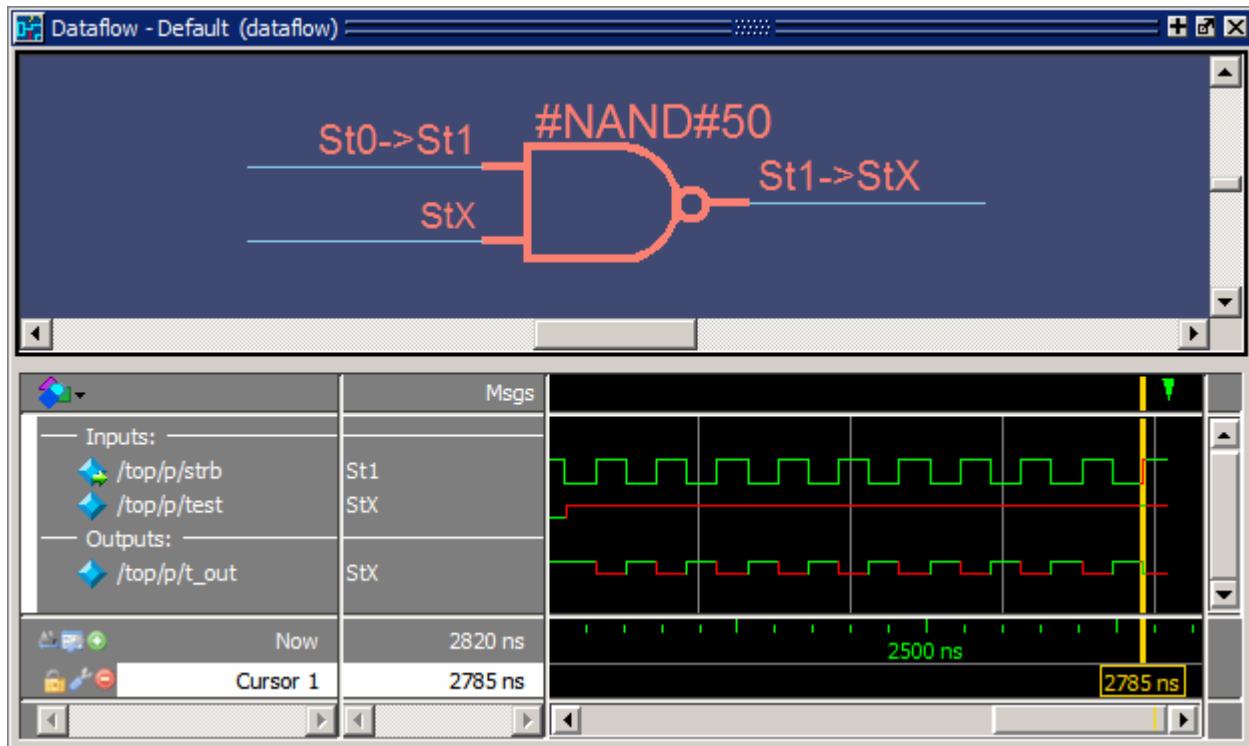
Once again, the source code view is opened with the `t_out` signal highlighted.

Double-clicking the waveform in the Wave window also automatically opens a Dataflow window and displays `t_out`, its associated process, and its waveform.

- c. Click the Dataflow tab.

Since the Wave Viewer was open when you last closed the window, it opens again inside the Dataflow window with the `t_out` signal highlighted (Figure 10-13).

Figure 10-13. Dataflow Window with Wave Viewer



- d. Move the cursor in the Wave Viewer.

As you move the cursor in the Wave Viewer, the value of  $t\_out$  changes in the flow diagram portion of the window.

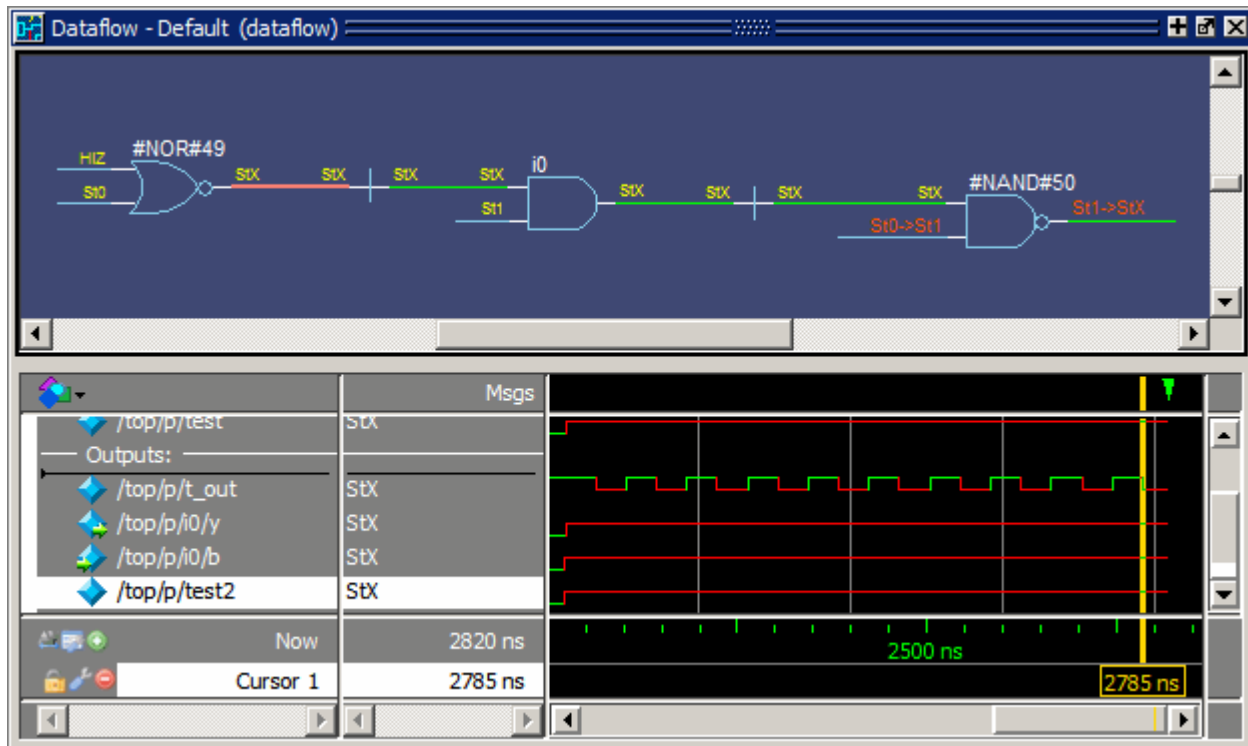
Position the cursor at a time when  $t\_out$  is unknown (for example, 2725 ns).

2. Trace the unknown.

- a. Select  $t\_out$  signal in the Wave Viewer. This highlights the output signal  $t\_out$ .
- b. In the Dataflow Viewer, click the highlighted signal to make the Viewer active. (A black frame appears around the Dataflow Viewer when it is active. The signal will be orange when selected.)
- c. Select **Tools > Trace > ChaseX** from the menus.

The design expands to show the source of the unknown state for  $t\_out$  (Figure 10-14). In this case there is a HiZ value (U in the VHDL version) on input signal  $test\_in$  and a 0 on input signal  $\_rw$  ( $bar\_rw$  in the VHDL version). This causes the  $test2$  output signal to resolve to an unknown state (StX). The unknown state propagates through the design to  $t\_out$ .

Figure 10-14. ChaseX Identifies Cause of Unknown on t\_out



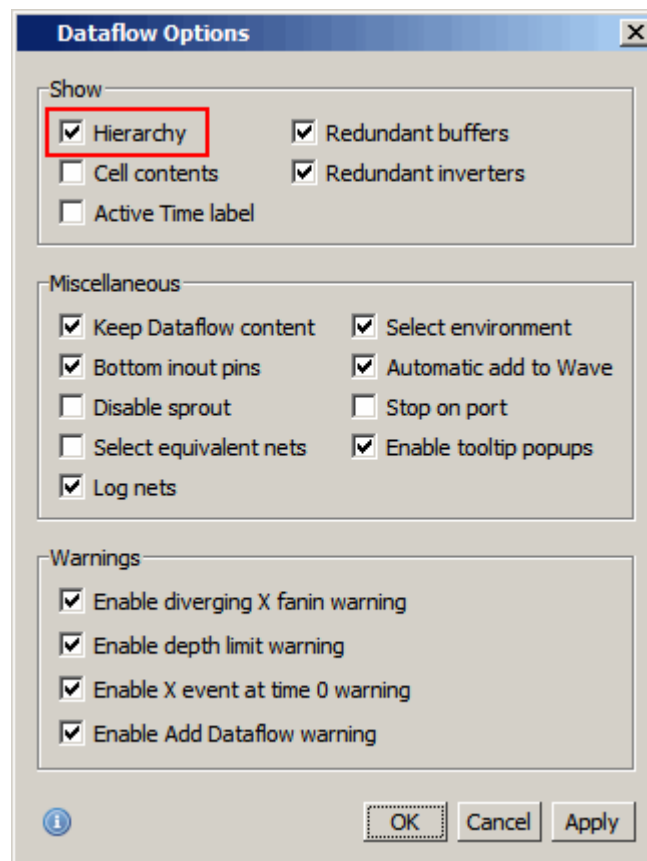
3. Clear the Dataflow window before continuing.
  - a. Click the **Delete All** icon to clear the Dataflow Viewer.
  - b. Click the **Show Wave** icon to close the Wave view of the Dataflow window.

## Displaying Hierarchy in the Dataflow Window

You can display connectivity in the Dataflow window using hierarchical instances. You enable this by modifying the options prior to adding objects to the window.

1. Change options to display hierarchy.
  - a. Select **Dataflow > Dataflow Preferences > Options** from the Main window menus. (When the Dataflow window is undocked, select **Tools > Options** from the Dataflow window menu bar.) This will open the Dataflow Options dialog (Figure 10-15).

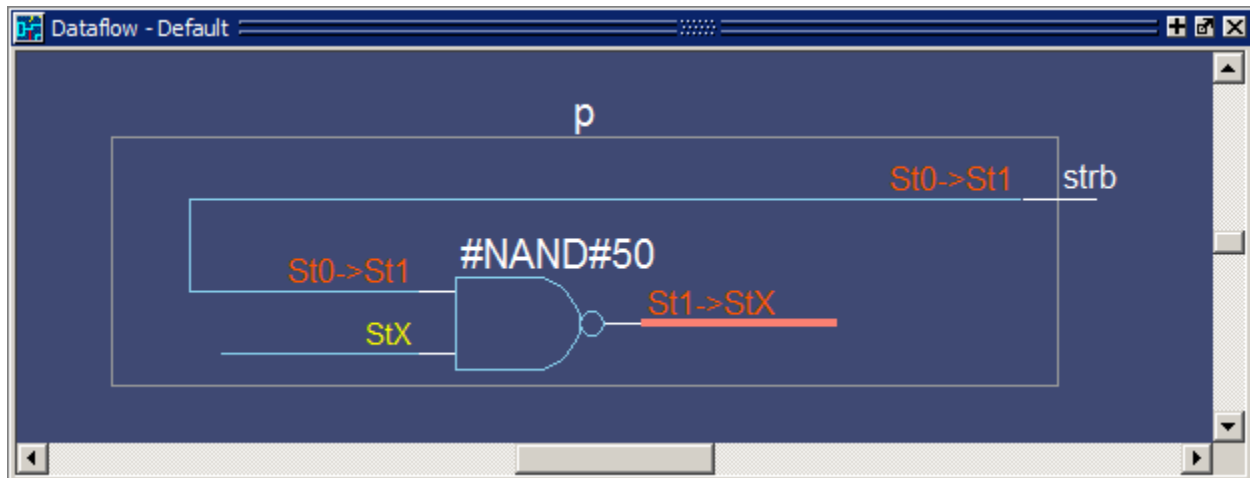
Figure 10-15. Dataflow Options Dialog



- b. Select **Show: Hierarchy** and then click **OK**.
2. Add signal *t\_out* to the Dataflow window.
  - a. Type **add dataflow /top/p/t\_out** at the VSIM> prompt.

The Dataflow window will display *t\_out* and all hierarchical instances (Figure 10-16).

Figure 10-16. Displaying Hierarchy in the Dataflow Window



## Lesson Wrap-Up

This concludes this lesson. Before continuing we need to end the current simulation.

1. Type **quit -sim** at the VSIM> prompt.

To return the wildcard filter to its factory default settings, enter:

**set WildcardFilter "default"**

# Chapter 11

## Viewing And Initializing Memories

---

### Introduction

In this lesson you will learn how to view and initialize memories. ModelSim defines and lists any of the following as memories:

- reg, wire, and std\_logic arrays
- Integer arrays
- Single dimensional arrays of VHDL enumerated types other than std\_logic

### Design Files for this Lesson

The installation comes with Verilog and VHDL versions of the example design located in the following directories:

**Verilog** – *<install\_dir>/examples/tutorials/verilog/memory*

**VHDL** – *<install\_dir>/examples/tutorials/vhdl/memory*

This lesson uses the Verilog version for the exercises. If you have a VHDL license, use the VHDL version instead.

### Related Reading

User's Manual Section: [Memory List Window](#).

Reference Manual commands: [mem display](#), [mem load](#), [mem save](#), and [radix](#).

### Compile and Load the Design

1. Create a new directory and copy the tutorial files into it.

Start by creating a new directory for this exercise (in case other users will be working with these lessons). Create the directory and copy all files from *<install\_dir>/examples/tutorials/verilog/memory* to the new directory.

If you have a VHDL license, copy the files in *<install\_dir>/examples/tutorials/vhdl/memory* instead.

2. Start ModelSim and change to the exercise directory.

If you just finished the previous lesson, ModelSim should already be running. If not, start ModelSim.

- a. Type **vsim** at a UNIX shell prompt or use the ModelSim icon in Windows.

If the Welcome to ModelSim dialog appears, click **Close**.

- b. Select **File > Change Directory** and change to the directory you created in step 1.

3. Create the working library and compile the design.

- a. Type **vlib work** at the ModelSim> prompt.

- b. **Verilog:**

Type **vlog \*.v** at the ModelSim> prompt to compile all verilog files in the design.

**VHDL:**

Type **vcom -93 sp\_syn\_ram.vhd dp\_syn\_ram.vhd ram\_tb.vhd** at the ModelSim> prompt.

4. Optimize the design

- a. Enter the following command at the ModelSim> prompt:

**vopt +acc ram\_tb -o ram\_tb\_opt**

The +acc switch for the **vopt** command provides visibility into the design for debugging purposes.

The -o switch allows you designate the name of the optimized design file (ram\_tb\_opt).

---

#### Note



You must provide a name for the optimized design file when you use the vopt command.

---

5. Load the design.

- a. On the Library tab of the Main window Workspace, click the "+" icon next to the *work* library.

- b. Use the optimized design name to load the design with the **vsim** command:

**vsim ram\_tb\_opt**

## View a Memory and its Contents

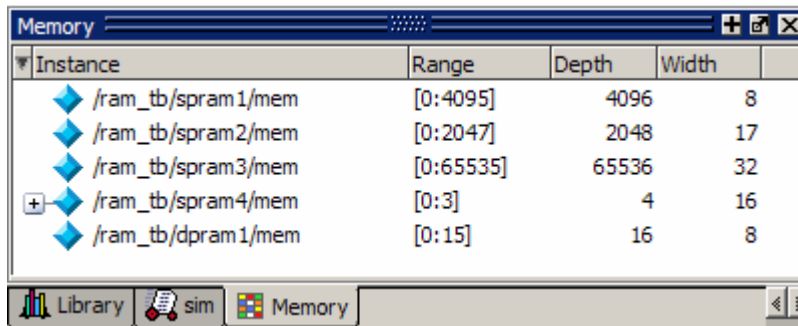
The Memory window lists all memory instances in the design, showing for each instance the range, depth, and width. Double-clicking an instance opens a window displaying the memory data.



1. Open the Memory window and view the data of a memory instance
  - a. If the Memory window is not already open, select **View > Memory List**.

A Memory window opens as shown in [Figure 11-1](#).

**Figure 11-1. The Memory List in the Memory window**



- b. Double-click the `/ram_tb/spram1/mem` instance in the memory list to view its contents.

A Memory Data window opens displaying the contents of `spram1`. The first column (blue hex characters) lists the addresses, and the remaining columns show the data values.

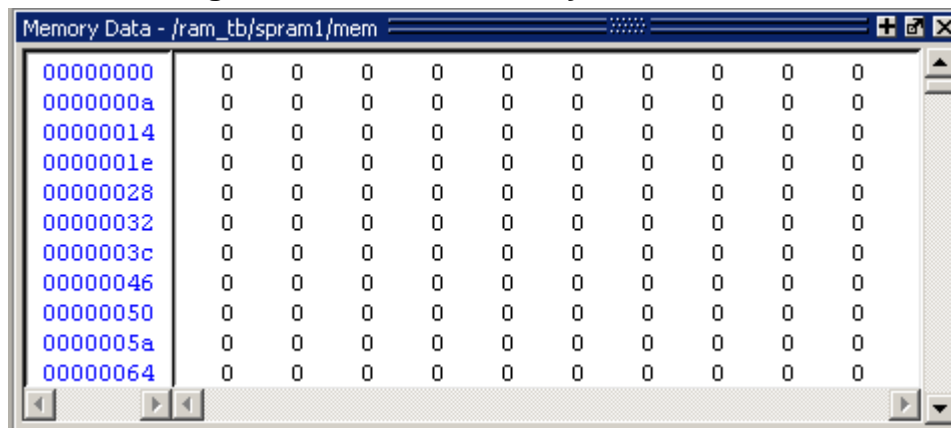
If you are using the Verilog example design, the data is all **X** ([Figure 11-2](#)) because you have not yet simulated the design.


**Figure 11-2. Verilog Memory Data Window**



If you are using the VHDL example design, the data is all zeros ([Figure 11-3](#)).

**Figure 11-3. VHDL Memory Data Window**



- c. Double-click the instance `/ram_tb/spram2/mem` in the Memory window. This opens a second Memory Data window that contains the addresses and data for the `spram2` instance. For each memory instance that you click in the Memory window, a new Memory Data window opens.
2. Simulate the design.
    - a. Click the **run -all** icon in the Main window. 

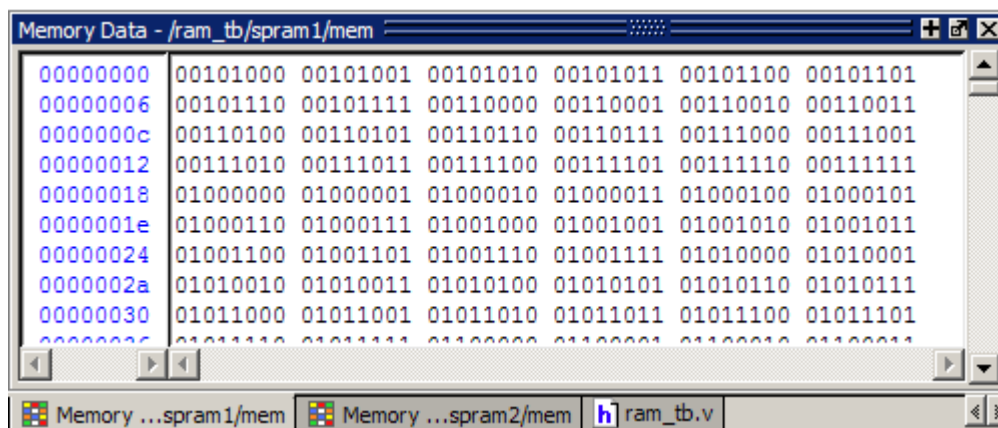
A Source window opens showing the source code for the `ram_tb` file at the point where the simulation stopped.

#### VHDL:

In the Transcript window, you will see NUMERIC\_STD warnings that can be ignored and an assertion failure that is functioning to stop the simulation. The simulation itself has not failed.

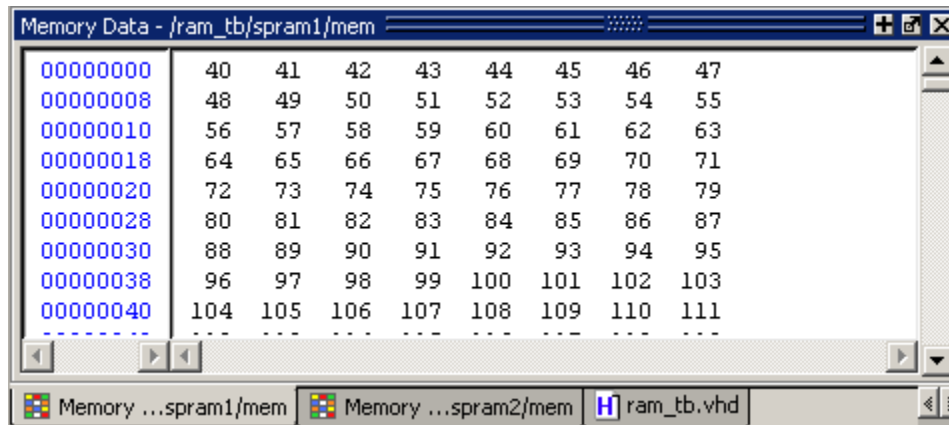
- a. Click the **Memory ...spram1/mem** tab to bring that Memory data window to the foreground. The Verilog data fields are shown in [Figure 11-4](#).

**Figure 11-4. Verilog Data After Running Simulation**



The VHDL data fields are show in [Figure 11-5](#).

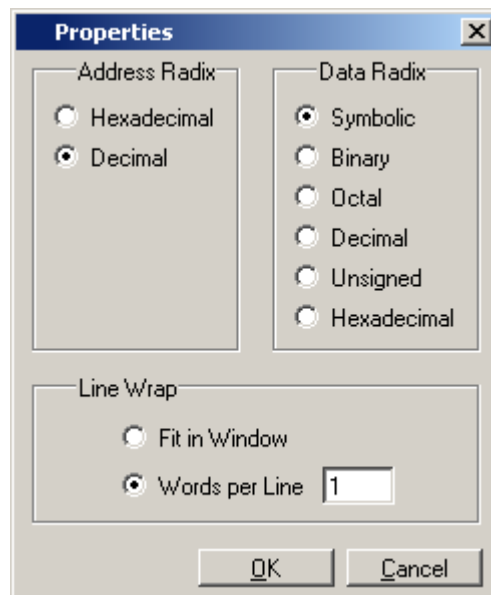
**Figure 11-5. VHDL Data After Running Simulation**



Address	40	41	42	43	44	45	46	47
00000000	48	49	50	51	52	53	54	55
00000008	56	57	58	59	60	61	62	63
00000010	64	65	66	67	68	69	70	71
00000018	72	73	74	75	76	77	78	79
00000020	80	81	82	83	84	85	86	87
00000028	88	89	90	91	92	93	94	95
00000030	96	97	98	99	100	101	102	103
00000038	104	105	106	107	108	109	110	111
00000040	...	...	...	...	...	...	...	...

3. Change the address radix and the number of words per line for instance */ram\_tb/spram1/mem*.
  - a. Right-click anywhere in the spram1 Memory Data window and select **Properties**.
  - b. The Properties dialog box opens ([Figure 11-6](#)).

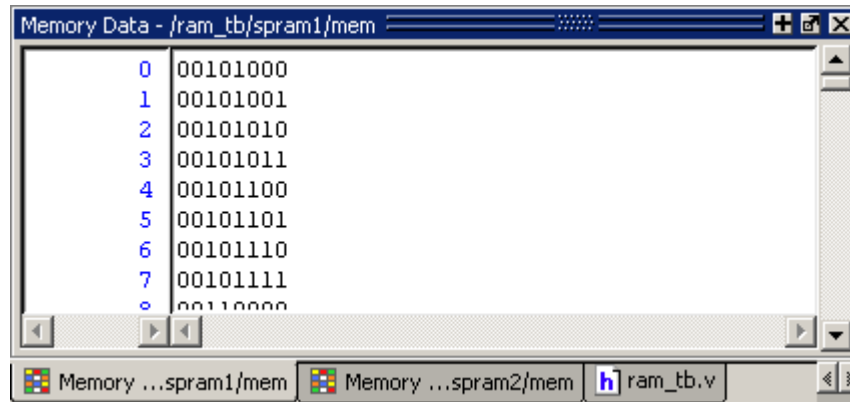
**Figure 11-6. Changing the Address Radix**



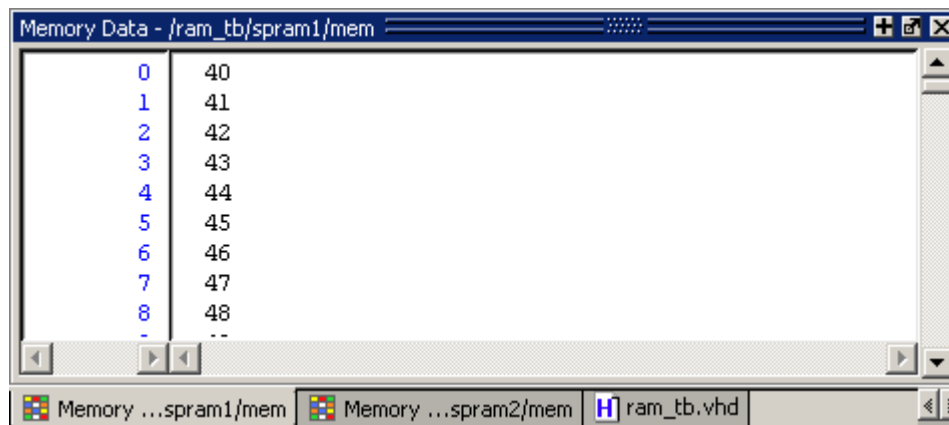
- c. For the **Address Radix**, select **Decimal**. This changes the radix for the addresses only.
    - d. Select **Words per line** and type **1** in the field.
    - e. Click OK.

You can see the Verilog results of the settings in [Figure 11-7](#) and the VHDL results in [Figure 11-8](#). If the figure doesn't match what you have in your ModelSim session, check to make sure you set the Address Radix rather than the Data Radix. Data Radix should still be set to Symbolic, the default.

**Figure 11-7. New Address Radix and Line Length (Verilog)**



**Figure 11-8. New Address Radix and Line Length (VHDL)**



## Navigate Within the Memory

You can navigate to specific memory address locations, or to locations containing particular data patterns. First, you will go to a specific address.

1. Use Goto to find a specific address.
  - a. Right-click anywhere in address column and select **Goto** ([Figure 11-9](#)).

The Goto dialog box opens in the data pane.

**Figure 11-9. Goto Dialog**

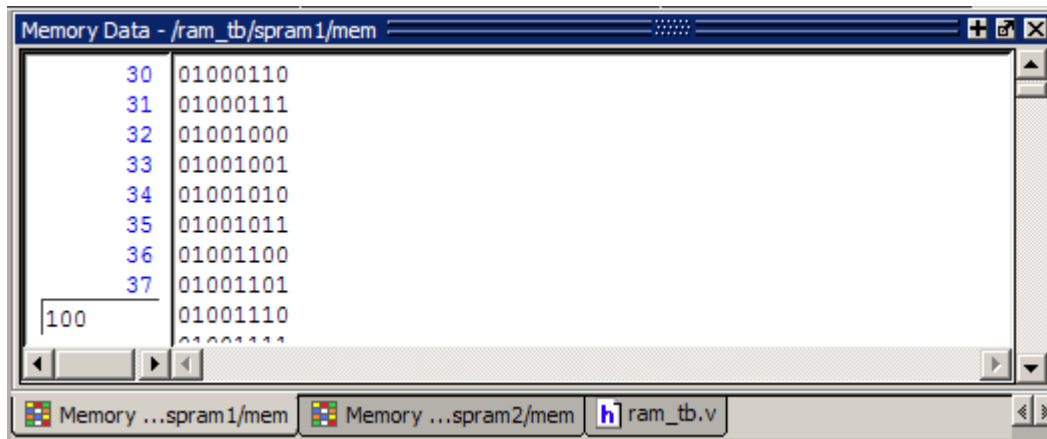


- b. Type **30** in the Goto Address field.
- c. Click **OK**.

The requested address appears in the top line of the window.

- 2. Edit the address location directly.
  - a. To quickly move to a particular address, do the following:
    - i. Double click address 38 in the address column.
    - ii. Enter address 100 (Figure 11-10).

**Figure 11-10. Editing the Address Directly**



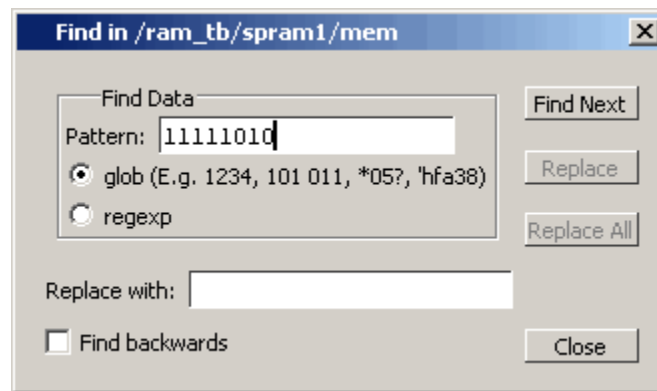
- iii. Press the Enter or Return key on your keyboard.

The pane jumps to address 100.

- 3. Now, let's find a particular data entry.
  - a. Right-click anywhere in the data column and select **Find**.

The Find in dialog box opens (Figure 11-11).

**Figure 11-11. Searching for a Specific Data Value**



b. **Verilog:** Type **11111010** in the **Find data:** field and click **Find Next**.

**VHDL:** Type **250** in the **Find data:** field and click **Find Next**.

The data scrolls to the first occurrence of that address. Click **Find Next** a few more times to search through the list.

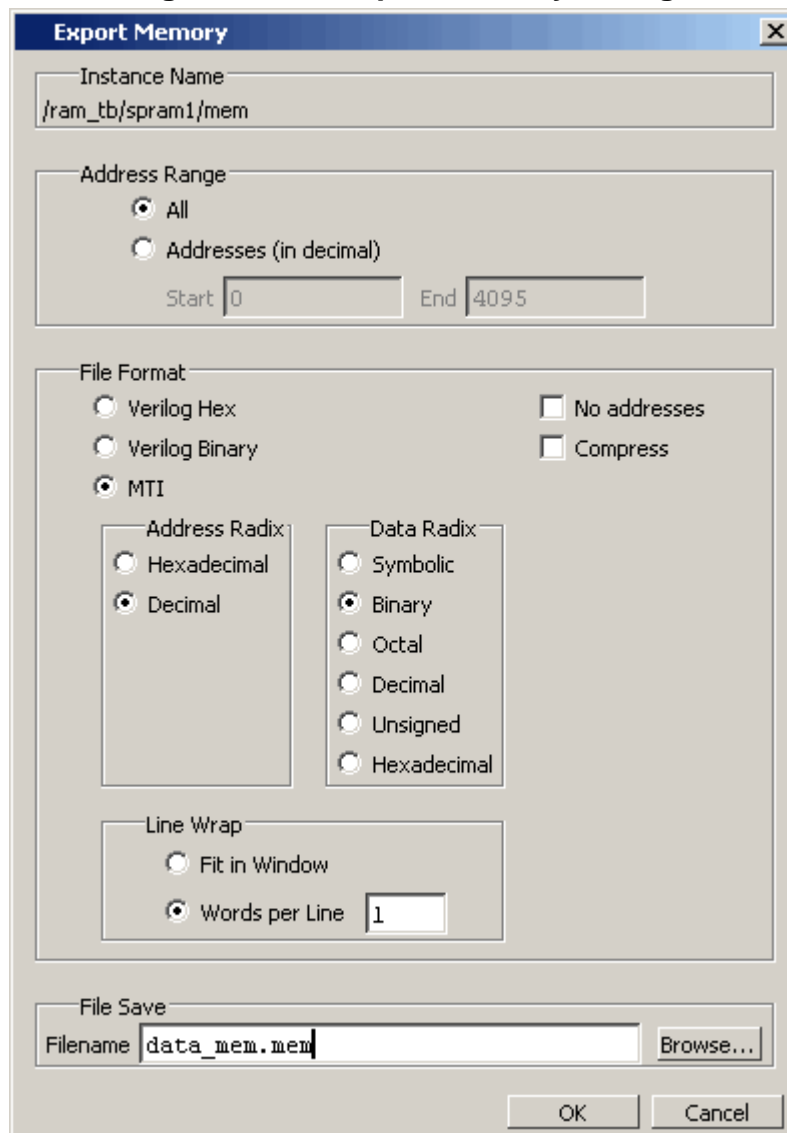
c. Click **Close** to close the dialog box.

## Export Memory Data to a File

You can save memory data to a file that can be loaded at some later point in simulation.

1. Export a memory pattern from the */ram\_tb/spram1/mem* instance to a file.
  - a. Make sure */ram\_tb/spram1/mem* is open and selected.
  - b. Select **File > Export > Memory Data** to bring up the Export Memory dialog box (Figure 11-12).

Figure 11-12. Export Memory Dialog



- c. For the Address Radix, select **Decimal**.
- d. For the Data Radix, select **Binary**.
- e. For the Words per Line, set to 1.
- f. Type **data\_mem.mem** into the Filename field.
- g. Click OK.

You can view the exported file in any editor.

Memory pattern files can be exported as relocatable files, simply by leaving out the address information. Relocatable memory files can be loaded anywhere in a memory because no addresses are specified.

2. Export a relocatable memory pattern file from the */ram\_tb/spram2/mem* instance.
  - a. Select the Memory Data window for the */ram\_tb/spram2/mem* instance.
  - b. Right-click on the memory contents to open a popup menu and select **Properties**.
  - c. In the Properties dialog, set the Address Radix to **Decimal**; the Data Radix to **Binary**; and the Line Wrap to 1 **Words per Line**. Click OK to accept the changes and close the dialog.
  - d. Select **File > Export > Memory Data** to bring up the Export Memory dialog box.
  - e. For the Address Range, specify a Start address of **0** and End address of **250**.
  - f. For the File Format, select **MTI** and **No addresses** to create a memory pattern that you can use to relocate somewhere else in the memory, or in another memory.
  - g. For Address Radix select **Decimal**, and for Data Radix select **Binary**.
  - h. For the Words per Line, set to 1.
  - i. Enter the file name as **reloc.mem**, then click OK to save the memory contents and close the dialog. You will use this file for initialization in the next section.

## Initialize a Memory

In ModelSim, it is possible to initialize a memory using one of three methods: from an exported memory file, from a fill pattern, or from both.

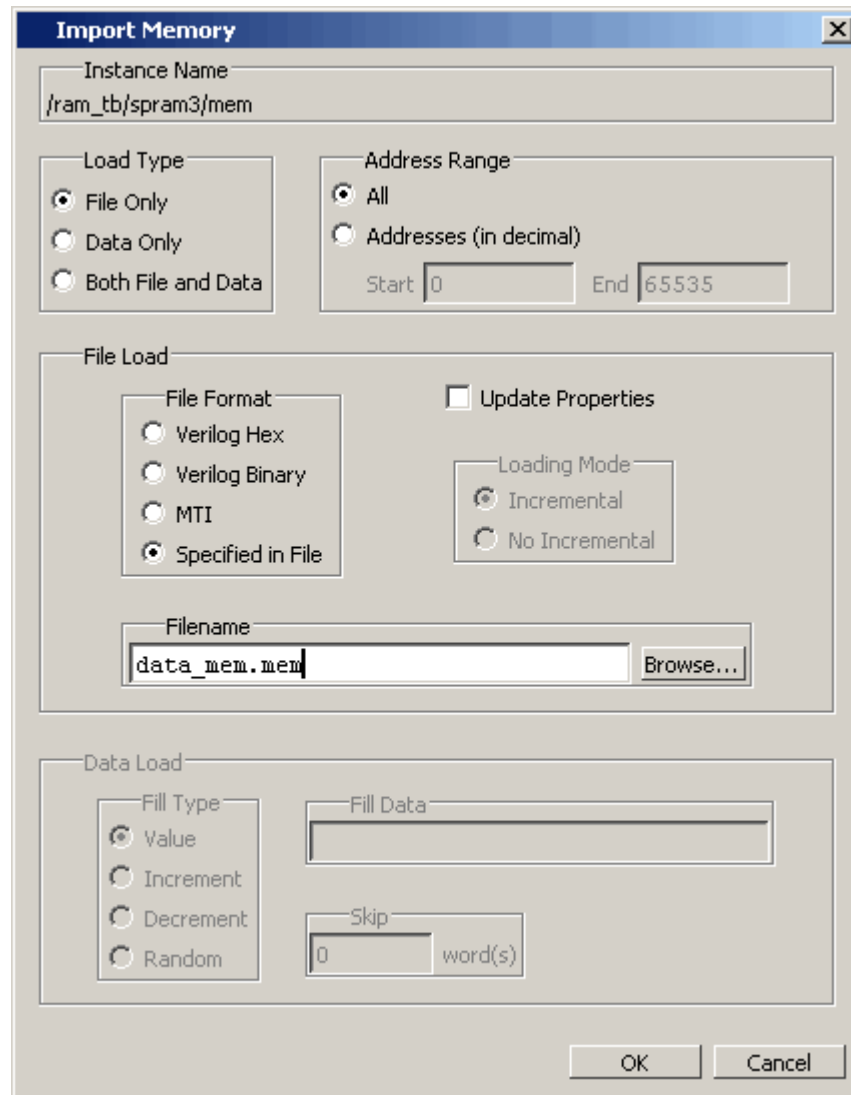
First, let's initialize a memory from a file only. You will use the one you exported previously, *data\_mem.mem*.

1. View instance */ram\_tb/spram3/mem*.
  - a. Double-click the */ram\_tb/spram3/mem* instance in the Memories tab.

This will open a new Memory Data window to display the contents of */ram\_tb/spram3/mem*. Familiarize yourself with the contents so you can identify changes once the initialization is complete.
  - b. Right-click and select **Properties** to bring up the Properties dialog.
  - c. Change the Address Radix to **Decimal**, Data Radix to **Binary**, **Words per Line to 1**, and click OK.
2. Initialize *spram3* from a file.
  - a. Right-click anywhere in the data column and select **Import Data Patterns** to bring up the Import Memory dialog box ([Figure 11-13](#)).



**Figure 11-13. Import Memory Dialog**



The dialog box is titled "Import Memory" and contains the following sections:

- Instance Name:** A text field containing the path `/ram_tb/spram3/mem`.
- Load Type:** Three radio buttons:   
☒ File Only  
☐ Data Only  
☐ Both File and Data
- Address Range:** Two radio buttons:   
☒ All  
☐ Addresses (in decimal)  
Below these are two text fields: **Start** (containing 0) and **End** (containing 65535).
- File Load:** A group box containing:
  - File Format:** Four radio buttons:   
☐ Verilog Hex  
☐ Verilog Binary  
☐ MTI  
☒ Specified in File
  - ☐ Update Properties
  - Loading Mode:** Two radio buttons:   
☒ Incremental  
☐ No Incremental
- Filename:** A text field containing `data_mem.mem` and a **Browse...** button.
- Data Load:** A group box containing:
  - Fill Type:** Four radio buttons:   
☒ Value  
☐ Increment  
☐ Decrement  
☐ Random
  - Fill Data:** An empty text field.
  - Skip:** A text field containing 0, followed by the label **word(s)**.

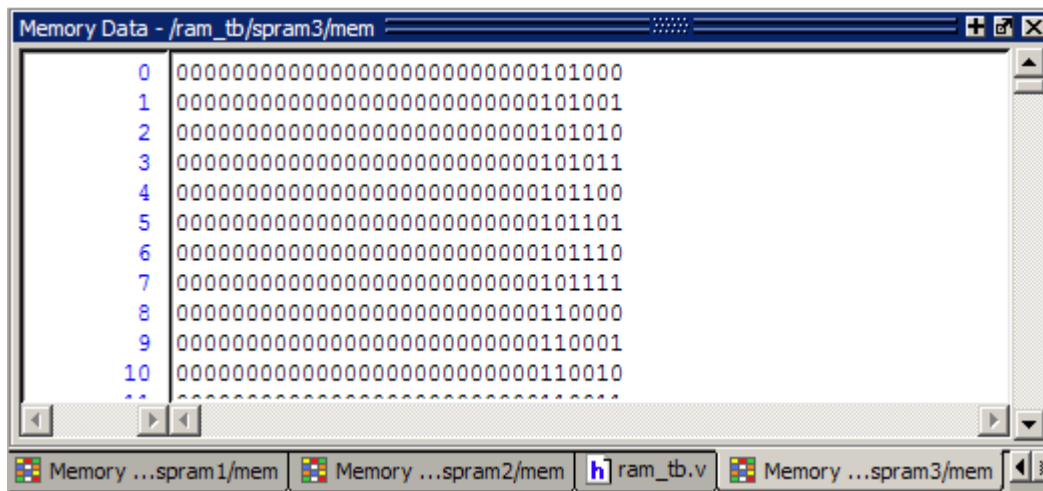
At the bottom right are **OK** and **Cancel** buttons.

The default Load Type is File Only.

- b. Type `data_mem.mem` in the Filename field.
- c. Click **OK**.

The addresses in instance `/ram_tb/spram3/mem` are updated with the data from `data_mem.mem` (Figure 11-14).

**Figure 11-14. Initialized Memory from File and Fill Pattern**



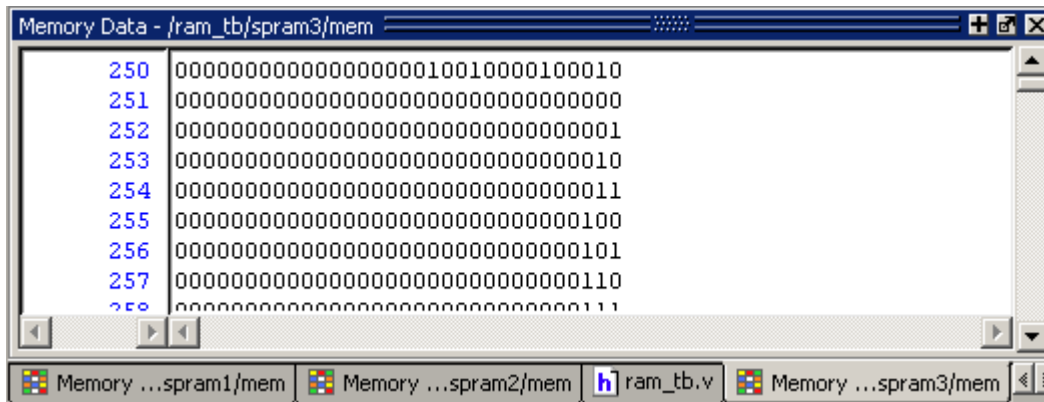
In this next step, you will experiment with importing from both a file and a fill pattern. You will initialize *spram3* with the 250 addresses of data you exported previously into the relocatable file *reloc.mem*. You will also initialize 50 additional address entries with a fill pattern.

3. Import the */ram\_tb/spram3/mem* instance with a relocatable memory pattern (*reloc.mem*) and a fill pattern.
  - a. Right-click in the data column of *spram3* and select **Import Data Patterns** to bring up the Import Memory dialog box.
  - b. For Load Type, select **Both File and Data**.
  - c. For Address Range, select **Addresses** and enter **0** as the Start address and **300** as the End address.

This means that you will be loading the file from 0 to 300. However, the *reloc.mem* file contains only 251 addresses of data. Addresses 251 to 300 will be loaded with the fill data you specify next.

- d. For File Load, select the MTI File Format and enter **reloc.mem** in the Filename field.
  - e. For Data Load, select a Fill Type of **Increment**.
  - f. In the Fill Data field, set the seed value of **0** for the incrementing data.
  - g. Click **OK**.
  - h. View the data near address 250 by double-clicking on any address in the Address column and entering **250**.

You can see the specified range of addresses overwritten with the new data. Also, you can see the incrementing data beginning at address 251 (Figure 11-15).

**Figure 11-15. Data Increments Starting at Address 251**

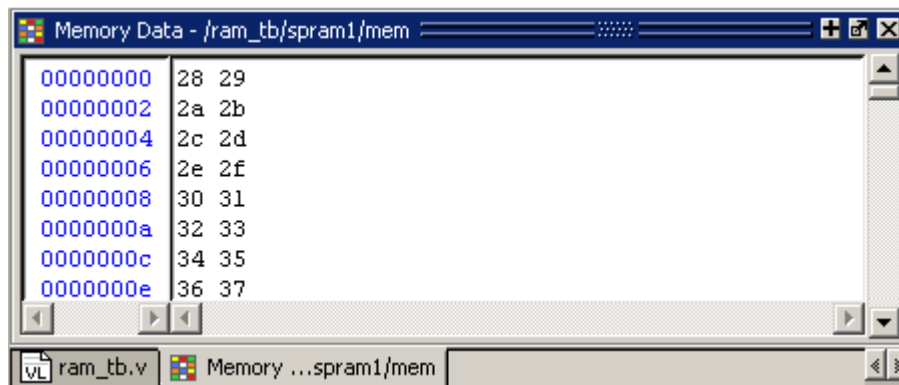
Now, before you leave this section, go ahead and clear the memory instances already being viewed.

4. Right-click in one of the Memory Data windows and select **Close All**.

## Interactive Debugging Commands

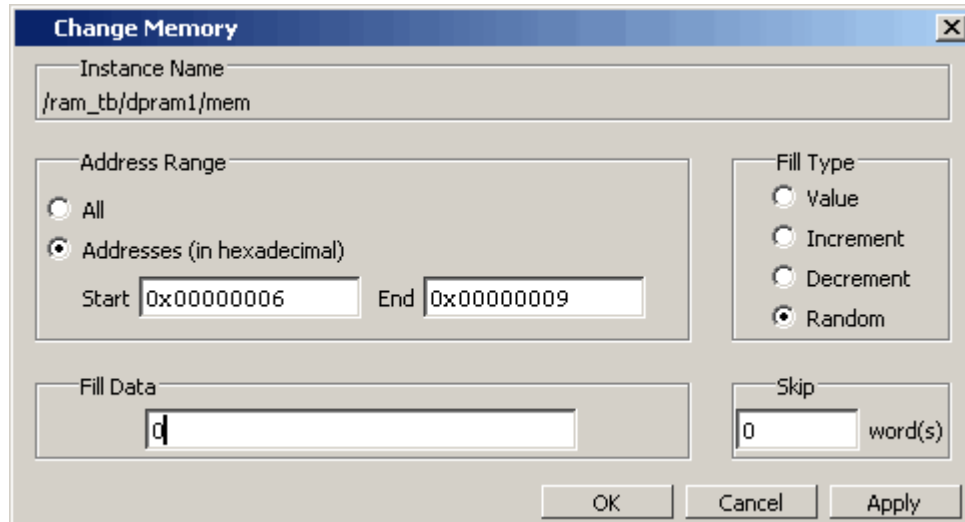
The Memory Data windows can also be used interactively for a variety of debugging purposes. The features described in this section are useful for this purpose.

1. Open a memory instance and change its display characteristics.
  - a. Double-click instance */ram\_tb/dpram1/mem* in the Memories window.
  - b. Right-click in the *dpram1* Memory Data window and select **Properties**.
  - c. Change the Address and Data Radix to **Hexadecimal**.
  - d. Select **Words per line** and enter **2**.
  - e. Click **OK**. The result should be as in [Figure 11-16](#).

**Figure 11-16. Original Memory Content**

2. Initialize a range of memory addresses from a fill pattern.
  - a. Right-click in the data column of `/ram_tb/dpram1/mem` and select **Change** to open the Change Memory dialog (Figure 11-17).

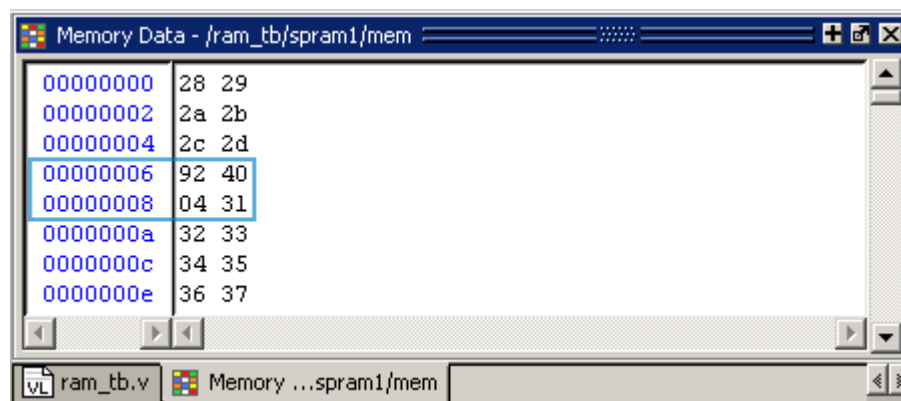
**Figure 11-17. Changing Memory Content for a Range of Addresses\*\*OK**



- b. Select **Addresses** and enter the start address as **0x00000006** and the end address as **0x00000009**. The "0x" hex notation is optional.
- c. Select **Random** as the **Fill Type**.
- d. Enter **0** as the **Fill Data**, setting the seed for the Random pattern.
- e. Click **OK**.

The data in the specified range are replaced with a generated random fill pattern (Figure 11-18).

**Figure 11-18. Random Content Generated for a Range of Addresses**

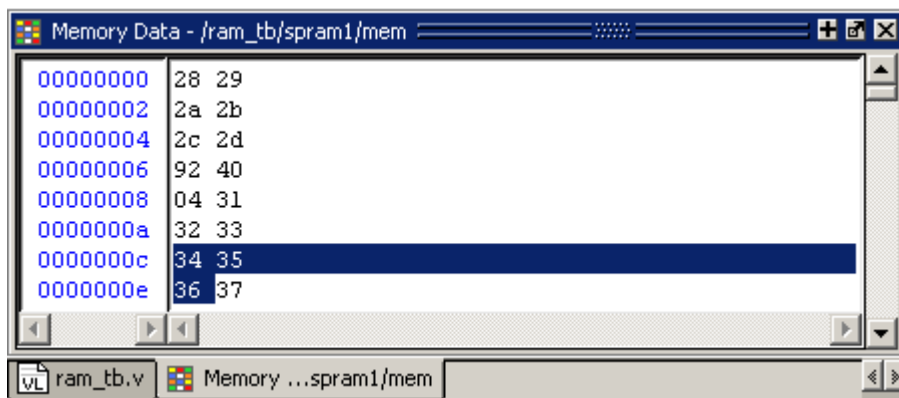


3. Change contents by highlighting.

You can also change data by highlighting them in the Address Data pane.

- a. Highlight the data for the addresses **0x0000000c:0x0000000e**, as shown in [Figure 11-19](#).

**Figure 11-19. Changing Memory Contents by Highlighting**

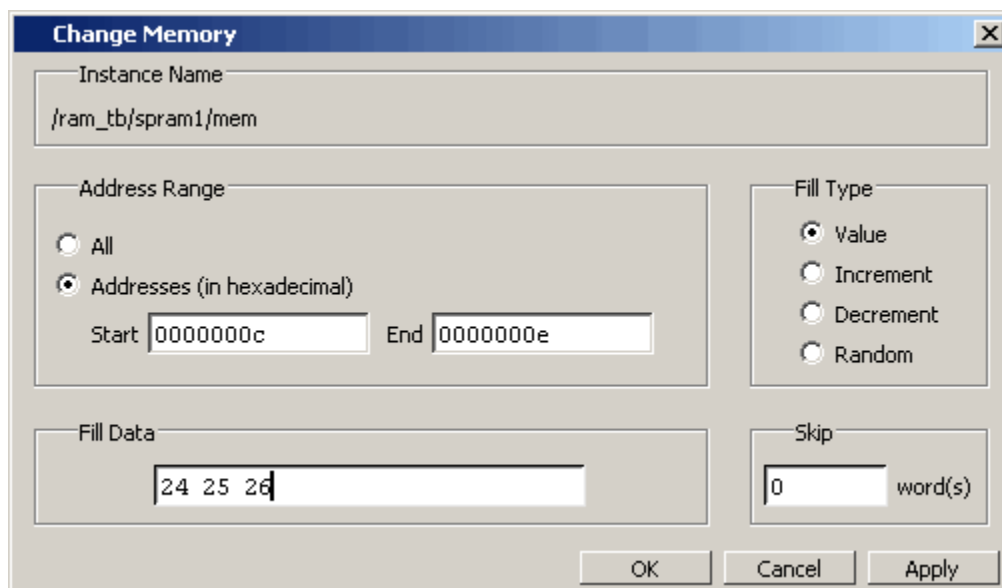


- b. Right-click the highlighted data and select **Change**.

This brings up the Change memory dialog box. Note that the Addresses field is already populated with the range you highlighted.

- c. Select **Value** as the Fill Type. (Refer to [Figure 11-20](#))
- d. Enter the data values into the Fill Data field as follows: **24 25 26**.

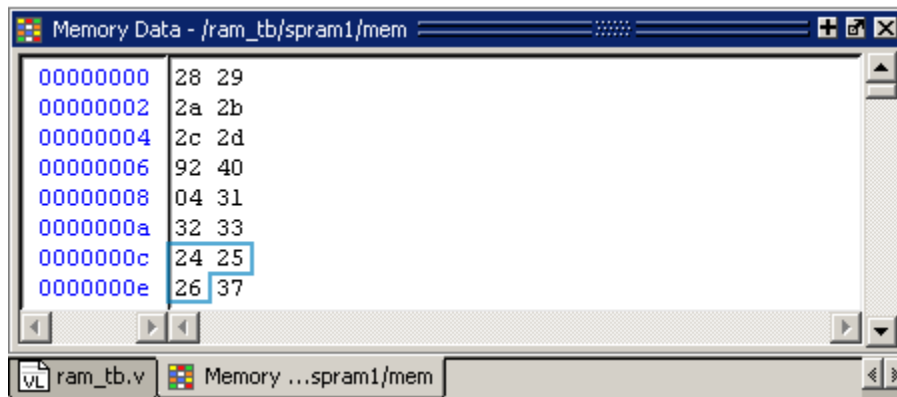
**Figure 11-20. Entering Data to Change\*\*OK**



- e. Click **OK**.

The data in the address locations change to the values you entered (Figure 11-21).

**Figure 11-21. Changed Memory Contents for the Specified Addresses**



4. Edit data in place.

To edit only one value at a time, do the following:

- a. Double click any value in the Data column.
- b. Enter the desired value and press the Enter or Return key on your keyboard.

If you needed to cancel the edit function, press the Esc key on your keyboard.

## Lesson Wrap-Up

This concludes this lesson. Before continuing we need to end the current simulation.

1. Select **Simulate > End Simulation**. Click Yes.

# Chapter 12

## Analyzing Performance With The Profiler

---

### Introduction

The Profiler identifies the percentage of simulation time spent in each section of your code as well as the amount of memory allocated to each function and instance. With this information, you can identify bottlenecks and reduce simulation time by optimizing your code. Users have reported up to 75% reductions in simulation time after using the Profiler.

This lesson introduces the Profiler and shows you how to use the main Profiler commands to identify performance bottlenecks.

#### Note



The functionality described in this tutorial requires a profile license feature in your ModelSim license file. Please contact your Mentor Graphics sales representative if you currently do not have such a feature.

---

### Design Files for this Lesson

The example design for this lesson consists of a finite state machine which controls a behavioral memory. The test bench *test\_sm* provides stimulus.

The ModelSim installation comes with Verilog and VHDL versions of this design. The files are located in the following directories:

**Verilog** – `<install_dir>/examples/tutorials/verilog/profiler`

**VHDL** – `<install_dir>/examples/tutorials/vhdl/profiler_sm_seq`

This lesson uses the Verilog version for the exercises. If you have a VHDL license, use the VHDL version instead.

### Related Reading

User's Manual Chapters: [Profiling Performance and Memory Use](#) and [Tcl and Macros \(DO Files\)](#).

### Compile and Load the Design

1. Create a new directory and copy the tutorial files into it.

Start by creating a new directory for this exercise (in case other users will be working with these lessons). Create the directory and copy all files from `<install_dir>/examples/tutorials/verilog/profiler` to the new directory.

If you have a VHDL license, copy the files in `<install_dir>/examples/tutorials/vhdl/profiler_sm_seq` instead.

2. Start ModelSim and change to the exercise directory.

If you just finished the previous lesson, ModelSim should already be running. If not, start ModelSim.

- a. Type **vsim** at a UNIX shell prompt or use the ModelSim icon in Windows.

If the Welcome to ModelSim dialog appears, click **Close**.

- b. Select **File > Change Directory** and change to the directory you created in step 1.

3. Create the work library.

- a. Type **vlib work** at the ModelSim> prompt.

4. Compile the design files.

- a. Verilog: Type **vlog test\_sm.v sm\_seq.v sm.v beh\_sram.v** at the ModelSim> prompt.

**VHDL:** Type **vcom -93 sm.vhd sm\_seq.vhd sm\_sram.vhd test\_sm.vhd** at the ModelSim> prompt.

5. Optimize the design.

- a. Enter the following command at the ModelSim> prompt in the Transcript window:

**vopt +acc test\_sm -o test\_sm\_opt**

The **+acc** switch for the **vopt** command provides visibility into the design for debugging purposes.

The **-o** switch allows you designate the name of the optimized design file (test\_sm\_opt).

---

**Note**

You must provide a name for the optimized design file when you use the vopt command.

---


6. Load the optimized design unit.

- a. Enter **vsim test\_sm\_opt** at the ModelSim> prompt.

## Run the Simulation

You will now run the simulation and view the profiling data.



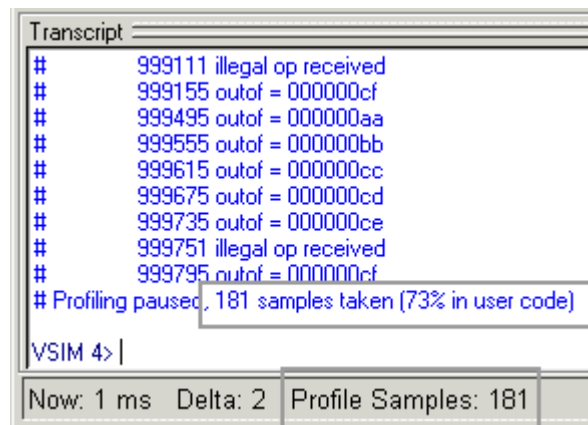
1. Enable the statistical sampling profiler.
  - a. Select **Tools > Profile > Performance** or click the **Performance Profiling** icon in the toolbar. 

This must be done prior to running the simulation. ModelSim is now ready to collect performance data when the simulation is run.

2. Run the simulation.
  - a. Type **run 1 ms** at the VSIM> prompt.

Notice that the number of samples taken is displayed both in the Transcript and the Main window status bar (Figure 12-1). (Your results may not match those in the figure.) Also, ModelSim reports the percentage of samples that were taken in your design code (versus in internal simulator code).

**Figure 12-1. Sampling Reported in the Transcript**



## View Performance Data in Profile Windows

Statistical performance data is displayed in four profile windows: Ranked, Call Tree, Structural, and Design Unit. Additional profile details about those statistics are displayed in the Profile Details window. All of these windows are accessible through the **View > Profiling** menu selection in the Main GUI window.

1. View ranked performance profile data.
  - a. Select **View > Profiling > Ranked Profile**.

The Ranked window displays the results of the statistical performance profiler and the memory allocation profiler for each function or instance (Figure 12-2). By default, ranked performance data is sorted by values in the In% column, which shows the percentage of the total samples collected for each function or instance. (Your results may not match those in the figure.)

Figure 12-2. The Ranked Window

Click here to hide or display columns. →

Name	In(raw)	In(%)	Under(%)	Under(raw)
Tcd_WaitForEvent	26	31.0%	31.0%	26
_vl_systf_calltf	14	16.7%	52.4%	44
test_sm.v:92	5	6.0%	6.0%	5
test_sm.v:136	3	3.6%	3.6%	3
TcdpHasSockets	2	2.4%	2.4%	2
sm_seq.v	2	2.4%	2.4%	2
test_sm.v:122	1	1.2%	2.4%	2
Tcd_DeleteTimerHandler	1	1.2%	1.2%	1
_malloc_stack_space	1	1.2%	1.2%	1
_vl_new_general_thread	1	1.2%	1.2%	1
beh_sram.v:22	1	1.2%	1.2%	1

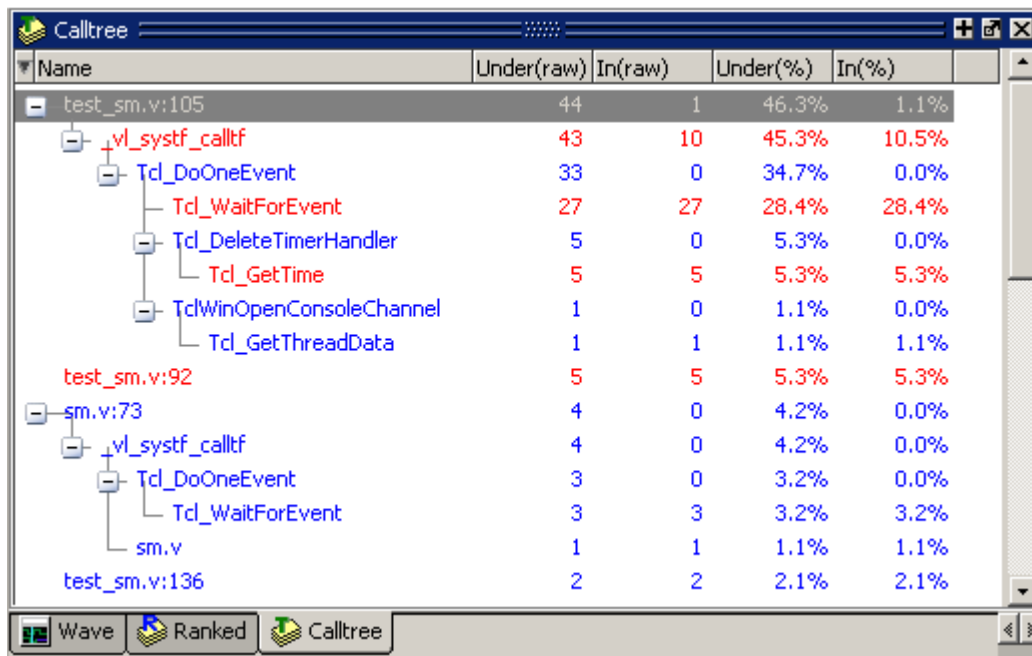
You can sort ranked results by any other column by simply clicking the column heading. Or, click the down arrow to the left of the Name column to open a Configure Columns dialog, which allows you to select which columns are to be hidden or displayed.

The use of colors in the display provides an immediate visual indication of where your design is spending most of its simulation time. By default, red text indicates functions or instances that are consuming 5% or more of simulation time.

The Ranked tab does not provide hierarchical, function-call information.

2. View performance profile data in a hierarchical, function-call tree display.
  - a. Select **View > Profiling > Call Tree Profile**.
  - b. Right-click in the Calltree window and select **Expand All** from the popup window. This displays the hierarchy of function calls (Figure 12-3). Data is sorted (by default) according to the Under(%) column.

**Figure 12-3. Expand the Hierarchical Function Call Tree**

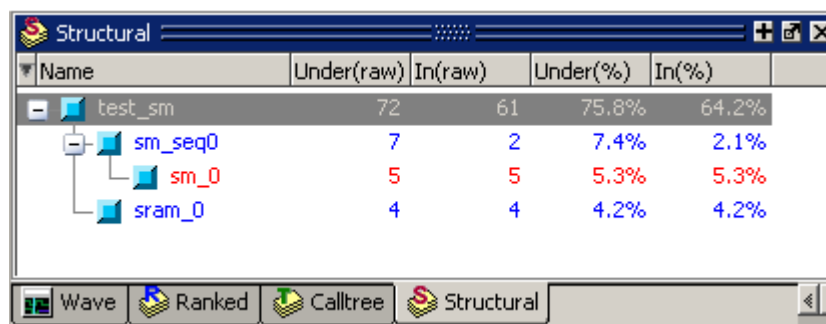


**Note**

Your results may look slightly different as a result of the computer you're using and different system calls that occur during the simulation. Also, the line number reported may be one or two lines off in the actual source file. This happens due to how the stacktrace is decoded on different platforms.

3. View instance-specific performance profile data in a hierarchical format.
  - a. Select **View > Profiling > Structural Profile**.
  - b. Right-click in the Structural profile window and select Expand All from the popup menu. Figure 12-4 displays information found in the Calltree window but adds an additional dimension with which to categorize performance samples. Data is sorted (by default) according to the Under(%) column.

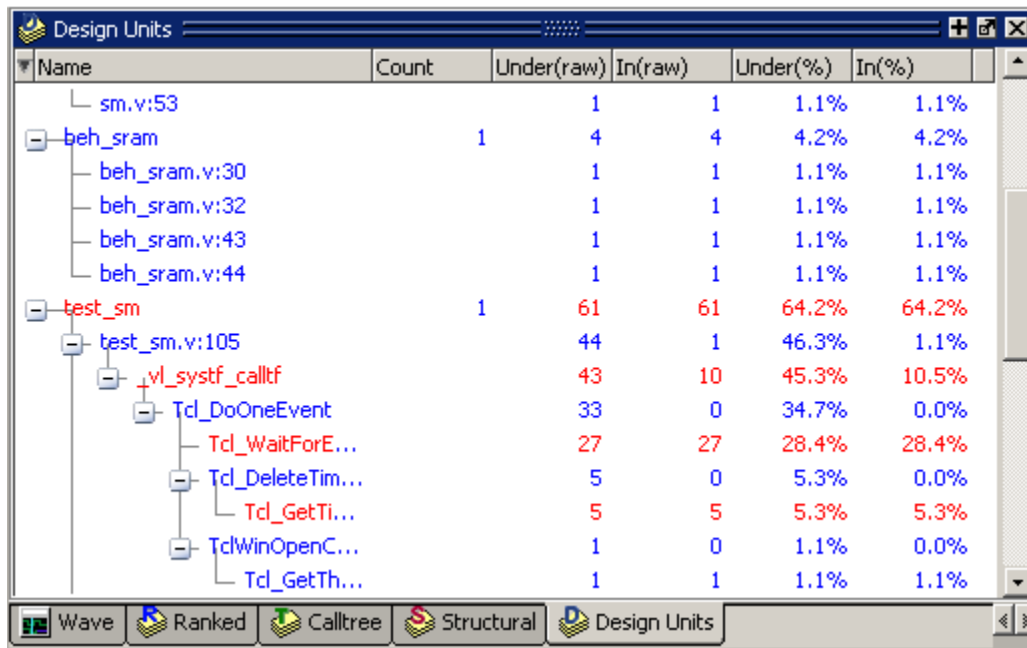
**Figure 12-4. Structural Profile Window**



4. View performance profile data organized by design unit.
  - a. Select **View > Profiling > Design Unit Profile**.

The Design Units profile window provides information similar to the Structural profile window, but organized by design unit, rather than hierarchically. Data is sorted (by default) according to the Under(%) column.

**Figure 12-5. Design Unit Performance Profile**



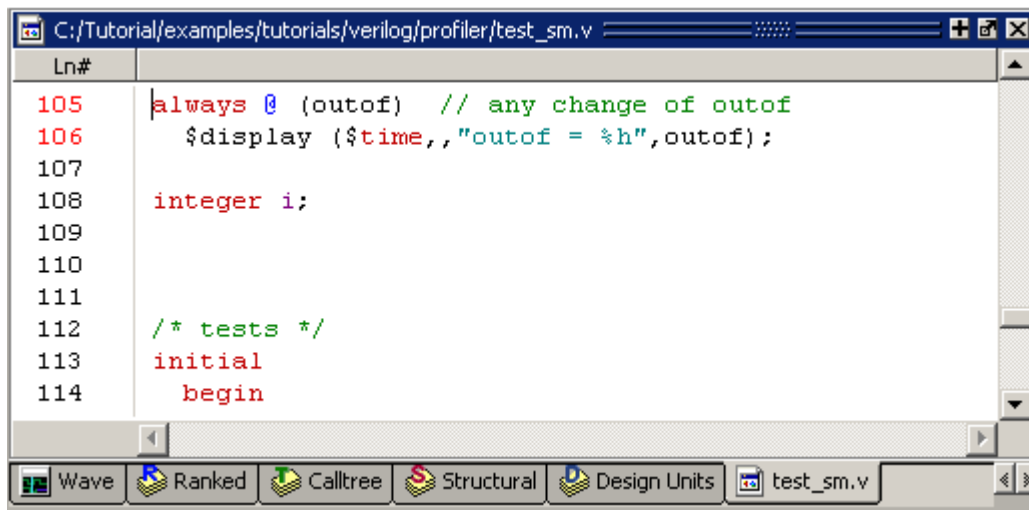
## View Source Code by Clicking in Profile Window

The performance profile windows are dynamically linked to the Source window. You can double-click a specific instance, function, design unit, or line and jump directly to the relevant source code in a Source window. You can perform the same task by right-clicking any function, instance, design unit, or line in any of the profile windows and selecting **View Source** from the popup menu.

- a. **Verilog:** Double-click *test\_sm.v:105* in the Design Units profile window. The Source window opens with line 105 displayed (Figure 12-6).

**VHDL:** Double-click *test\_sm.vhd:203*. The Source window opens with line 203 displayed.

Figure 12-6. Source Window Shows Line from Profile Data



## View Profile Details

The Profile Details window increases visibility into simulation performance. Right-clicking any function in the Ranked or Call Tree windows opens a popup menu that includes a **Function Usage** selection. When you select **Function Usage**, the Profile Details window opens and displays all instances that use the selected function.

1. View the Profile Details of a function in the Call Tree window.
  - a. Right-click the *Tcl\_WaitForEvent* function and select **Function Usage** from the popup menu.

The Profile Details window displays all instances using function *Tcl\_WaitForEvent* (Figure 12-7). The statistical performance data show how much simulation time is used by *Tcl\_WaitForEvent* in each instance.

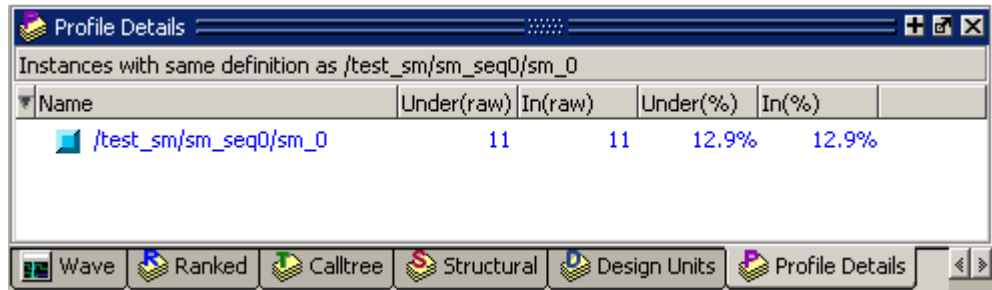
Figure 12-7. Profile Details of the Function *Tcl\_Close*

Name	Under(raw)	In(raw)	Under(%)	In(%)
/test_sm	19	19	22.4%	22.4%
/test_sm/sm_seq0/sm_0	6	6	7.1%	7.1%

When you right-click a selected function or instance in the Structural window, the popup menu displays either a Function Usage selection or an Instance Usage selection, depending on the object selected.

1. View the Profile Details of an instance in the Structural window.
  - a. Select the **Structural** tab to change to the Structural window.
  - b. Right-click *test\_sm* and select **Expand All** from the popup menu.
  - c. **Verilog:** Right-click the *sm\_0* instance and select **Instance Usage** from the popup menu. The Profile Details shows all instances with the same definition as */test\_sm/sm\_seq0/sm\_0* (Figure 12-8).

**Figure 12-8. Profile Details of Function *sm\_0***



Name	Under(raw)	In(raw)	Under(%)	In(%)
/test_sm/sm_seq0/sm_0	11	11	12.9%	12.9%

**VHDL:** Right-click the *dut* instance and select **Instance Usage** from the popup menu. The Profile Details shows all instances with the same definition as */test\_sm/dut*.

## Filtering the Data

As a last step, you will filter out lines that take less than 3% of the simulation time using the Profiler toolbar.

1. Filter lines that take less than 3% of the simulation time.
  - a. Click the **Calltree** tab to change to the Calltree window.
  - b. Change the **Under(%)** field to 3 (Figure 12-9).

**Figure 12-9. The Profile Toolbar**



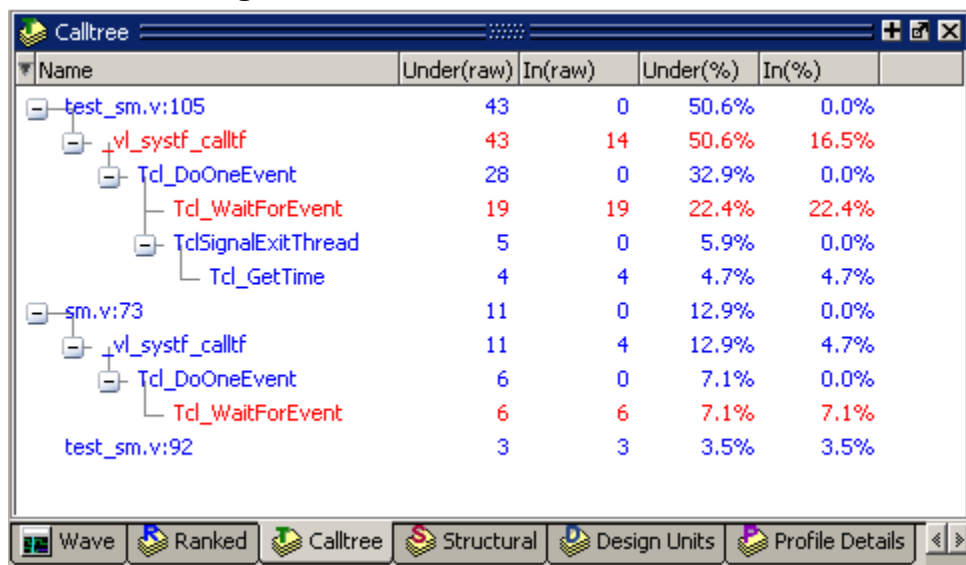
If you do not see these toolbar buttons, right-click in a blank area of the toolbar and select Profile from the popup menu of available toolbars.

- c. Click the **Refresh Profile Data** button.



ModelSim filters the list to show only those lines that take 3% or more of the simulation time (Figure 12-10).

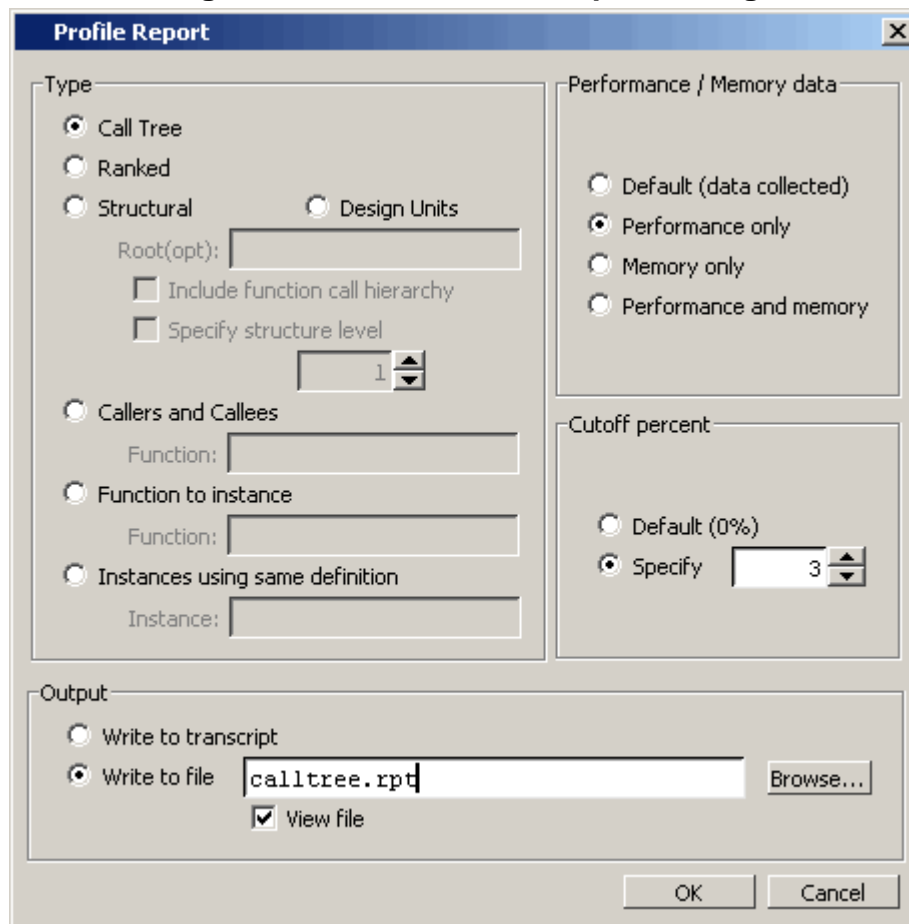
**Figure 12-10. The Filtered Profile Data**



## Creating a Performance Profile Report

1. Create a call tree type report of the performance profile.
  - a. With the Calltree window open, select **Tools > Profile > Profile Report** from the menus to open the Profile Report dialog.
  - b. In the Profile Report dialog (Figure 12-11), select the **Call Tree** Type.

**Figure 12-11. The Profile Report Dialog**

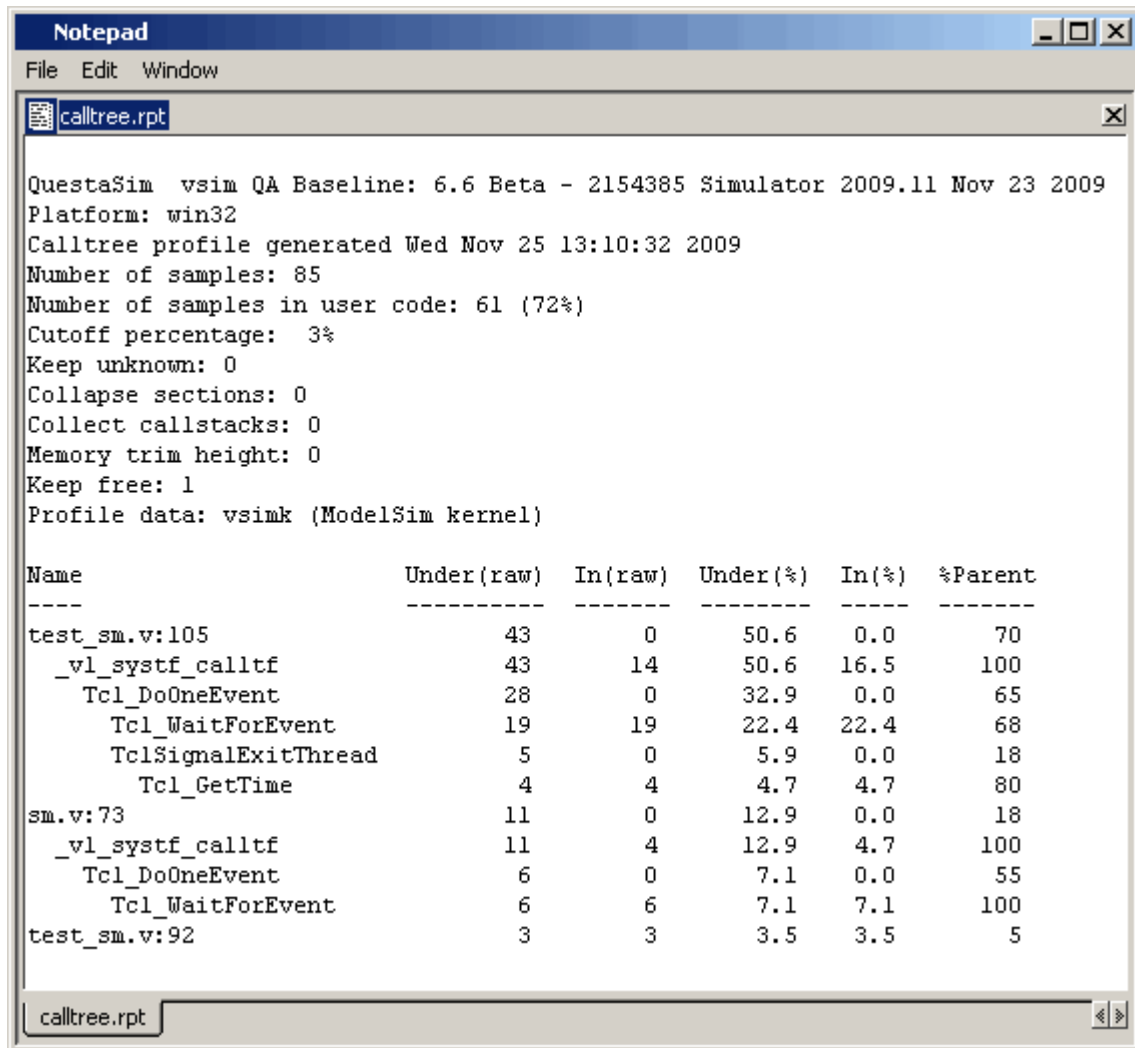


- c. In the Performance/Memory data section select **Performance only**.
- d. Specify the **Cutoff percent** as 3%.
- e. Select **Write to file** and type calltree.rpt in the file **name** field.
- f. **View file** is selected by default when you select **Write to file**. Leave it selected.
- g. Click **OK**.

The *calltree.rpt* report file will open automatically in Notepad ([Figure 12-12](#)).



Figure 12-12. The *calltree.rpt* Report



```

QuestaSim vsim QA Baseline: 6.6 Beta - 2154385 Simulator 2009.11 Nov 23 2009
Platform: win32
Calltree profile generated Wed Nov 25 13:10:32 2009
Number of samples: 85
Number of samples in user code: 61 (72%)
Cutoff percentage: 3%
Keep unknown: 0
Collapse sections: 0
Collect callstacks: 0
Memory trim height: 0
Keep free: 1
Profile data: vsimk (ModelSim kernel)

```

Name	Under(raw)	In(raw)	Under(%)	In(%)	%Parent
test_sm.v:105	43	0	50.6	0.0	70
_vl_systf_calltf	43	14	50.6	16.5	100
Tcl_DoOneEvent	28	0	32.9	0.0	65
Tcl_WaitForEvent	19	19	22.4	22.4	68
Tcl_SignalExitThread	5	0	5.9	0.0	18
Tcl_GetTime	4	4	4.7	4.7	80
sm.v:73	11	0	12.9	0.0	18
_vl_systf_calltf	11	4	12.9	4.7	100
Tcl_DoOneEvent	6	0	7.1	0.0	55
Tcl_WaitForEvent	6	6	7.1	7.1	100
test_sm.v:92	3	3	3.5	3.5	5

You can also output this report from the command line using the **profile report** command. See the *ModelSim Command Reference* for details.

## Lesson Wrap-Up

This concludes this lesson. Before continuing we need to end the current simulation.

Select **Simulate > End Simulation**. Click Yes.



# Chapter 13

## Simulating With Code Coverage

---

### Introduction

ModelSim Code Coverage gives you graphical and report file feedback on which executable statements, branches, conditions, and expressions in your source code have been executed. It also measures bits of logic that have been toggled during execution.

#### Note



The functionality described in this lesson requires a coverage license feature in your ModelSim license file. Please contact your Mentor Graphics sales representative if you currently do not have such a feature.

---

### Design Files for this Lesson

The sample design for this lesson consists of a finite state machine which controls a behavioral memory. The test bench *test\_sm* provides stimulus.

The ModelSim installation comes with Verilog and VHDL versions of this design. The files are located in the following directories:

**Verilog** – `<install_dir>/examples/tutorials/verilog/coverage`

**VHDL** – `<install_dir>/examples/tutorials/vhdl/coverage`

This lesson uses the Verilog version in the examples. If you have a VHDL license, use the VHDL version instead. When necessary, we distinguish between the Verilog and VHDL versions of the design.

### Related Reading

User's Manual Chapter: [Code Coverage](#).

### Compile the Design

Enabling Code Coverage is a simple process: You compile the design files and identify which coverage statistics you want to collect. Then you load the design and tell ModelSim to produce those statistics.

1. Create a new directory and copy the tutorial files into it.

Start by creating a new directory for this exercise (in case other users will be working with these lessons). Create the directory and copy all files from `<install_dir>/modeltech/examples/tutorials/verilog/coverage` to the new directory.

If you have a VHDL license, copy the files in `<install_dir>/modeltech/examples/tutorials/vhdl/coverage` instead.

2. Start ModelSim and change to the exercise directory.

If you just finished the previous lesson, ModelSim should already be running. If not, start ModelSim.

- a. Type **vsim** at a UNIX shell prompt or use the ModelSim icon in Windows.

If the Welcome to ModelSim dialog appears, click **Close**.

- b. Select **File > Change Directory** and change to the directory you created in step 1.

3. Create the working library.

- a. Type **vlib work** at the ModelSim> prompt.

4. Compile all design files.

- a. For Verilog – Type **vlog \*.v** at the ModelSim> prompt.

For VHDL – Type **vcom \*.vhd** at the ModelSim> prompt.

5. Designate the coverage statistics you want to collect.

- a. Type **vopt +cover=bcesxf test\_sm -o test\_sm\_opt** at the ModelSim> prompt.

The **+cover=bcesxf** argument instructs ModelSim to collect branch, condition, expression statement, extended toggle, and finite state machine coverage statistics. Refer to the [Overview of Code Coverage Types](#) in the User's Manual for more information on the available coverage types.

The **-o** argument is used to designate a name (in this case, *test\_sm\_opt*) for the optimized design. This argument is required with the **vopt** command.

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#### Note



By default, ModelSim optimizations are performed on all designs (see [Optimizing Designs with vopt](#)).

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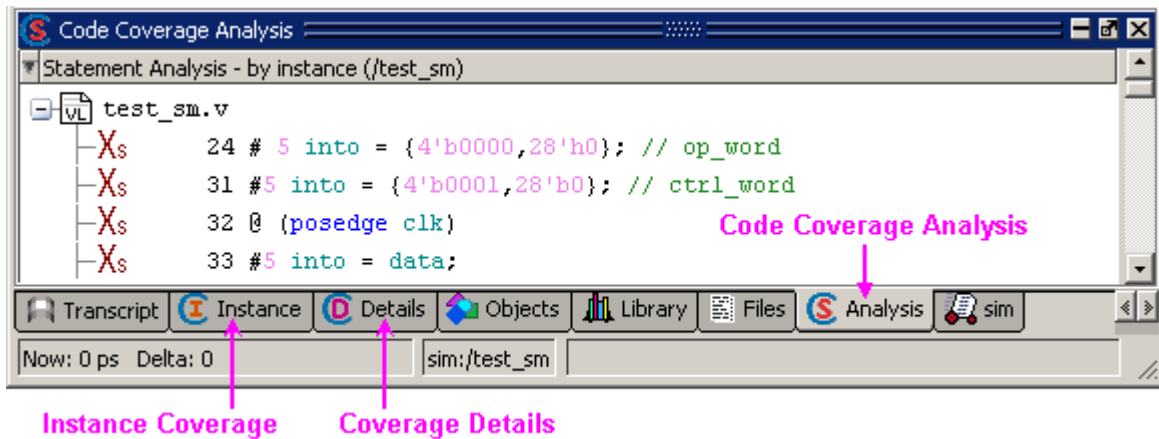
## Load and Run the Design

1. Load the design.

- a. Enter **vsim -coverage test\_sm\_opt** at the ModelSim> prompt. (The optimized design is loaded.)

Three code coverage windows will open: Code Coverage Analysis, Instance Coverage, and Coverage Details (Figure 13-1).

**Figure 13-1. Code Coverage Windows**








Within the Code Coverage Analysis window you can perform statement, branch, condition, expression, FSM, and toggle coverage analysis. Each line in the Code Coverage analysis window includes an icon that indicates whether elements in the line (statements, branches, conditions, or expressions) were executed, not executed, or excluded. Table 13-1 displays the Code Coverage icons.

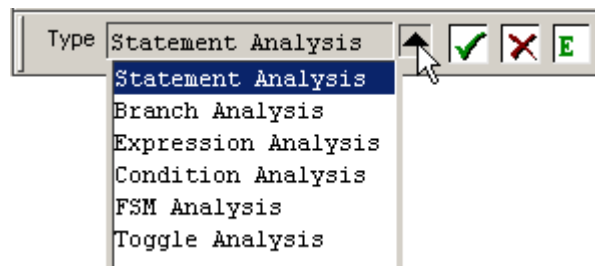
**Table 13-1. Code Coverage Icons**

Icon	Description/Indication
✓	All statements, branches, conditions, or expressions on a particular line have been executed
X	Multiple kinds of coverage on the line were not executed
X <sub>T</sub>	True branch not executed (BC column)
X <sub>F</sub>	False branch not executed (BC column)
X <sub>C</sub>	Condition not executed (Hits column)
X <sub>E</sub>	Expression not executed (Hits column)
X <sub>B</sub>	Branch not executed (Hits column)
X <sub>S</sub>	Statement not executed (Hits column)

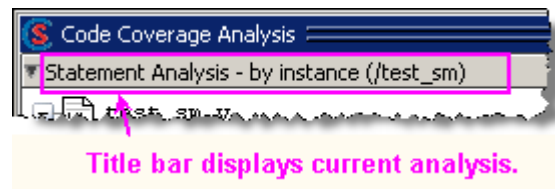
**Table 13-1. Code Coverage Icons**

Icon	Description/Indication
	Indicates a line of code to which active coverage exclusions have been applied. Every item on the line is excluded; none are hit.
	Some excluded items are hit
	Some items are excluded, and all items not excluded are hit
	Some items are excluded, and some items not excluded have missing coverage
	Auto exclusions have been applied to this line. Hover the cursor over the E <sub>A</sub> and a tool tip balloon appears with the reason for exclusion,

You can select the analysis you want to perform in the Analysis toolbar (Figure 13-2).

**Figure 13-2. Analysis Toolbar**

You can identify which analysis is currently open by the title bar in the Code Coverage Analysis window (Figure 13-3).

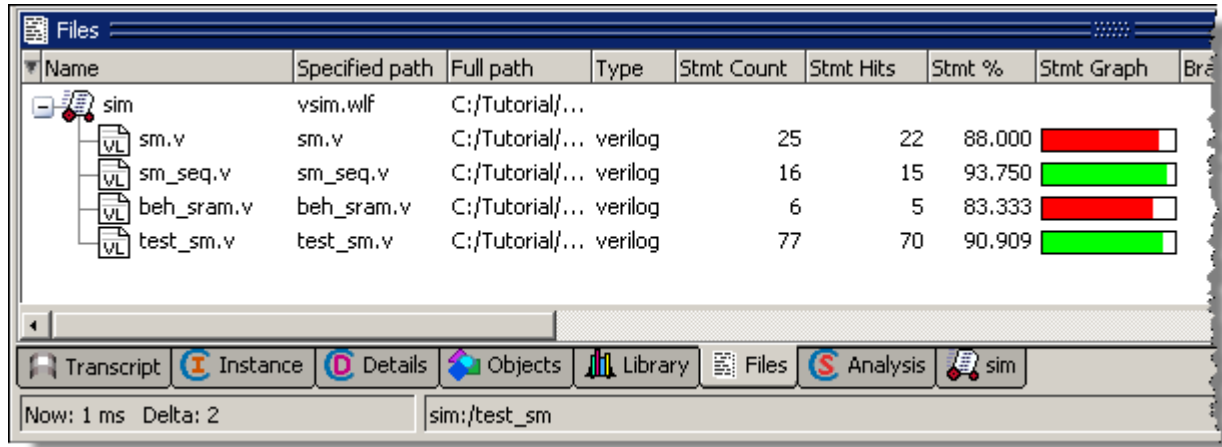
**Figure 13-3. Title Bar Displays Current Analysis**

By default, Statement Analysis is displayed the first time the Code Coverage Analysis window opens. For subsequent invocations, the last-chosen analysis window is displayed.

2. Run the simulation
  - a. Type **run 1 ms** at the VSIM> prompt.

When you load a design with Code Coverage enabled, ModelSim adds several coverage data columns to the Files and Structure (sim) windows (Figure 13-4). Use the horizontal scroll bar to see more coverage data columns. (Your results may not match those shown in the figure.)

**Figure 13-4. Code Coverage Columns in the Structure (sim) Window**

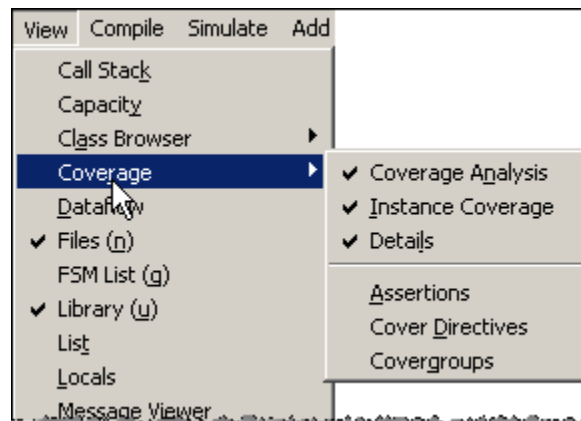


Name	Specified path	Full path	Type	Stmt Count	Stmt Hits	Stmt %	Stmt Graph	Branch
sim	vsim.wlf	C:/Tutorial/...						
VL sm.v	sm.v	C:/Tutorial/...	verilog	25	22	88.000	<div><div></div></div>	
VL sm_seq.v	sm_seq.v	C:/Tutorial/...	verilog	16	15	93.750	<div><div></div></div>	
VL beh_sram.v	beh_sram.v	C:/Tutorial/...	verilog	6	5	83.333	<div><div></div></div>	
VL test_sm.v	test_sm.v	C:/Tutorial/...	verilog	77	70	90.909	<div><div></div></div>	

Now: 1 ms Delta: 2 sim:/test\_sm

You can open and close coverage windows with the **View > Coverage** menu selection.

**Figure 13-5. Coverage Menu**



All coverage windows can be re-sized, rearranged, and undocked to make the data more easily viewable. To resize a window, click-and-drag on any border. To move a window, click-and-drag on the header handle (three rows of dots in the middle of the header) or click and drag the tab. To undock a window you can select it then drag it out of the Main window, or you can click the Dock/Undock button in the header bar (top right). To redock the window, click the Dock/Undock button again.

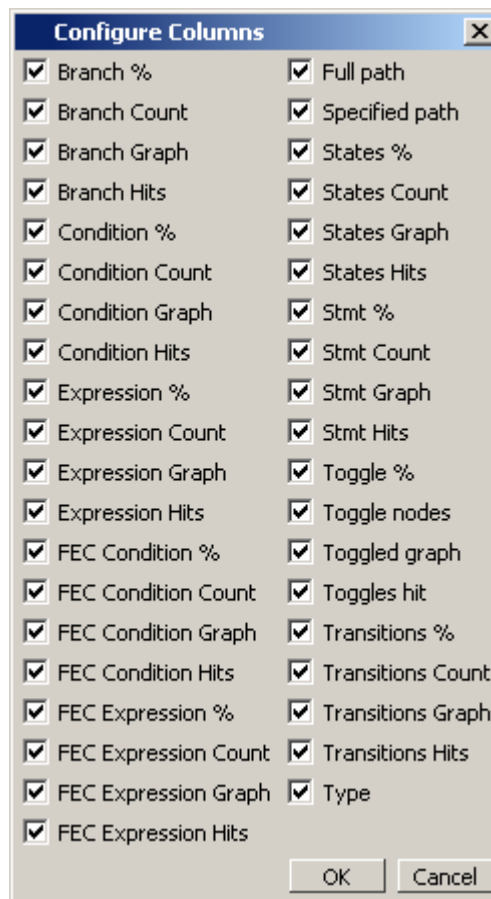
We will look at some of the coverage windows more closely in the next exercise.

## Viewing Coverage Data

Let's take a look at the coverage data displayed in different coverage windows.

1. View coverage data in the Structure (sim) window.
  - a. Select the **sim** tab and use the horizontal scroll bar to view coverage data in the coverage columns. Coverage data is shown for each object in the design.
  - b. Select the **Files** tab to switch to the Files window and scroll to the right. You can change which coverage data columns are displayed by right clicking on any column name, selecting **Change Column Visibility**, and selecting columns from the popup list.

**Figure 13-6. Right-click a Column Heading to Show Column List**



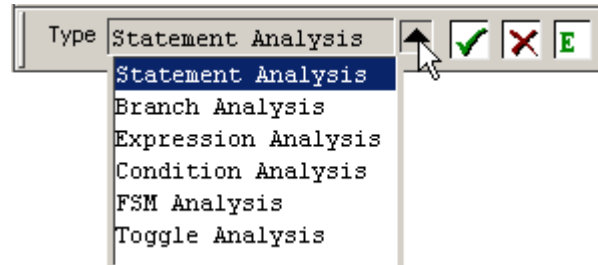
All checked columns are displayed. Unchecked columns are hidden. The status of every column, whether displayed or hidden, is persistent between invocations of ModelSim.

2. View coverage data in the Statement Analysis view of the Code Coverage Analysis window.



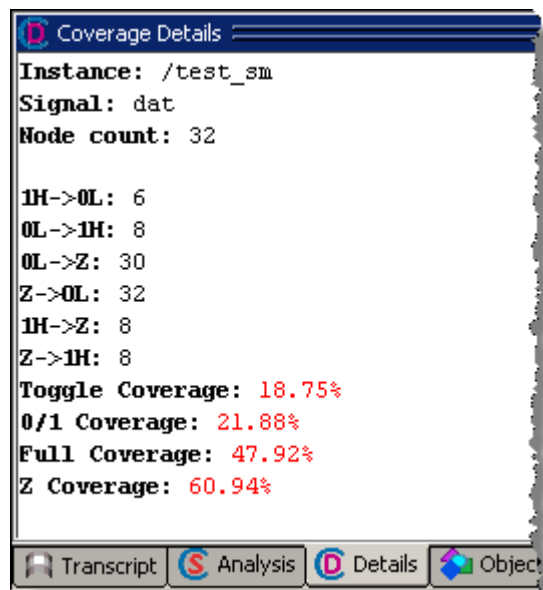
- a. If the Statement Analysis view is not displayed in the Code Coverage Analysis window, select Statement Analysis from the Analysis toolbar (Figure 13-7).

**Figure 13-7. Select Statement Analysis**



- b. Select different files from the Files window. The Code Coverage Analysis window updates to show coverage data for the selected file in the Statement Analysis view.
  - c. Double-click any entry in the Statement Analysis view to display that line in a Source window.
3. View toggle coverage details in the Coverage Details window.
    - a. Switch to the Toggle Analysis view in the Code Coverage Analysis window by selecting the Toggle Analysis in the Analysis Toolbar (Figure 13-7).
    - b. Click the Details tab to open the Coverage Details window.  
If the Details tab is not visible, select **View > Coverage > Details** from the Main menu.
    - c. Select any object in the Toggle Analysis and view its coverage details in the Coverage Details window (Figure 13-8).

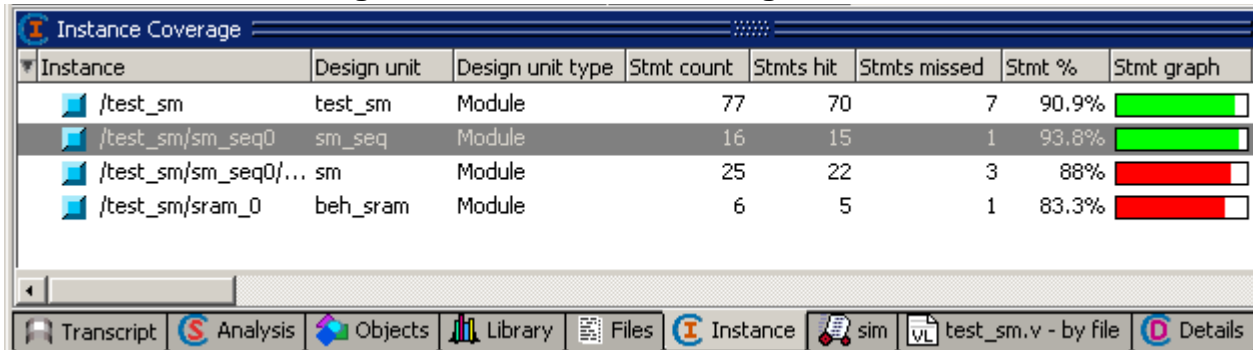
**Figure 13-8. Coverage Details Window Undocked**



4. View instance coverage data.
  - a. Click the Instance tab to switch to the Instance Coverage window. If the Instance tab is not visible, select **View > Coverage > Instance Coverage** from the Main menu.

The Instance Coverage window displays coverage statistics for each instance in a flat, non-hierarchical view. Double-click any instance in the Instance Coverage window to see its source code displayed in the Source window.

**Figure 13-9. Instance Coverage Window**



Instance	Design unit	Design unit type	Stmt count	Stmts hit	Stmts missed	Stmt %	Stmt graph
/test_sm	test_sm	Module	77	70	7	90.9%	<div><div></div></div>
/test_sm/sm_seq0	sm_seq	Module	16	15	1	93.8%	<div><div></div></div>
/test_sm/sm_seq0/...	sm	Module	25	22	3	88%	<div><div></div></div>
/test_sm/sram_0	beh_sram	Module	6	5	1	83.3%	<div><div></div></div>

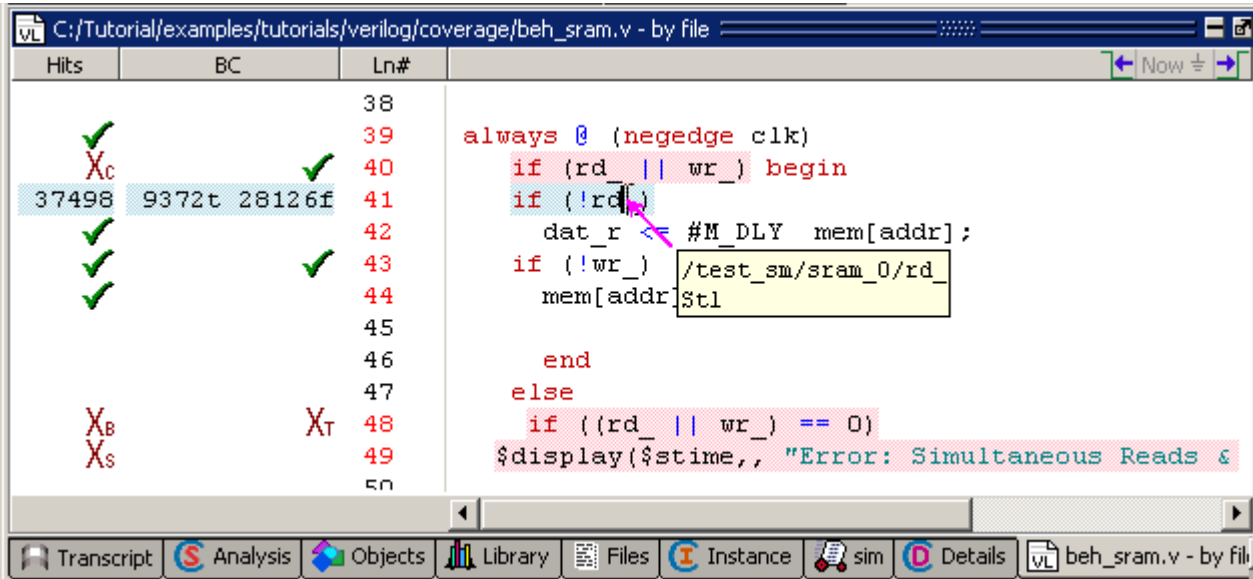
The screenshot shows the 'Instance Coverage' window with a table of coverage data. The table has columns for Instance, Design unit, Design unit type, Stmt count, Stmts hit, Stmts missed, Stmt %, and Stmt graph. The data rows show instances like /test\_sm, /test\_sm/sm\_seq0, /test\_sm/sm\_seq0/..., and /test\_sm/sram\_0 with their respective coverage statistics. The Stmt graph column shows a green bar for each instance, indicating coverage status. Below the table is a toolbar with buttons for Transcript, Analysis, Objects, Library, Files, Instance, sim, test\_sm.v - by file, and Details.

## Coverage Statistics in the Source Window

The Source window contains coverage statistics of its own.

1. View coverage statistics for *beh\_sram* in the Source window.
  - a. Double-click *beh\_sram.v* in the **Files** window to open a source code view in the Source window.
  - b. Scroll the Source window to view the code shown in [Figure 13-10](#).

Figure 13-10. Coverage Statistics in the Source Window



The Source window includes a Hits and a BC column to display statement Hits and Branch Coverage, respectively. In Figure 13-10, the mouse cursor is hovering over the source code in line 41. This causes the coverage icons to change to coverage numbers. Table 13-2 describes the various coverage icons.

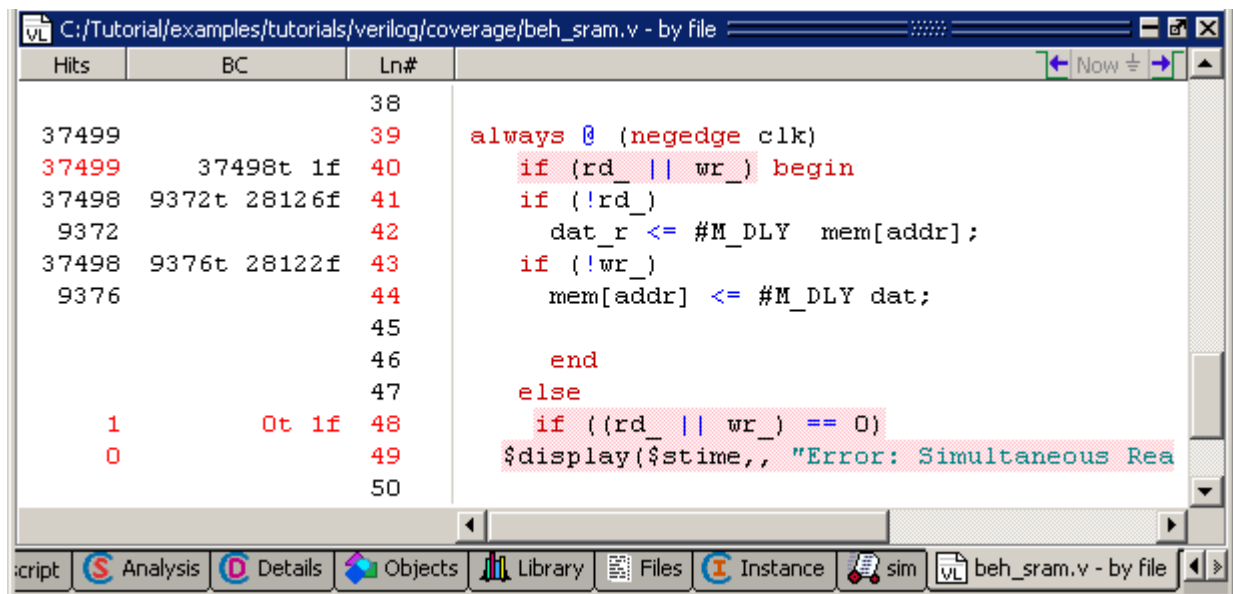
Table 13-2. Coverage Icons in the Source Window

Icon	Description
green checkmark	Indicates a statement that has been executed
green E	Indicates a line that has been excluded from code coverage statistics
red X	An X in the Hits column indicates a missed (unexecuted) statement ( $X_S$ ), branch ( $X_B$ ), or condition ( $X_C$ ). An X in the BC column indicates a missed true ( $X_T$ ) or false ( $X_F$ ) branch.

- c. Select **Tools > Code Coverage > Show coverage numbers**.

The coverage icons in the Hits and BC columns are replaced by execution counts on every line. Red numbers indicate missed coverage in that line of code. An ellipsis (...) is displayed whenever there are multiple statements on the line.

**Figure 13-11. Coverage Numbers Shown by Hovering the Mouse Pointer**



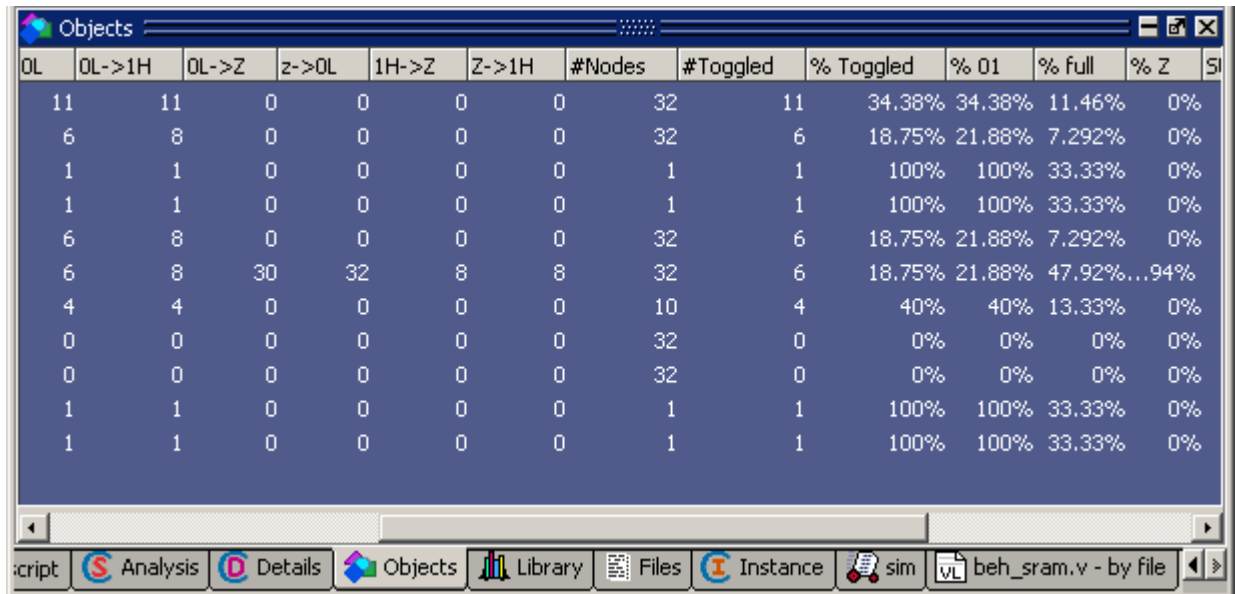
- d. Select **Tools > Code Coverage > Show coverage numbers** again to uncheck the selection and return to icon display.

## Toggle Statistics in the Objects Window

Toggle coverage counts each time a logic node transitions from one state to another. Earlier in the lesson you enabled six-state toggle coverage by using the **-cover x** argument with the **vlog**, **vcom**, or **vopt** command. Refer to the section [Toggle Coverage](#) in the User's Manual for more information.

1. View toggle data in the Objects window.
  - a. Select *test\_sm* in the Structure (sim) window.
  - b. If the Objects window isn't open already, select **View > Objects**. Scroll to the right to see the various toggle coverage columns ([Figure 13-12](#)), or undock and expand the window until all columns are displayed. If you do not see the toggle coverage columns, simply right-click the column title bar and select **Show All Columns** from the popup menu.

Figure 13-12. Toggle Coverage in the Objects Window



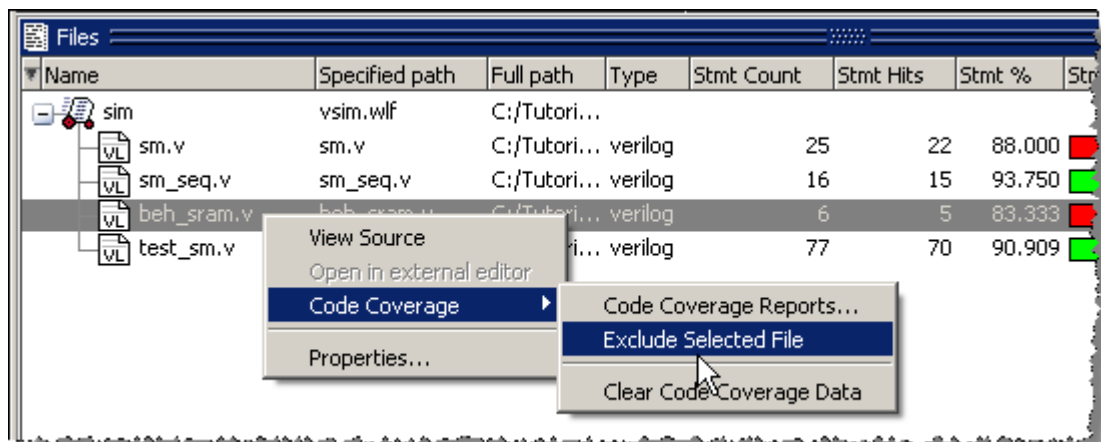
OL	OL->1H	OL->Z	z->OL	1H->Z	Z->1H	#Nodes	#Toggled	% Toggled	% 01	% full	% Z	SI
11	11	0	0	0	0	32	11	34.38%	34.38%	11.46%	0%	
6	8	0	0	0	0	32	6	18.75%	21.88%	7.292%	0%	
1	1	0	0	0	0	1	1	100%	100%	33.33%	0%	
1	1	0	0	0	0	1	1	100%	100%	33.33%	0%	
6	8	0	0	0	0	32	6	18.75%	21.88%	7.292%	0%	
6	8	30	32	8	8	32	6	18.75%	21.88%	47.92%...94%		
4	4	0	0	0	0	10	4	40%	40%	13.33%	0%	
0	0	0	0	0	0	32	0	0%	0%	0%	0%	
0	0	0	0	0	0	32	0	0%	0%	0%	0%	
1	1	0	0	0	0	1	1	100%	100%	33.33%	0%	
1	1	0	0	0	0	1	1	100%	100%	33.33%	0%	

## Excluding Lines and Files from Coverage Statistics

ModelSim allows you to exclude lines and files from code coverage statistics. You can set exclusions with GUI menu selections, with a text file called an "exclusion filter file", or with "pragmas" in your source code. Pragmas are statements that instruct ModelSim to ignore coverage statistics for the bracketed code. Refer to the section [Coverage Exclusions](#) in the User's Manual for more details on exclusion filter files and pragmas.

1. Exclude a line in the Statement Analysis view of the Code Coverage Analysis window.
  - a. Right click a line in the Statement Analysis view and select **Exclude Selection** from the popup menu. (You can also exclude the selection for the current instance only by selecting Exclude Selection For Instance <inst\_name>.)
2. Cancel the exclusion of the excluded statement.
  - a. Right-click the line you excluded in the previous step and select **Cancel Selected Exclusions**.
3. Exclude an entire file.
  - a. In the Files window, locate the *sm.v* file (or the *sm.vhd* file if you are using the VHDL example).
  - b. Right-click the file name and select **Code Coverage > Exclude Selected File** ([Figure 13-13](#)).

Figure 13-13. Excluding a File Using GUI Menus



## Creating Code Coverage Reports

You can create textual or HTML reports on coverage statistics using menu selections in the GUI or by entering commands in the Transcript window. You can also create textual reports of coverage exclusions using menu selections.

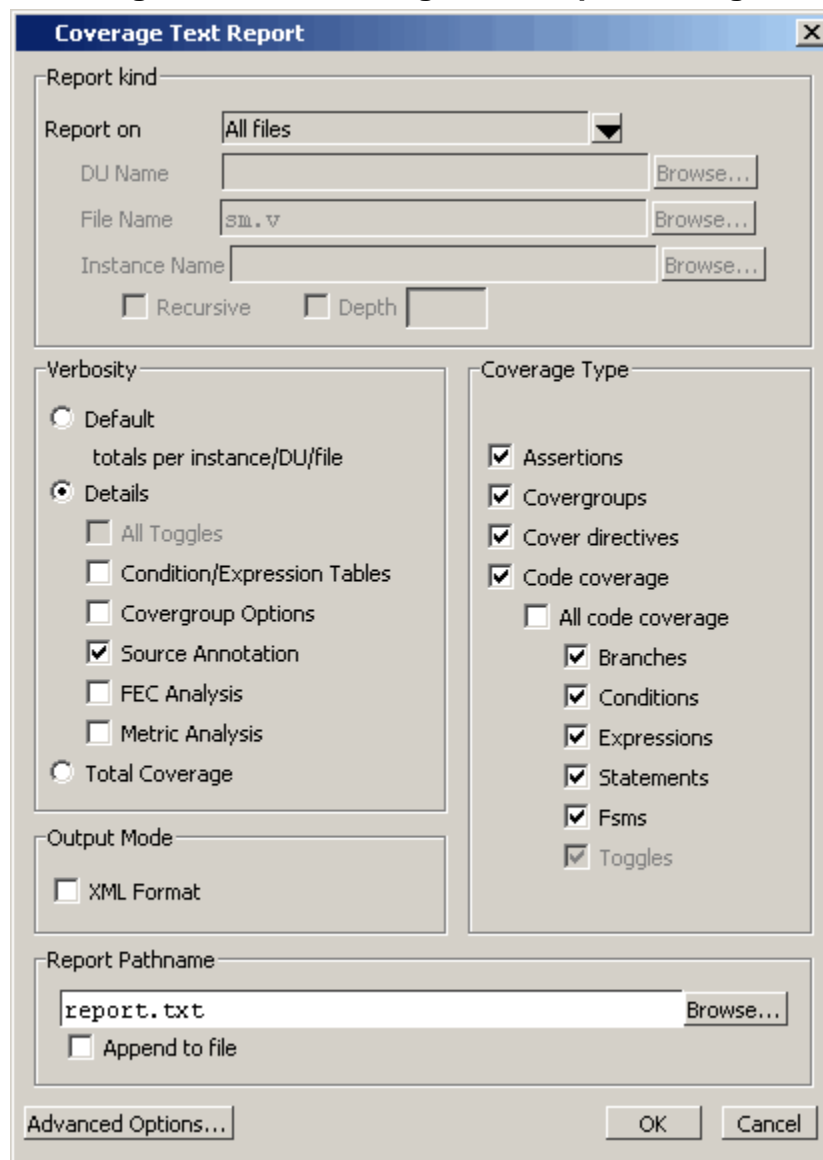
To create textual coverage reports using GUI menu selections, do one of the following:

- Select **Tools > Coverage Report > Text** from the Main window menu bar.
- Right-click any object in the **sim** or **Files** windows and select **Code Coverage > Code Coverage Reports** from the popup context menu.
- Right-click any object in the Instance Coverage window and select **Code coverage reports** from the popup context menu. You may also select **Instance Coverage > Code coverage reports** from the Main window menu bar when the Instance Coverage window is active.

This will open the Coverage Text Report dialog (Figure 13-14) where you can elect to report on:

- all files,
- all instances,
- all design units,
- specified design unit(s),
- specified instance(s), or
- specified source file(s).

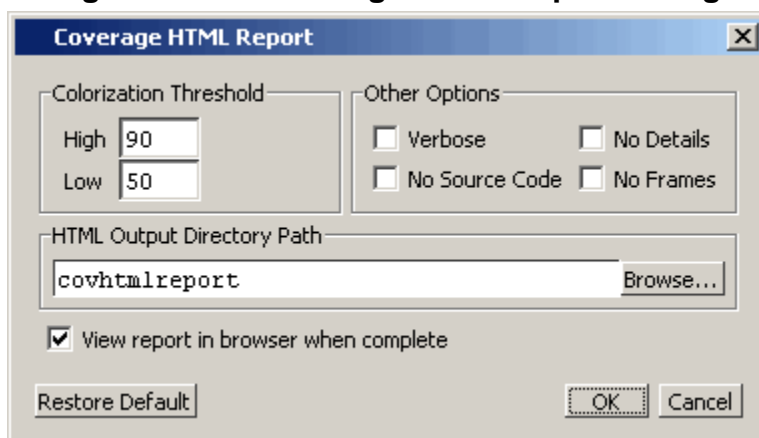
**Figure 13-14. Coverage Text Report Dialog**



ModelSim creates a file (named *report.txt* by default) in the current directory and immediately displays the report in the Notepad text viewer/editor included with the product.

To create a coverage report in HTML, select **Tools > Coverage Report > HTML** from the Main window menu bar. This opens the Coverage HTML Report dialog where you can designate an output directory path for the HTML report.

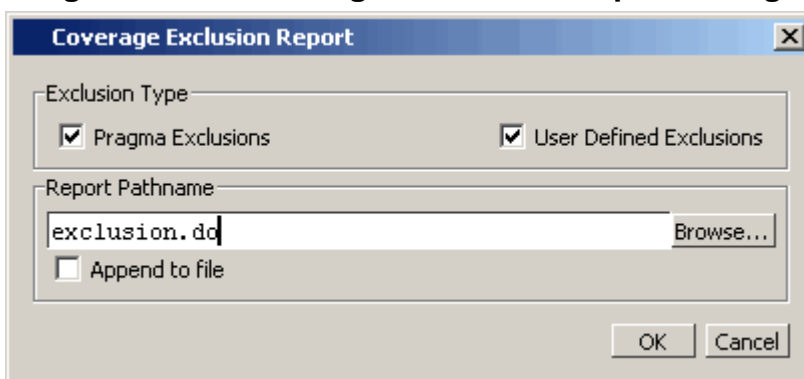
**Figure 13-15. Coverage HTML Report Dialog**



By default, the `coverage report` command will produce textual files unless the `-html` argument is used. You can display textual reports in the Notepad text viewer/editor included with the product by using the `notepad <filename>` command.

To create a coverage exclusions report, select **Tools > Coverage Report > Exclusions** from the Main window menu bar. This opens the Coverage Exclusions Report dialog where you can elect to show only pragma exclusions, only user defined exclusions, or both.

**Figure 13-16. Coverage Exclusions Report Dialog**



## Lesson Wrap-Up

This concludes this lesson. Before continuing we need to end the current simulation.

1. Type **quit -sim** at the VSIM> prompt.



# Chapter 14

## Comparing Waveforms

---

### Introduction

Waveform Compare computes timing differences between test signals and reference signals. The general procedure for comparing waveforms has four main steps:

1. Select the simulations or datasets to compare
2. Specify the signals or regions to compare
3. Run the comparison
4. View the comparison results

In this exercise you will run and save a simulation, edit one of the source files, run the simulation again, and finally compare the two runs.

---

#### Note



The functionality described in this tutorial requires a compare license feature in your ModelSim license file. Please contact your Mentor Graphics sales representative if you currently do not have such a feature.

---

### Design Files for this Lesson

The sample design for this lesson consists of a finite state machine which controls a behavioral memory. The test bench *test\_sm* provides stimulus.

The ModelSim installation comes with Verilog and VHDL versions of this design. The files are located in the following directories:

**Verilog** – *<install\_dir>/examples/tutorials/verilog/compare*

**VHDL** – *<install\_dir>/examples/tutorials/vhdl/compare*

This lesson uses the Verilog version in the examples. If you have a VHDL license, use the VHDL version instead. When necessary, instructions distinguish between the Verilog and VHDL versions of the design.

### Related Reading

User's Manual sections: [Waveform Compare](#) and [Recording Simulation Results With Datasets](#).

## Creating the Reference Dataset

The reference dataset is the *.wlf* file that the test dataset will be compared against. It can be a saved dataset, the current simulation dataset, or any part of the current simulation dataset.

1. Create a new directory and copy the tutorial files into it.

Start by creating a new directory for this exercise (in case other users will be working with these lessons). Create the directory and copy all files from `<install_dir>/examples/tutorials/verilog/compare` to the new directory.

If you have a VHDL license, copy the files in `<install_dir>/examples/tutorials/vhdl/compare` instead.

2. Start ModelSim and change to the exercise directory.

If you just finished the previous lesson, ModelSim should already be running. If not, start ModelSim.

- a. Type **vsim** at a UNIX shell prompt or use the ModelSim icon in Windows.

If the Welcome to ModelSim dialog appears, click **Close**.

- b. Select **File > Change Directory** and change to the directory you created in step 1.

3. Execute the following commands:

- o Verilog

```
vlib work
vlog *.v
vopt +acc test_sm -o opt_test_gold
vsim -wlf gold.wlf opt_test_gold
add wave *
run 750 ns
quit -sim
```

- o VHDL

```
vlib work
vcom -93 sm.vhd sm_seq.vhd sm_sram.vhd test_sm.vhd
vopt +acc test_sm -o opt_test_gold
vsim -wlf gold.wlf opt_test_gold
add wave *
run 750 ns
quit -sim
```

The **-wlf** switch is used with the **vsim** command to create the reference dataset called *gold.wlf*.

## Creating the Test Dataset

The test dataset is the *.wlf* file that will be compared against the reference dataset. Like the reference dataset, the test dataset can be a saved dataset, the current simulation dataset, or any part of the current simulation dataset.

To simplify matters, you will create the test dataset from the simulation you just ran. However, you will edit the test bench to create differences between the two runs.

### Verilog

1. Edit the test bench.
  - a. Select **File > Open** and open *test\_sm.v*.
  - b. Scroll to line 122, which looks like this:

```
@ (posedge clk) wt_wd('h10,'haa);
```
  - c. Change the data pattern 'haa' to 'hab':

```
@ (posedge clk) wt_wd('h10,'hab);
```
  - d. Select **File > Save** to save the file.
2. Compile the revised file and rerun the simulation.

```
vlog test_sm.v
vopt +acc test_sm -o opt_test_sm
vsim opt_test_sm
add wave *
run 750 ns
```

### VHDL

1. Edit the test bench.
  - a. Select **File > Open** and open *test\_sm.vhd*.
  - b. Scroll to line 151, which looks like this:

```
wt_wd ( 16#10#, 16#aa#, clk, into );
```
  - c. Change the data pattern 'aa' to 'ab':

```
wt_wd ( 16#10#, 16#ab#, clk, into );
```
  - d. Select **File > Save** to save the file.
2. Compile the revised file and rerun the simulation.
  - o VHDL

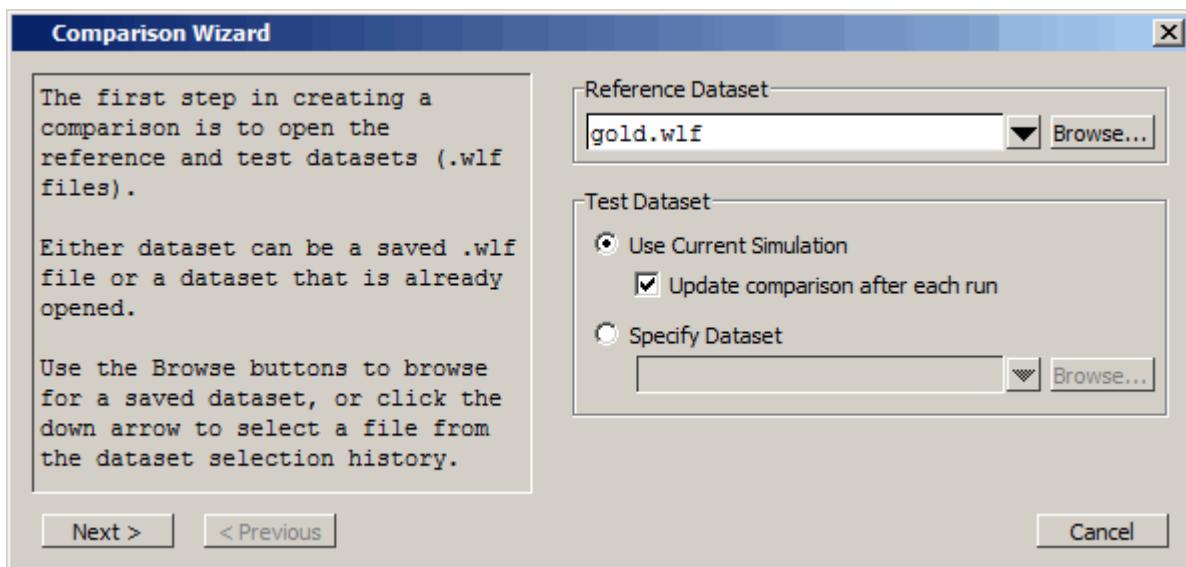
```
vcom test_sm.vhd
vopt +acc test_sm -o opt_test_sm
vsim opt_test_sm
add wave *
run 750 ns
```

## Comparing the Simulation Runs

ModelSim includes a Comparison Wizard that walks you through the process. You can also configure the comparison manually with menu or command line commands.

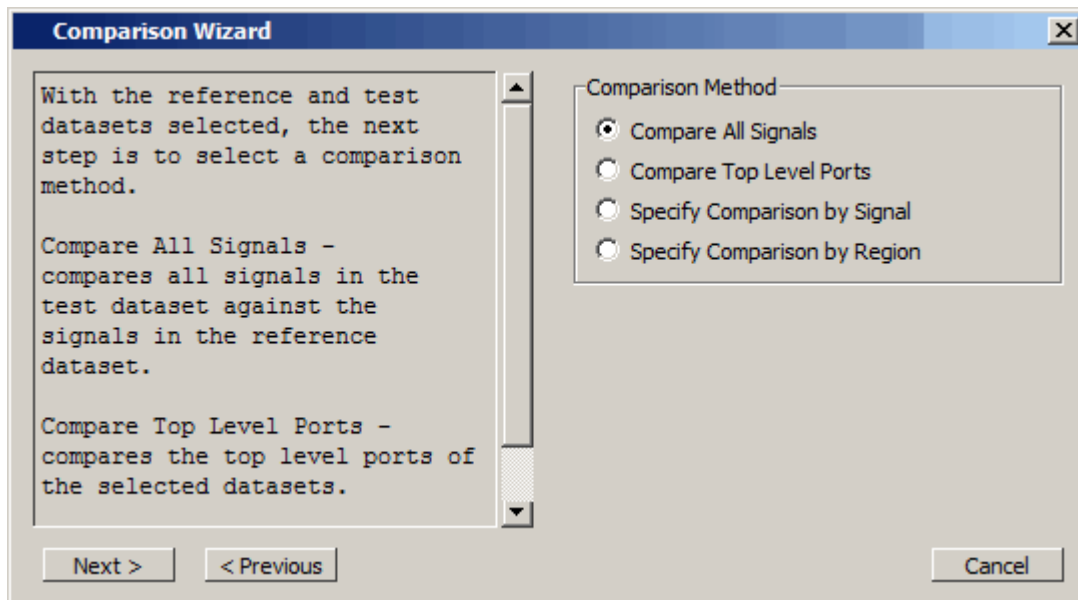
1. Create a comparison using the Comparison Wizard.
  - a. Select **Tools > Waveform Compare > Comparison Wizard**.
  - b. Click the **Browse** button and select *gold.wlf* as the reference dataset (Figure 14-1). Recall that *gold.wlf* is from the first simulation run.

**Figure 14-1. First dialog of the Waveform Comparison Wizard**



- c. Leaving the test dataset set to **Use Current Simulation**, click **Next**.
    - d. Select **Compare All Signals** in the second dialog (Figure 14-2) and click **Next**.

**Figure 14-2. Second dialog of the Waveform Comparison Wizard**



- e. In the next three dialogs, click **Next**, **Compute Differences Now**, and **Finish**, respectively.

ModelSim performs the comparison and displays the compared signals in the Wave window.

## Viewing Comparison Data

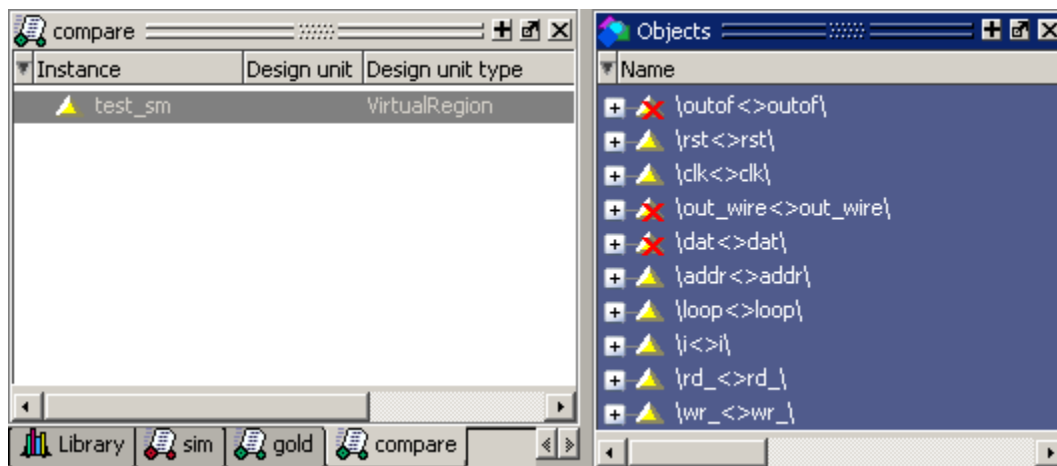
Comparison data is displayed in the Structure (compare), Transcript, Objects, Wave and List windows. Compare objects are denoted by a yellow triangle.

The Compare window shows the region that was compared.

The Transcript window shows the number of differences found between the reference and test datasets.

The Objects window shows comparison differences when you select the comparison object in the Structure (compare) window ([Figure 14-3](#)).

**Figure 14-3. Comparison information in the compare and Objects windows**

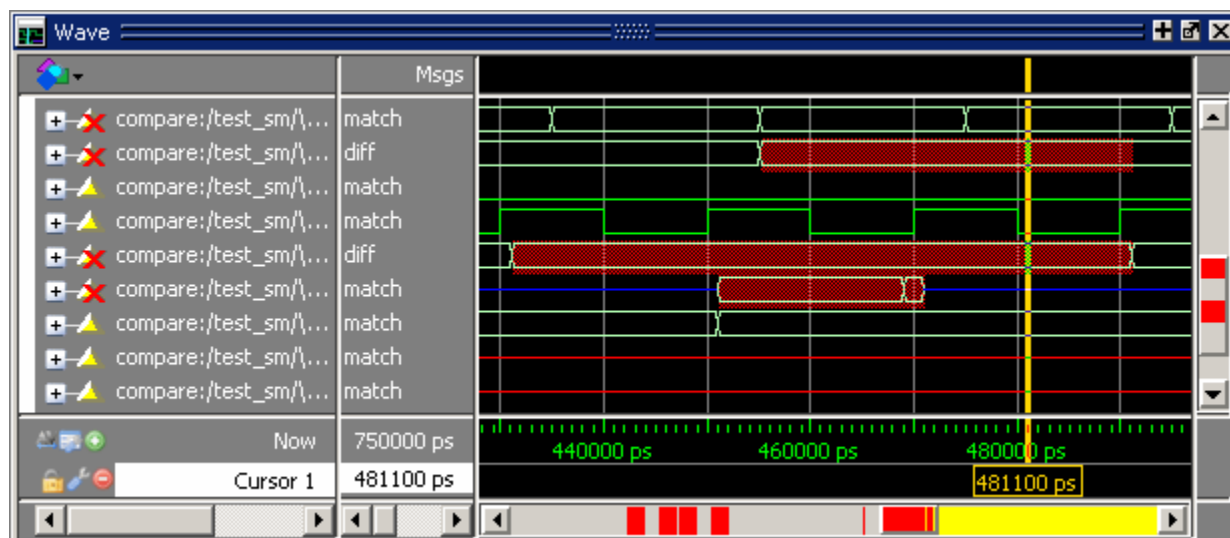


## Comparison Data in the Wave Window

The Wave window displays comparison information as follows:

- timing differences are denoted by a red X's in the pathnames column (Figure 14-4),

**Figure 14-4. Comparison objects in the Wave window**



- red areas in the waveform view show the location of the timing differences,
- red lines in the scrollbars also show the location of timing differences,
- and, annotated differences are highlighted in blue.

The Wave window includes six compare icons that let you quickly jump between differences (Figure 14-5).

**Figure 14-5. The compare icons**



From left to right, the buttons do the following: Find first difference, Find previous annotated difference, Find previous difference, Find next difference, Find next annotated difference, Find last difference. Use these icons to move the selected cursor.

The compare icons cycle through differences on all signals. To view differences in only a selected signal, use <tab> and <shift> - <tab>.

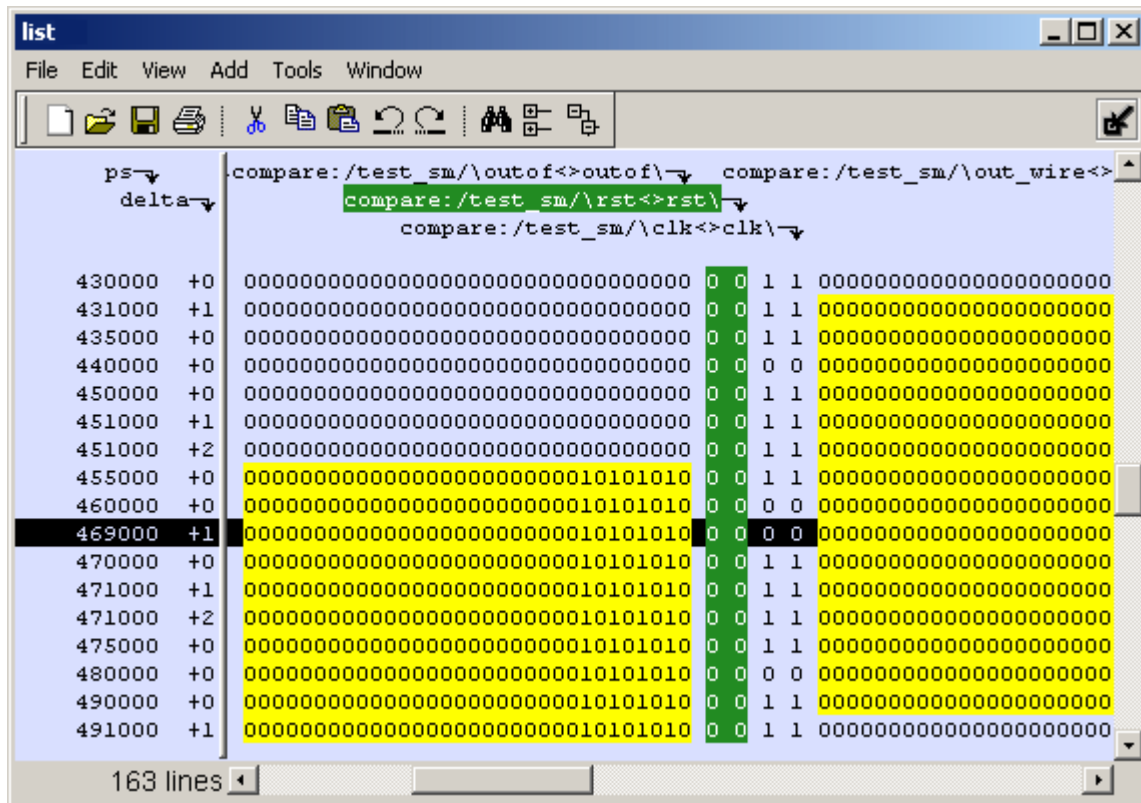
## Comparison Data in the List Window

You can also view the results of your waveform comparison in the List window.

1. Add comparison data to the List window.
  - a. Select **View > List** from the Main window menu bar.
  - b. Drag the *test\_sm* comparison object from the compare tab of the Main window to the List window.
  - c. Scroll down the window.

Differences are noted with yellow highlighting ([Figure 14-6](#)). Differences that have been annotated have red highlighting.

Figure 14-6. Compare differences in the List window



## Saving and Reloading Comparison Data

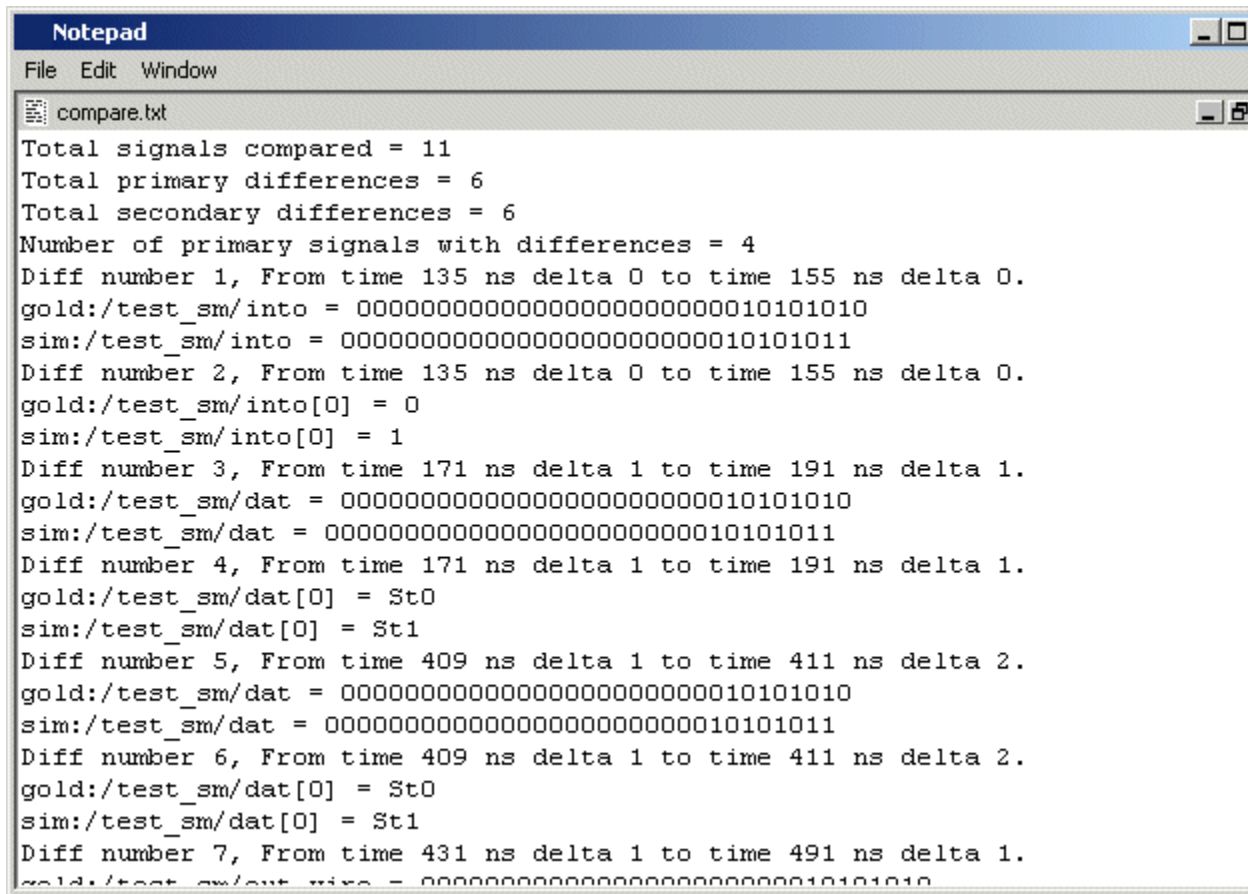
You can save comparison data for later viewing, either in a text file or in files that can be reloaded into ModelSim.

To save comparison data so it can be reloaded into ModelSim, you must save two files. First, you save the computed differences to one file; next, you save the comparison configuration rules to a separate file. When you reload the data, you must have the reference dataset open.

1. Save the comparison data to a text file.
  - a. In the Main window, select **Tools > Waveform Compare > Differences > Write Report**.
  - b. Click **Save**.  
This saves *compare.txt* to the current directory.
  - c. Type **notepad compare.txt** at the VSIM> prompt to display the report (Figure 14-7).



Figure 14-7. Coverage data saved to a text file



```

Notepad
File Edit Window
compare.txt
Total signals compared = 11
Total primary differences = 6
Total secondary differences = 6
Number of primary signals with differences = 4
Diff number 1, From time 135 ns delta 0 to time 155 ns delta 0.
gold:/test_sm/into = 00000000000000000000000010101010
sim:/test_sm/into = 00000000000000000000000010101011
Diff number 2, From time 135 ns delta 0 to time 155 ns delta 0.
gold:/test_sm/into[0] = 0
sim:/test_sm/into[0] = 1
Diff number 3, From time 171 ns delta 1 to time 191 ns delta 1.
gold:/test_sm/dat = 00000000000000000000000010101010
sim:/test_sm/dat = 00000000000000000000000010101011
Diff number 4, From time 171 ns delta 1 to time 191 ns delta 1.
gold:/test_sm/dat[0] = St0
sim:/test_sm/dat[0] = St1
Diff number 5, From time 409 ns delta 1 to time 411 ns delta 2.
gold:/test_sm/dat = 00000000000000000000000010101010
sim:/test_sm/dat = 00000000000000000000000010101011
Diff number 6, From time 409 ns delta 1 to time 411 ns delta 2.
gold:/test_sm/dat[0] = St0
sim:/test_sm/dat[0] = St1
Diff number 7, From time 431 ns delta 1 to time 491 ns delta 1.
gold:/test_sm/out_wire = 00000000000000000000000010101010
  
```

- d. Close Notepad when you have finished viewing the report.
2. Save the comparison data in files that can be reloaded into ModelSim.
  - a. Select **Tools > Waveform Compare > Differences > Save**.
  - b. Click **Save**.  
This saves *compare.dif* to the current directory.
  - c. Select **Tools > Waveform Compare > Rules > Save**.
  - d. Click **Save**.  
This saves *compare.rul* to the current directory.
  - e. Select **Tools > Waveform Compare > End Comparison**.
3. Reload the comparison data.
  - a. With the Structure (sim) window active, select **File > Open**.
  - b. Change the **Files of Type** to Log Files (\*.wlf) (Figure 14-8).

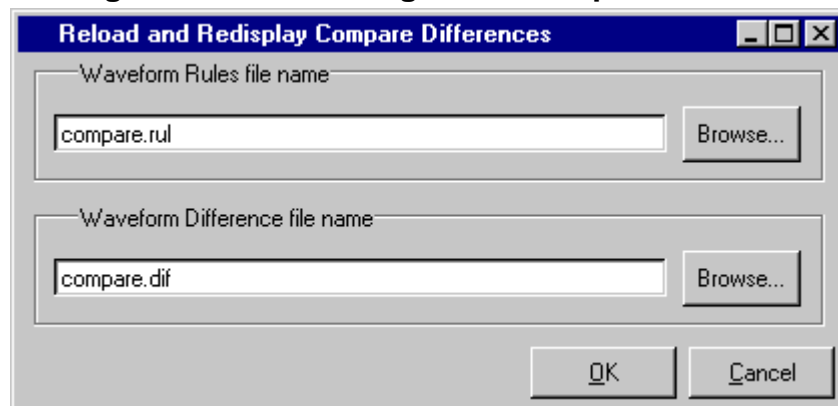
**Figure 14-8. Displaying Log Files in the Open dialog**



- c. Double-click *gold.wlf* to open the dataset.
- d. Select **Tools > Waveform Compare > Reload**.

Since you saved the data using default file names, the dialog should already have the correct Waveform Rules and Waveform Difference files specified (Figure 14-9).

**Figure 14-9. Reloading saved comparison data**



- e. Click **OK**.

The comparison reloads. You can drag the comparison object to the Wave or List window to view the differences again.

## Lesson Wrap-Up

This concludes this lesson. Before continuing we need to end the current simulation and close the *gold.wlf* dataset.

1. Type **quit -sim** at the VSIM> prompt.
2. Type **dataset close gold** at the ModelSim> prompt.

# Chapter 15

## Automating Simulation

---

### Introduction

Aside from executing a couple of pre-existing DO files, the previous lessons focused on using ModelSim in interactive mode: executing single commands, one after another, via the GUI menus or Main window command line. In situations where you have repetitive tasks to complete, you can increase your productivity with DO files.

DO files are scripts that allow you to execute many commands at once. The scripts can be as simple as a series of ModelSim commands with associated arguments, or they can be full-blown Tcl programs with variables, conditional execution, and so forth. You can execute DO files from within the GUI or you can run them from the system command prompt without ever invoking the GUI.

#### Note



This lesson assumes that you have added the `<install_dir>/<platform>` directory to your PATH. If you did not, you will need to specify full paths to the tools (i.e., vlib, vmap, vlog, vcom, and vsim) that are used in the lesson.

---

### Related Reading

User's Manual Chapter: [Tcl and Macros \(DO Files\)](#).

*Practical Programming in Tcl and Tk*, Brent B. Welch, Copyright 1997

## Creating a Simple DO File

Creating a DO file is as simple as typing a set of commands in a text file. In this exercise, you will create a DO file that loads a design, adds signals to the Wave window, provides stimulus to those signals, and then advances the simulation. You can also create a DO file from a saved transcript file. Refer to "[Saving a Transcript File as a Macro \(DO file\)](#)."

1. Change to the directory you created in the "Basic Simulation" lesson.
2. Create a DO file that will add signals to the Wave window, force signals, and run the simulation.
  - a. Select **File > New > Source > Do** to create a new DO file.
  - b. Enter the following commands into the Source window:

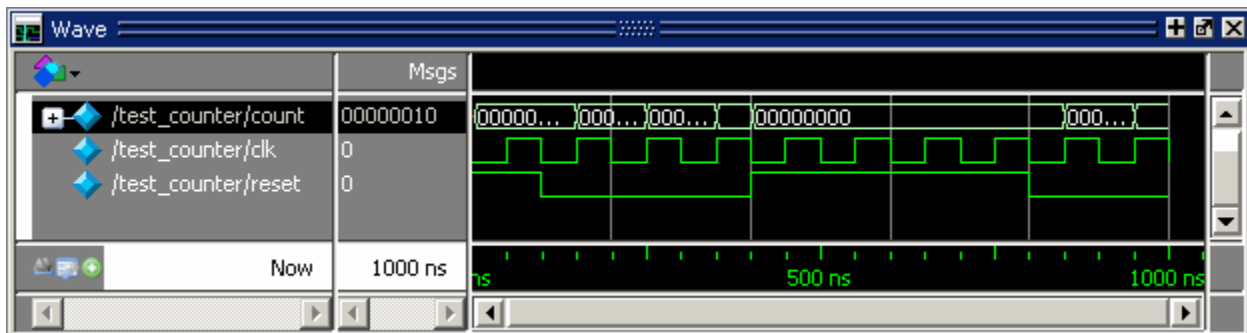
```
vsim testcounter_opt
```

```
add wave count
add wave clk
add wave reset
force -freeze clk 0 0, 1 {50 ns} -r 100
force reset 1
run 100
force reset 0
run 300
force reset 1
run 400
force reset 0
run 200
```

3. Save the file.
  - a. Select **File > Save As**.
  - b. Type **sim.do** in the File name: field and save it to the current directory.
4. Execute the DO file.
  - a. Enter **do sim.do** at the VSIM> prompt.

ModelSim loads the design, executes the saved commands and draws the waves in the Wave window. (Figure 15-1)

**Figure 15-1. Wave Window After Running the DO File**



5. When you are done with this exercise, select **File > Quit** to quit ModelSim.

## Running in Command-Line Mode

We use the term "command-line mode" to refer to simulations that are run from a DOS/ UNIX prompt without invoking the GUI. Several ModelSim commands (e.g., `vsim`, `vlib`, `vlog`, etc.) are actually stand-alone executables that can be invoked at the system command prompt. Additionally, you can create a DO file that contains other ModelSim commands and specify that file when you invoke the simulator.

1. Create a new directory and copy the tutorial files into it.

Start by creating a new directory for this exercise. Create the directory and copy the following files into it:

- `/<install_dir>/examples/tutorials/verilog/automation/counter.v`
- `/<install_dir>/examples/tutorials/verilog/automation/stim.do`

This lesson uses the Verilog file *counter.v*. If you have a VHDL license, use *the counter.vhd* and *stim.do* files in the `/<install_dir>/examples/tutorials/vhdl/automation` directory instead.

2. Create a new design library and compile the source file.

Again, enter these commands at a DOS/ UNIX prompt in the new directory you created in step 1.

- a. Type **vlib work** at the DOS/ UNIX prompt.
- b. For Verilog, type **vlog counter.v** at the DOS/ UNIX prompt. For VHDL, type **vcom counter.vhd**.

3. Create a DO file.

- a. Open a text editor.
- b. Type the following lines into a new file:

```
# list all signals in decimal format
add list -decimal *

# read in stimulus
do stim.do

# output results
write list counter.lst

# quit the simulation
quit -f
```

- c. Save the file with the name *sim.do* and place it in the current directory.

4. Optimize the counter design unit.

- a. Enter the following command at the DOS/UNIX prompt:  
**vopt +acc counter -o counter\_opt**

5. Run the batch-mode simulation.

- a. Enter the following command at the DOS/UNIX prompt:  
**vsim -c -do sim.do counter\_opt -wlf counter\_opt.wlf**

The **-c** argument instructs ModelSim not to invoke the GUI. The **-wlf** argument saves the simulation results in a WLF file. This allows you to view the simulation results in the GUI for debugging purposes.

6. View the list output.
  - a. Open *counter.lst* and view the simulation results. Output produced by the Verilog version of the design should look like the following:

```

ns      /counter/count
delta   /counter/clk
        /counter/reset
0 +0    x z *
3 +0    0 z *
50 +0   0 * *
100 +0  0 0 *
100 +1  0 0 0
150 +0  0 * 0
152 +0  1 * 0
200 +0  1 0 0
250 +0  1 * 0
.
.
.

```

The output may appear slightly different if you used the VHDL version.

7. View the results in the GUI.

Since you saved the simulation results in *counter\_opt.wlf*, you can view them in the GUI by invoking VSIM with the **-view** argument.

#### Note



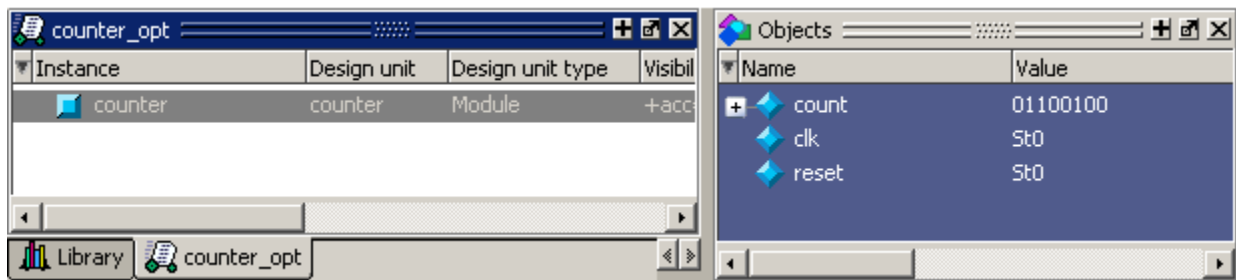
Make sure your PATH environment variable is set with the current version of ModelSim at the front of the string.

---

- a. Type **vsim -view counter\_opt.wlf** at the DOS/ UNIX prompt.

The GUI opens and a dataset tab named "counter\_opt" is displayed (Figure 15-2).

**Figure 15-2. The counter\_opt.wlf Dataset in the Main Window Workspace**



- b. Right-click the *counter* instance and select **Add > To Wave > All items in region**.

The waveforms display in the Wave window.

8. When you finish viewing the results, select **File > Quit** to close ModelSim.

## Using Tcl with the Simulator

The DO files used in previous exercises contained only ModelSim commands. However, DO files are really just Tcl scripts. This means you can include a whole variety of Tcl constructs such as procedures, conditional operators, math and trig functions, regular expressions, and so forth.

In this exercise, you create a simple Tcl script that tests for certain values on a signal and then adds bookmarks that zoom the Wave window when that value exists. Bookmarks allow you to save a particular zoom range and scroll position in the Wave window. The Tcl script also creates buttons in the Main window called bookmarks.

1. Create the script.

- a. In a text editor, open a new file and enter the following lines:

```
proc add_wave_zoom {stime num} {  
    echo "Bookmarking wave $num"  
    bookmark add wave "bk$num" "[expr $stime - 50] [expr $stime + 100]" 0  
    add button "$num" [list bookmark goto wave bk$num]  
}
```

These commands do the following:

- Create a new procedure called "add\_wave\_zoom" that has two arguments, *stime* and *num*.
- Create a bookmark with a zoom range from the current simulation time minus 50 time units to the current simulation time plus 100 time units.
- Add a button to the Main window that calls the bookmark.

- b. Now add these lines to the bottom of the script:

```
add wave -r /*  
when {clk'event and clk="1"} {  
    echo "Count is [exa count]"  
    if {[examine count]== "00100111"} {  
        add_wave_zoom $now 1  
    } elseif {[examine count]== "01000111"} {  
        add_wave_zoom $now 2  
    }  
}
```

These commands do the following:

- Add all signals to the Wave window.
- Use a **when** statement to identify when *clk* transitions to 1.
- Examine the value of *count* at those transitions and add a bookmark if it is a certain value.

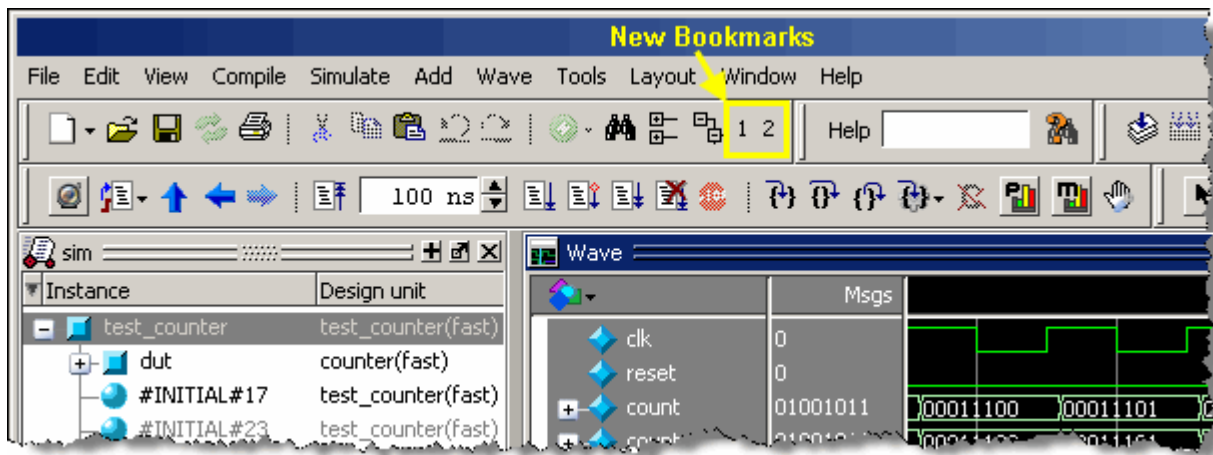
- c. Save the script with the name "*add\_bkmrk.do*" into the directory you created in the [Basic Simulation](#) lesson.

2. Load the *test\_counter* design unit.
  - a. Start ModelSim.
  - b. Select **File > Change Directory** and change to the directory you saved the DO file to in step 1c above.
  - c. Enter the following command at the QuestaSim> prompt:  
**vsim testcounter\_opt**
3. Execute the DO file and run the design.
  - a. Type **do add\_bkmrk.do** at the VSIM> prompt.
  - b. Type **run 1500 ns** at the VSIM> prompt.

The simulation runs and the DO file creates two bookmarks.

It also creates buttons (labeled "1" and "2") on the Main window toolbar that jump to the bookmarks (Figure 15-3).

**Figure 15-3. Buttons Added to the Main Window Toolbar**



- c. Click the buttons and watch the Wave window zoom in and scroll to the time when *count* is the value specified in the DO file.
- d. If the Wave window is docked in the Main window make it the active window (click anywhere in the Wave window), then select **Wave > Bookmarks > bk1**. If the window is undocked, select **View > Bookmarks > bk1** in the Wave window.

Watch the Wave window zoom in and scroll to the time when *count* is 00100111. Try the **bk2** bookmark as well.

## Lesson Wrap-Up

This concludes this lesson.



1. Select **File > Quit** to close ModelSim.



# Chapter 16

## Getting Started With Power Aware

---

### Introduction

The following sections describe how to run a Power Aware simulation of an RTL design.

Objectives of this lab include:

- Creating a configuration file in Unified Power Format (UPF), which defines the low-power design intent.
- Working through the usage flow for Power Aware verification, such as user-defined assertions, power intent UPF file isolation, retention.
- Observing the role of Power Aware retention flip-flop models in accurately modeling power up/ down and retention behavior at the Register Transfer Level.

### Design Files For This Lesson

The design for this example is a clock-driven memory interleaver with an associated test bench. The directory structure is located under *<install\_dir>/examples/tutorials/pa\_sim/*

where

```
pa_sim
|
+-- example_one
|   |
|   +-- Libraries ..... Verilog and SystemVerilog library source
|       |
|       +-- io
|           |
|           +-- sram_256x16
|
|   +-- Questa ..... Simulation directory
|       |
|       +-- scripts .... Compilation & simulation commands
|
|   +-- RTL ..... Source files for interleaver design
|
|   +-- UPF ..... UPF file for power intent
```

For this exercise, you run all simulations from the `example_one` directory.

## Script Files

The /Questa/scripts directory contains do files for compiling and running all simulation:

- analyze\_rtl.do — Analyze UPF and extract PA netlist
- compile\_rtl.do — Compile RTL source
- ./scripts/doit\_rtl.do — Run RTL simulation
- ./scripts/sim.do — Simulation commands

## Create a Working Location

Before you simulate the design for this example, you should make a copy of it in a working location, create a library, and compile the source code into that library.

1. Create a new directory outside your installation directory for ModelSim, and copy the design files for this example into it.
2. Invoke ModelSim (if necessary).
  - a. Type vsim at a UNIX shell prompt or double-click the ModelSim icon in Windows.  
When you open ModelSim for the first time, you will see the Welcome to ModelSim dialog box. Click Close.
  - b. When ModelSim displays, choose File > Change Directory from the main menu, and navigate to

`<my_tutorial>/pa_sim/example_one`

where *my\_tutorial* is the directory you created in Step 1.

## Compile the Source Files of the Design

The compilation step processes the HDL design and generates code for simulation. This step is the same for both Power Aware and non-Power Aware simulation. You use the same output for either kind of simulation.

1. To compile all RTL source files for this example, enter the following in the Transcript window:

```
do ./Questa/scripts/compile_rtl.do
```

Note that this do file is a script that runs the following ModelSim commands:

```
vlib work
```

```
vlog -novopt -f ./Questa/scripts/compile_rtl.f
```

Also note that neither of these commands provides any special actions related to Power Aware.

## Annotate Power Intent

The power annotation step processes the Unified Power Format (UPF) file or files associated with the design, extracts the power intent from those files, and extends the compiled HDL model to reflect this power intent. This includes the following:

- Construction of the power distribution network (supply ports, nets, sets, and switches),
- Construction of the power control architecture (retention registers, isolation cells, level shifters, and their control signals)
- Insertion of power-related behavior (retention, corruption, and isolation clamping on power down; restoration on power up)
- Insertion of automatic assertions to check for power-related error conditions (such as correct control signal sequencing)

1. To analyze the UPF and perform power annotation, enter the following in the Transcript window:

```
do ./Questa/scripts/analyze_rtl.do
```

which runs the vopt command with the following Power Aware arguments:

```
vopt rtl_top \  
-pa_upf ./UPF/rtl_top.upf \  
-pa_prefix "/interleaver_tester/" \  
-pa_replacetop "dut" \  
-pa_genrpt=u+v \  
-pa_checks=i+r+p+cp+s+uml \  
-o discard_opt
```

Note that these arguments of the vopt command control the power annotation process:

- |                |                                                                                                                         |
|----------------|-------------------------------------------------------------------------------------------------------------------------|
| -pa_upf        | Specifies the location of the power intent file written in UPF.                                                         |
| -pa_prefix     | Specifies the name of the testbench into which the DUT (for which power annotation is being done) will be instantiated. |
| -pa_replacetop | Specifies the instance name of the top-level DUT.                                                                       |
| -pa_genrpt     | Generates a power-aware report file that is saved to the current directory.                                             |
| -pa_checks     | Enables built-in assertion checks.                                                                                      |

## Specifying Power Aware Options

There are many options for Power Aware simulation available as arguments to the vopt command. Refer to the vopt command in the Reference Manual for a complete list of these Power Aware arguments (all begin with -pa\_).

Specifying “s” as part of the -pa\_checks argument turns on static checks for insertion of level shifters. During analysis, messages are printed to standard out indicating valid and missing level shifters. The output from the above run of vopt shows the following:

```
** Note: (vopt-9694) [ UPF_LS_STATIC_CHK ] Found Total 29 Valid level shifters.
```

1. Open the text file named report.static.txt, which is a text file written to the current directory. The -pa\_checks argument creates this report, which contains a detailed list of all level shifters including the source and sink domains for each level shifter.
2. Examine the list of level shifters in the report.
3. Close the file.

## Simulate the Power Aware Design

Power Aware simulation accurately models the behavior of the power architecture and the effects of the power architecture on the HDL design. It also monitors the operation of the power control signals and detects and reports possible errors.

1. To begin Power Aware simulation, enter the following in the Transcript window:

```
do ./Questa/scripts/doit_rtl.do
```

which runs the vsim command with the following arguments:

```
vsim interleaver_tester \  
  -novopt \  
  +nowarnTSCALE \  
  +nowarnTFMPC \  
  -L mtiPA \  
  -pa \  
  -l rtl.log \  
  -wlf rtl.wlf \  
  -assertdebug \  
  +notimingchecks \  
  -do ./scripts/sim.do
```

For simulation, the -pa argument of vsim causes the simulator to be invoked in Power Aware mode. The mtiPA library is a precompiled library containing default models for corruption, isolation, and retention. This library is loaded with the -L library switch.

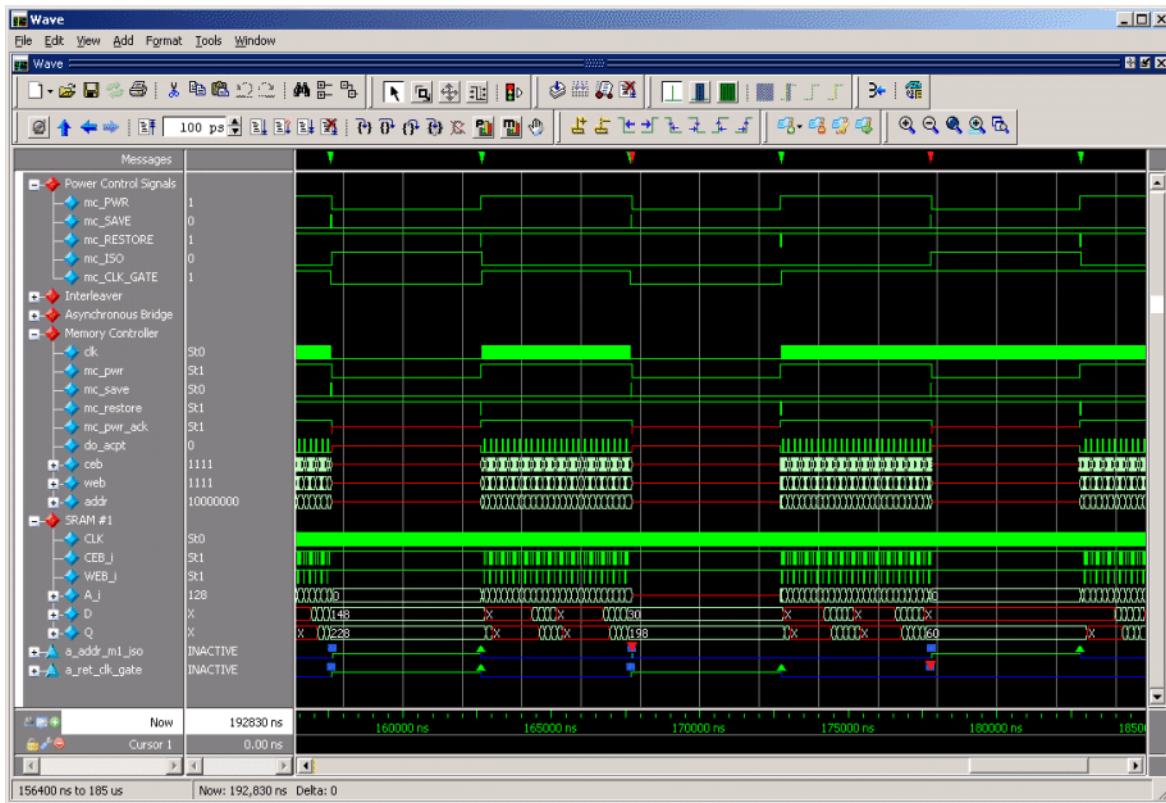
2. Note that the main window has added Object, Wave, and Source windows, along with the sim tab in the Structure window.
3. In the Structure window, click the sim tab then scroll to the top of the list until you see the testbench labeled interleaver\_tester.
4. Double-click on interleaver\_tester in the sim tab, which displays the source file for the testbench (interleaver\_tester.sv) in the Source window.
5. In the Source window, scroll down and look for the section named "Simulation control" section (beginning at line 54). This block provides an abstract representation of the power management block and runs the following tests:

power_down_normal	(Test 1, line 92) Normal power-down cycle where retention, isolation, and clock gating are done correctly.
power_down_no_iso	(Test 2, line 96) Power-down cycle with the isolation control signal not toggled correctly.
power_down_no_clk_gate	(Test 3, line 100) Power-down cycle where the clock is not gated properly.
sram_PWR	(Test 4, line 85/87) Toggles the built-in power control signal for the SRAM models.

## Analyze Results

1. Click the wave tab on the right side of the main window to view results of this simulation displayed in the Wave window.
2. In the Wave window, adjust the zoom level so that it shows the first three tests (about 155ms to 185ms), as shown in [Figure 16-1](#).

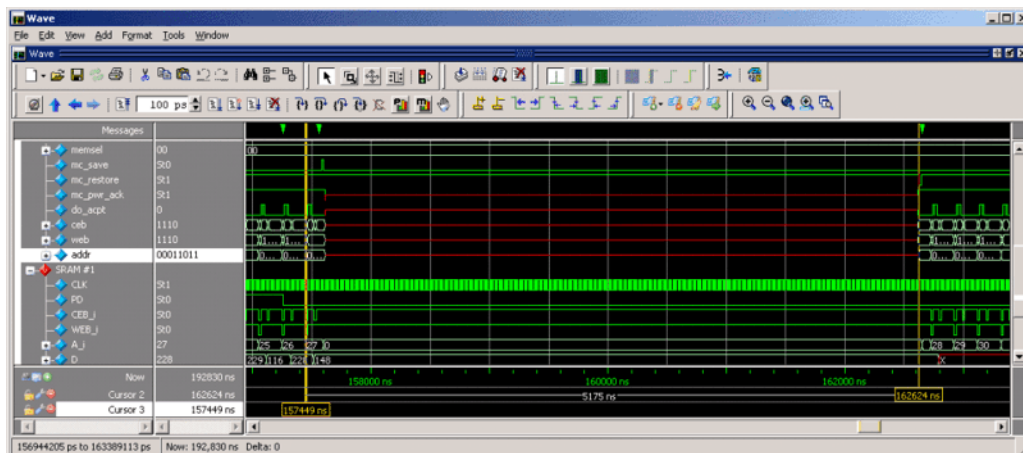
Figure 16-1. Results of the Power Aware RTL Simulation



## Results from Test 1 (power\_down\_normal)

1. Zoom in a little more to focus on the first test (around 155ms to 163ms). This test is a normal power-down cycle shown in [Figure 16-2](#).

Figure 16-2. Retention of addr During Normal Power Down Cycle





The isolation strategy for this example specified “parent” for the isolation insertion point. Notice that all the outputs from the “Memory Controller” are unknown. If you look at the downstream blocks from the memory controller’s outputs, you can see the isolated values. At the inputs to the SRAMs, the address is clamped at 0 and the chip and write enables are clamped at 1.

2. Look at the addr output from the memory controller. The last good value to the left of the unknown state (just before this block is powered down) is 00011011. Now look at this same signal just before power is turned back on. The value is restored to 00011011. This demonstrates the proper retention behavior.

## Results from Test 2 (power\_down\_no\_iso)

Now move a little later in time to the next test starting at about 167ms. This test powers down the design again, but this time without isolation. Notice that in this test the address input to the SRAM models is not clamped at zero. The unknown values from the memory controller have propagated to the SRAMs—this is a problem.

The solution is to use a built-in assertion to catch this. In this case, it is enabled with the -pa\_checks=i argument that was specified for the vopt command.

1. Open the transcript window by choosing the following from the main menu:

View > Transcript

You will see a message from this built-in assertion describing the problem:

```
** Error: MSPA_ISO_EN_PSO: Isolation control (0) is not enabled when power
is switched OFF for the following: Port: /interleaver_tester/dut/mc0/addr.
```

To complement the assertions built into ModelSim, you can also write your own assertions.

2. Open the Assertions window by choosing the following from the main menu:

View > Coverage > Assertions

All assertions that have fired are highlighted in red. The immediate assertion that generates the message shown above is labeled:

```
/mspa_top/blk6/MSPA_ISO_EN_PSO_1
```

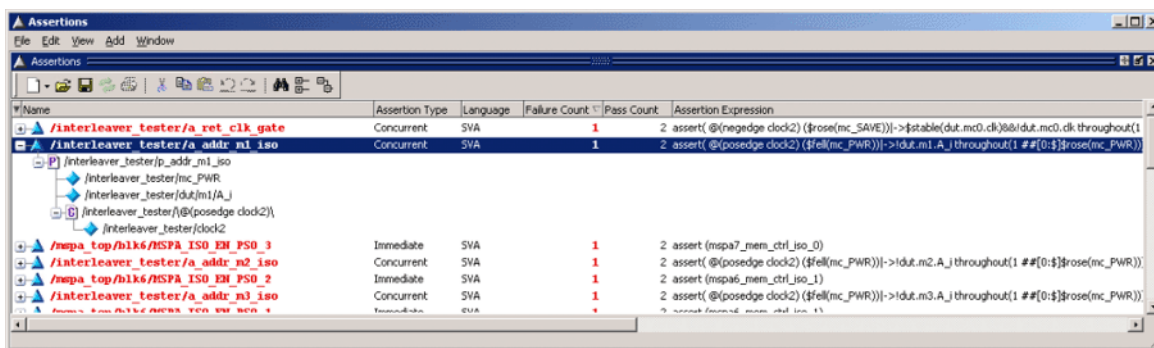
This is a built-in assertion. There are also some failed user-defined assertions.

3. Undock the Assertions window and look at the assertion named:

```
/interleaver_tester_a_addr_m2_iso
```

This is a user-defined assertion. In the Assertions window, you can see the signals that make up the assertion, the assertion expression, and various counts associated with that assertion. This is shown in [Figure 16-3](#).

**Figure 16-3. The Assertions Window**

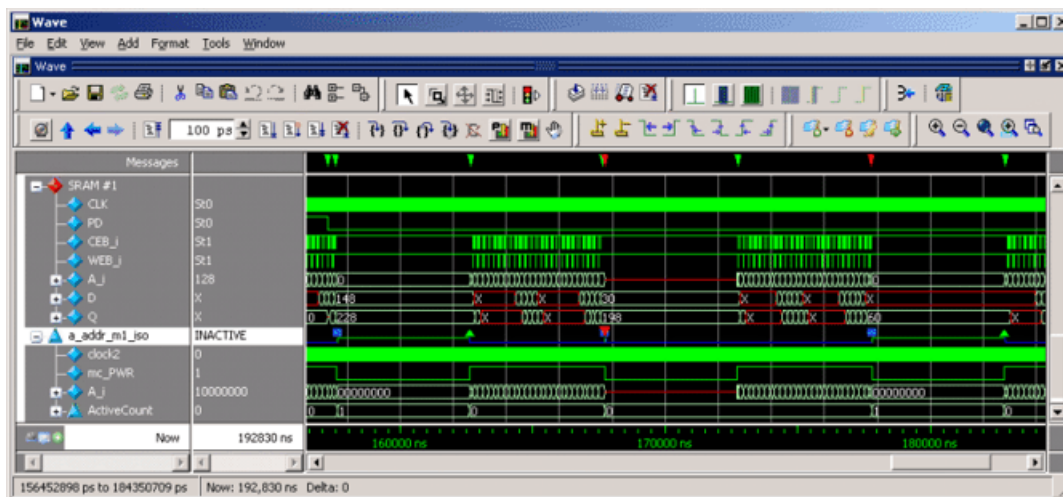


4. Select this assertion and right-click to display a popup menu.
5. Choose Add Wave > Selected Objects. This adds the group of Assertions to the pathname pane on the left side of the Wave window.
6. In the Wave window, zoom out a little bit so you can see all three tests. The green and red triangles represent assertion passes and failures, respectively.

During Test 1, which simulates the normal power-down cycle, you will see the assertion change from inactive (blue line) to active (green line) at power-down. At power-up, the assertion passes, which is indicated with a green triangle. The assertion then becomes inactive until the next test.

During Test 2, isolation is not enabled properly. The assertion starts at power-down. However, it fails on the next clock, since the address input to the SRAM is not clamped at the correct value. This is indicated by the red triangle, as shown in [Figure 16-4](#).

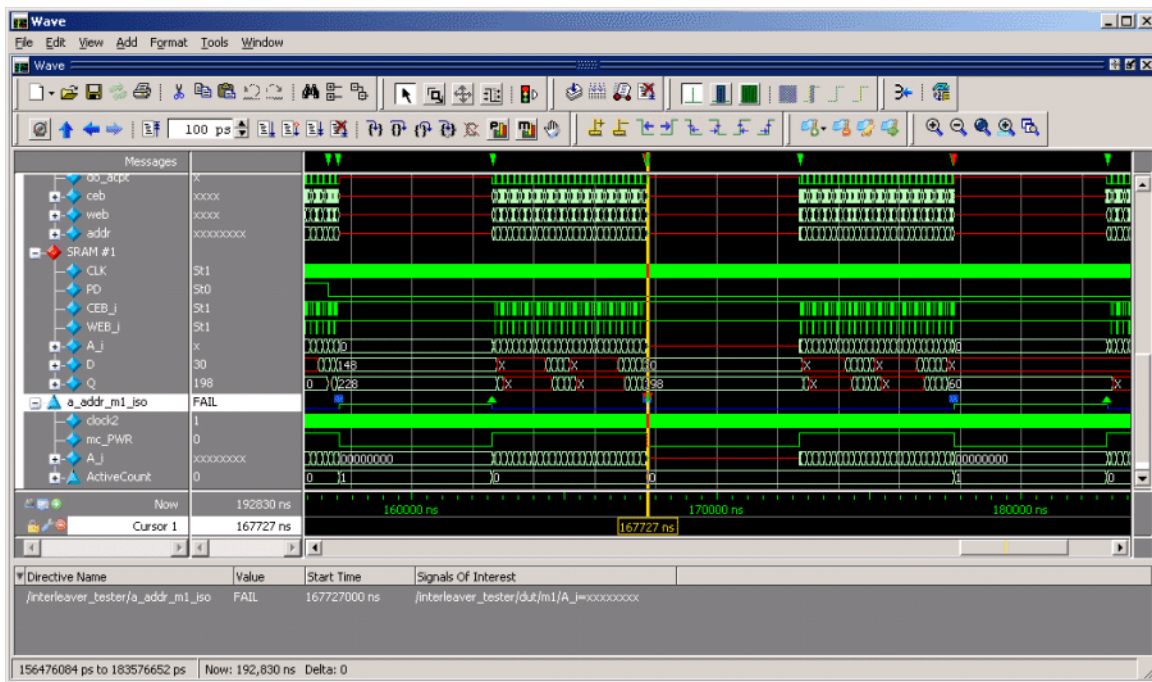
**Figure 16-4. User-Defined Assertion Failure (red triangle)**



7. Place a cursor over the red triangle at time 167727ns.
8. From the main menu, choose Wave > Assertion Debug. This opens a debug pane at the bottom of the Wave window, as shown in Figure 16-5. When the cursor is on an assertion failure, this pane displays information on the signal of interest. In this case, the message states that the assertion failed because:

`/interleaver_tester/dut/m1/A_i=xxxxxxxx`

**Figure 16-5. Assertion Debug Window**



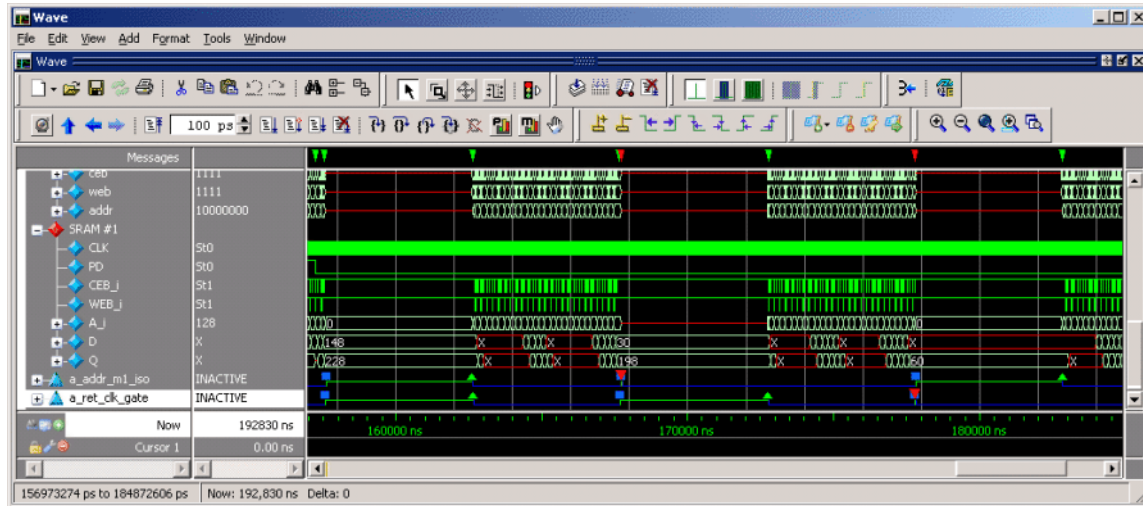
## Results from Test 3 (power\_down\_no\_clk\_gate)

The retention models used in this example require that the clock be gated LOW during a save/restore sequence. The third test verifies that the example does gate the clock LOW properly. In the RTL description, you can use an assertion to check for appropriate clock gating.

In the Assertions window, note that the assertion named `a_ret_clk_gate` has failed.

1. Select this assertion and right-click to display a popup menu.
2. Choose Add Wave > Selected Objects, which adds it to the Wave window.
3. Figure 16-6 shows that this assertion passed during the first two tests and failed during the third test.

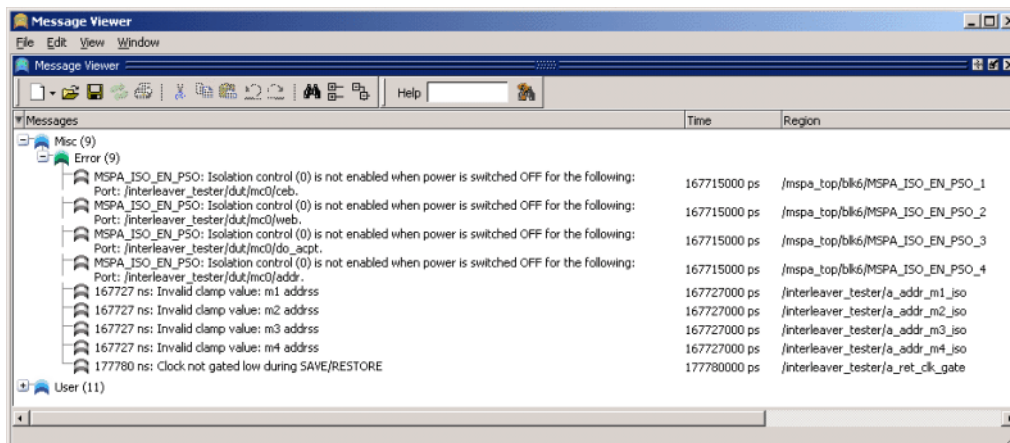
**Figure 16-6. Clock-Gating Assertion Failure**



4. If you place a cursor on the failure at time 177780ns, the attached debug window will show you the assertion failed because:
- ```
/interleaver_tester/dut/mc0/clk=St1
```
5. By default, the messages from all the assertion firings seen in these tests are dumped to the Transcript window, which can become cluttered with messages, commands, and miscellaneous transcript information. ModelSim provides a Message Viewer window (Figure 16-7) that organizes all messages for easy viewing, which you can display by choosing the following from the main menu:

View > Message Viewer

**Figure 16-7. Message Viewer Window**



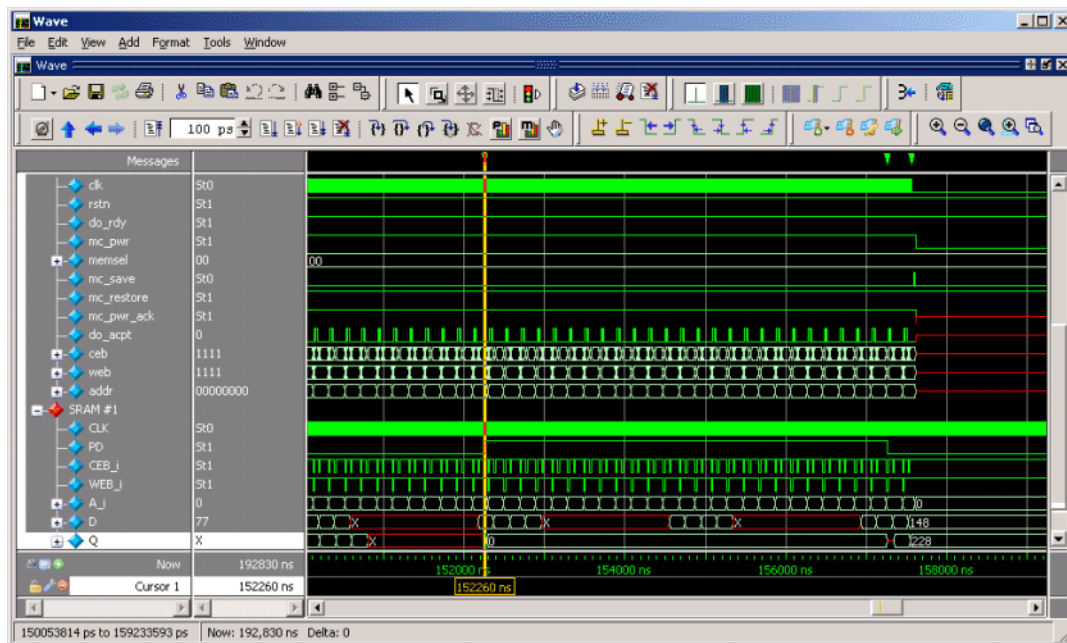
From this window, it is easier to navigate from the error message to the assertion's source, the Wave window, or the assertion debug pane.

## Results from Test 4 (sram\_PWR)

The SRAM models have a built-in power-down mode that clamps the model output to zero. This final test toggles the power signal to the model to test this capability.

1. In the wave window, move the cursor to time 152260 ns (as in [Figure 16-8](#)).
2. In the pathname pane, find the signal named SRAM #1, and click [+] to expand the listing below it (if it is not already expanded).
3. Find the power control signal m1/PD and note that it toggles at this time point. While the PD signal is active, output m1/Q from the SRAM is correctly clamped at zero.

**Figure 16-8. SRAM Power-Down**



## Lesson Wrap-Up

This concludes this exercise. Before continuing, you should finish the current simulation.

1. Select **Simulate > End Simulation**.

2. Click **Yes** when prompted to confirm that you wish to quit simulating.
3. You can now exit ModelSim or continue with another simulation.

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- 1.2. Amounts invoiced will be paid, in the currency specified on the applicable invoice, within 30 days from the date of such invoice. Any past due invoices will be subject to the imposition of interest charges in the amount of one and one-half percent per month or the applicable legal rate currently in effect, whichever is lower. Prices do not include freight, insurance, customs duties, taxes or other similar charges, which Mentor Graphics will state separately in the applicable invoice(s). Unless timely provided with a valid certificate of exemption or other evidence that items are not taxable, Mentor Graphics will invoice Customer for all applicable taxes including, but not limited to, VAT, GST, sales tax and service tax. Customer will make all payments free and clear of, and without reduction for, any withholding or other taxes; any such taxes imposed on payments by Customer hereunder will be Customer's sole responsibility. If Customer appoints a third party to place purchase orders and/or make payments on Customer's behalf, Customer shall be liable for payment under Orders placed by such third party in the event of default.
- 1.3. All Products are delivered FCA factory (Incoterms 2000), freight prepaid and invoiced to Customer, except Software delivered electronically, which shall be deemed delivered when made available to Customer for download. Mentor Graphics retains a security interest in all Products delivered under this Agreement, to secure payment of the purchase price of such Products, and Customer agrees to sign any documents that Mentor Graphics determines to be necessary or convenient for use in filing or perfecting such security interest. Mentor Graphics' delivery of Software by electronic means is subject to Customer's provision of both a primary and an alternate e-mail address.

2. **GRANT OF LICENSE.** The software installed, downloaded, or otherwise acquired by Customer under this Agreement, including any updates, modifications, revisions, copies, documentation and design data ("Software") are copyrighted, trade secret and confidential information of Mentor Graphics or its licensors, who maintain exclusive title to all Software and retain all rights not expressly granted by this Agreement. Mentor Graphics grants to Customer, subject to payment of applicable license fees, a nontransferable, nonexclusive license to use Software solely: (a) in machine-readable, object-code form (except as provided in Subsection 5.2); (b) for Customer's internal business purposes; (c) for the term of the license; and (d) on the computer hardware and at the site authorized by Mentor Graphics. A site is restricted to a one-half mile (800 meter) radius. Customer may have Software temporarily used by an employee for telecommuting purposes from locations other than a Customer office, such as the employee's residence, an airport or hotel, provided that such employee's primary place of employment is the site where the Software is authorized for use. Mentor Graphics' standard policies and programs, which vary depending on Software, license fees paid or services purchased, apply to the following: (a) relocation of Software; (b) use of Software, which may be limited, for example, to execution of a single session by a single user on the authorized hardware or for a restricted period of time (such limitations may be technically implemented through the use of authorization codes or similar devices); and (c) support services provided, including eligibility to receive telephone support, updates, modifications, and revisions. For the avoidance of doubt, if Customer requests any change or enhancement to Software, whether in the course of receiving support or consulting services, evaluating Software, performing beta testing or otherwise, any inventions, product

improvements, modifications or developments made by Mentor Graphics (at Mentor Graphics' sole discretion) will be the exclusive property of Mentor Graphics.

3. **ESC SOFTWARE.** If Customer purchases a license to use development or prototyping tools of Mentor Graphics' Embedded Software Channel ("ESC"), Mentor Graphics grants to Customer a nontransferable, nonexclusive license to reproduce and distribute executable files created using ESC compilers, including the ESC run-time libraries distributed with ESC C and C++ compiler Software that are linked into a composite program as an integral part of Customer's compiled computer program, provided that Customer distributes these files only in conjunction with Customer's compiled computer program. Mentor Graphics does NOT grant Customer any right to duplicate, incorporate or embed copies of Mentor Graphics' real-time operating systems or other embedded software products into Customer's products or applications without first signing or otherwise agreeing to a separate agreement with Mentor Graphics for such purpose.
4. **BETA CODE.**
  - 4.1. Portions or all of certain Software may contain code for experimental testing and evaluation ("Beta Code"), which may not be used without Mentor Graphics' explicit authorization. Upon Mentor Graphics' authorization, Mentor Graphics grants to Customer a temporary, nontransferable, nonexclusive license for experimental use to test and evaluate the Beta Code without charge for a limited period of time specified by Mentor Graphics. This grant and Customer's use of the Beta Code shall not be construed as marketing or offering to sell a license to the Beta Code, which Mentor Graphics may choose not to release commercially in any form.
  - 4.2. If Mentor Graphics authorizes Customer to use the Beta Code, Customer agrees to evaluate and test the Beta Code under normal conditions as directed by Mentor Graphics. Customer will contact Mentor Graphics periodically during Customer's use of the Beta Code to discuss any malfunctions or suggested improvements. Upon completion of Customer's evaluation and testing, Customer will send to Mentor Graphics a written evaluation of the Beta Code, including its strengths, weaknesses and recommended improvements.
  - 4.3. Customer agrees to maintain Beta Code in confidence and shall restrict access to the Beta Code, including the methods and concepts utilized therein, solely to those employees and Customer location(s) authorized by Mentor Graphics to perform beta testing. Customer agrees that any written evaluations and all inventions, product improvements, modifications or developments that Mentor Graphics conceived or made during or subsequent to this Agreement, including those based partly or wholly on Customer's feedback, will be the exclusive property of Mentor Graphics. Mentor Graphics will have exclusive rights, title and interest in all such property. The provisions of this Subsection 4.3 shall survive termination of this Agreement.
5. **RESTRICTIONS ON USE.**
  - 5.1. Customer may copy Software only as reasonably necessary to support the authorized use. Each copy must include all notices and legends embedded in Software and affixed to its medium and container as received from Mentor Graphics. All copies shall remain the property of Mentor Graphics or its licensors. Customer shall maintain a record of the number and primary location of all copies of Software, including copies merged with other software, and shall make those records available to Mentor Graphics upon request. Customer shall not make Products available in any form to any person other than Customer's employees and on-site contractors, excluding Mentor Graphics competitors, whose job performance requires access and who are under obligations of confidentiality. Customer shall take appropriate action to protect the confidentiality of Products and ensure that any person permitted access does not disclose or use it except as permitted by this Agreement. Customer shall give Mentor Graphics written notice of any unauthorized disclosure or use of the Products as soon as Customer learns or becomes aware of such unauthorized disclosure or use. Except as otherwise permitted for purposes of interoperability as specified by applicable and mandatory local law, Customer shall not reverse-assemble, reverse-compile, reverse-engineer or in any way derive any source code from Software. Log files, data files, rule files and script files generated by or for the Software (collectively "Files"), including without limitation files containing Standard Verification Rule Format ("SVRF") and Tcl Verification Format ("TVF") which are Mentor Graphics' proprietary syntaxes for expressing process rules, constitute or include confidential information of Mentor Graphics. Customer may share Files with third parties, excluding Mentor Graphics competitors, provided that the confidentiality of such Files is protected by written agreement at least as well as Customer protects other information of a similar nature or importance, but in any case with at least reasonable care. Customer may use Files containing SVRF or TVF only with Mentor Graphics products. Under no circumstances shall Customer use Software or Files or allow their use for the purpose of developing, enhancing or marketing any product that is in any way competitive with Software, or disclose to any third party the results of, or information pertaining to, any benchmark.
  - 5.2. If any Software or portions thereof are provided in source code form, Customer will use the source code only to correct software errors and enhance or modify the Software for the authorized use. Customer shall not disclose or permit disclosure of source code, in whole or in part, including any of its methods or concepts, to anyone except Customer's employees or contractors, excluding Mentor Graphics competitors, with a need to know. Customer shall not copy or compile source code in any manner except to support this authorized use.
  - 5.3. Customer may not assign this Agreement or the rights and duties under it, or relocate, sublicense or otherwise transfer the Products, whether by operation of law or otherwise ("Attempted Transfer"), without Mentor Graphics' prior written consent and payment of Mentor Graphics' then-current applicable relocation and/or transfer fees. Any Attempted Transfer without Mentor Graphics' prior written consent shall be a material breach of this Agreement and may, at Mentor Graphics' option, result in the immediate termination of the Agreement and/or the licenses granted under this Agreement. The terms of this Agreement, including without limitation the licensing and assignment provisions, shall be binding upon Customer's permitted successors in interest and assigns.

5.4. The provisions of this Section 5 shall survive the termination of this Agreement.

6. **SUPPORT SERVICES.** To the extent Customer purchases support services, Mentor Graphics will provide Customer updates and technical support for the Products, at the Customer site(s) for which support is purchased, in accordance with Mentor Graphics' then current End-User Support Terms located at <http://supportnet.mentor.com/about/legal/>.
7. **AUTOMATIC CHECK FOR UPDATES; PRIVACY.** Technological measures in Software may communicate with servers of Mentor Graphics or its contractors for the purpose of checking for and notifying the user of updates and to ensure that the Software in use is licensed in compliance with this Agreement. Mentor Graphics will not collect any personally identifiable data in this process and will not disclose any data collected to any third party without the prior written consent of Customer, except to Mentor Graphics' outside attorneys or as may be required by a court of competent jurisdiction.
8. **LIMITED WARRANTY.**
  - 8.1. Mentor Graphics warrants that during the warranty period its standard, generally supported Products, when properly installed, will substantially conform to the functional specifications set forth in the applicable user manual. Mentor Graphics does not warrant that Products will meet Customer's requirements or that operation of Products will be uninterrupted or error free. The warranty period is 90 days starting on the 15th day after delivery or upon installation, whichever first occurs. Customer must notify Mentor Graphics in writing of any nonconformity within the warranty period. For the avoidance of doubt, this warranty applies only to the initial shipment of Software under an Order and does not renew or reset, for example, with the delivery of (a) Software updates or (b) authorization codes or alternate Software under a transaction involving Software re-mix. This warranty shall not be valid if Products have been subject to misuse, unauthorized modification or improper installation. MENTOR GRAPHICS' ENTIRE LIABILITY AND CUSTOMER'S EXCLUSIVE REMEDY SHALL BE, AT MENTOR GRAPHICS' OPTION, EITHER (A) REFUND OF THE PRICE PAID UPON RETURN OF THE PRODUCTS TO MENTOR GRAPHICS OR (B) MODIFICATION OR REPLACEMENT OF THE PRODUCTS THAT DO NOT MEET THIS LIMITED WARRANTY, PROVIDED CUSTOMER HAS OTHERWISE COMPLIED WITH THIS AGREEMENT. MENTOR GRAPHICS MAKES NO WARRANTIES WITH RESPECT TO: (A) SERVICES; (B) PRODUCTS PROVIDED AT NO CHARGE; OR (C) BETA CODE; ALL OF WHICH ARE PROVIDED "AS IS."
  - 8.2. THE WARRANTIES SET FORTH IN THIS SECTION 8 ARE EXCLUSIVE. NEITHER MENTOR GRAPHICS NOR ITS LICENSORS MAKE ANY OTHER WARRANTIES EXPRESS, IMPLIED OR STATUTORY, WITH RESPECT TO PRODUCTS PROVIDED UNDER THIS AGREEMENT. MENTOR GRAPHICS AND ITS LICENSORS SPECIFICALLY DISCLAIM ALL IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE AND NON-INFRINGEMENT OF INTELLECTUAL PROPERTY.
9. **LIMITATION OF LIABILITY.** EXCEPT WHERE THIS EXCLUSION OR RESTRICTION OF LIABILITY WOULD BE VOID OR INEFFECTIVE UNDER APPLICABLE LAW, IN NO EVENT SHALL MENTOR GRAPHICS OR ITS LICENSORS BE LIABLE FOR INDIRECT, SPECIAL, INCIDENTAL, OR CONSEQUENTIAL DAMAGES (INCLUDING LOST PROFITS OR SAVINGS) WHETHER BASED ON CONTRACT, TORT OR ANY OTHER LEGAL THEORY, EVEN IF MENTOR GRAPHICS OR ITS LICENSORS HAVE BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. IN NO EVENT SHALL MENTOR GRAPHICS' OR ITS LICENSORS' LIABILITY UNDER THIS AGREEMENT EXCEED THE AMOUNT RECEIVED FROM CUSTOMER FOR THE HARDWARE, SOFTWARE LICENSE OR SERVICE GIVING RISE TO THE CLAIM. IN THE CASE WHERE NO AMOUNT WAS PAID, MENTOR GRAPHICS AND ITS LICENSORS SHALL HAVE NO LIABILITY FOR ANY DAMAGES WHATSOEVER. THE PROVISIONS OF THIS SECTION 9 SHALL SURVIVE THE TERMINATION OF THIS AGREEMENT.
10. **HAZARDOUS APPLICATIONS.** CUSTOMER ACKNOWLEDGES IT IS SOLELY RESPONSIBLE FOR TESTING ITS PRODUCTS USED IN APPLICATIONS WHERE THE FAILURE OR INACCURACY OF ITS PRODUCTS MIGHT RESULT IN DEATH OR PERSONAL INJURY ("HAZARDOUS APPLICATIONS"). NEITHER MENTOR GRAPHICS NOR ITS LICENSORS SHALL BE LIABLE FOR ANY DAMAGES RESULTING FROM OR IN CONNECTION WITH THE USE OF MENTOR GRAPHICS PRODUCTS IN OR FOR HAZARDOUS APPLICATIONS. THE PROVISIONS OF THIS SECTION 10 SHALL SURVIVE THE TERMINATION OF THIS AGREEMENT.
11. **INDEMNIFICATION.** CUSTOMER AGREES TO INDEMNIFY AND HOLD HARMLESS MENTOR GRAPHICS AND ITS LICENSORS FROM ANY CLAIMS, LOSS, COST, DAMAGE, EXPENSE OR LIABILITY, INCLUDING ATTORNEYS' FEES, ARISING OUT OF OR IN CONNECTION WITH THE USE OF PRODUCTS AS DESCRIBED IN SECTION 10. THE PROVISIONS OF THIS SECTION 11 SHALL SURVIVE THE TERMINATION OF THIS AGREEMENT.
12. **INFRINGEMENT.**
  - 12.1. Mentor Graphics will defend or settle, at its option and expense, any action brought against Customer in the United States, Canada, Japan, or member state of the European Union which alleges that any standard, generally supported Product acquired by Customer hereunder infringes a patent or copyright or misappropriates a trade secret in such jurisdiction. Mentor Graphics will pay costs and damages finally awarded against Customer that are attributable to the action. Customer understands and agrees that as conditions to Mentor Graphics' obligations under this section Customer must: (a) notify Mentor Graphics promptly in writing of the action; (b) provide Mentor Graphics all reasonable information and assistance to settle or defend the action; and (c) grant Mentor Graphics sole authority and control of the defense or settlement of the action.

- 12.2. If a claim is made under Subsection 12.1 Mentor Graphics may, at its option and expense, (a) replace or modify the Product so that it becomes noninfringing; (b) procure for Customer the right to continue using the Product; or (c) require the return of the Product and refund to Customer any purchase price or license fee paid, less a reasonable allowance for use.
- 12.3. Mentor Graphics has no liability to Customer if the action is based upon: (a) the combination of Software or hardware with any product not furnished by Mentor Graphics; (b) the modification of the Product other than by Mentor Graphics; (c) the use of other than a current unaltered release of Software; (d) the use of the Product as part of an infringing process; (e) a product that Customer makes, uses, or sells; (f) any Beta Code or Product provided at no charge; (g) any software provided by Mentor Graphics' licensors who do not provide such indemnification to Mentor Graphics' customers; or (h) infringement by Customer that is deemed willful. In the case of (h), Customer shall reimburse Mentor Graphics for its reasonable attorney fees and other costs related to the action.
- 12.4. THIS SECTION 12 IS SUBJECT TO SECTION 9 ABOVE AND STATES THE ENTIRE LIABILITY OF MENTOR GRAPHICS AND ITS LICENSORS FOR DEFENSE, SETTLEMENT AND DAMAGES, AND CUSTOMER'S SOLE AND EXCLUSIVE REMEDY, WITH RESPECT TO ANY ALLEGED PATENT OR COPYRIGHT INFRINGEMENT OR TRADE SECRET MISAPPROPRIATION BY ANY PRODUCT PROVIDED UNDER THIS AGREEMENT.
13. **TERMINATION AND EFFECT OF TERMINATION.** If a Software license was provided for limited term use, such license will automatically terminate at the end of the authorized term.
- 13.1. Mentor Graphics may terminate this Agreement and/or any license granted under this Agreement immediately upon written notice if Customer: (a) exceeds the scope of the license or otherwise fails to comply with the licensing or confidentiality provisions of this Agreement, or (b) becomes insolvent, files a bankruptcy petition, institutes proceedings for liquidation or winding up or enters into an agreement to assign its assets for the benefit of creditors. For any other material breach of any provision of this Agreement, Mentor Graphics may terminate this Agreement and/or any license granted under this Agreement upon 30 days written notice if Customer fails to cure the breach within the 30 day notice period. Termination of this Agreement or any license granted hereunder will not affect Customer's obligation to pay for Products shipped or licenses granted prior to the termination, which amounts shall be payable immediately upon the date of termination.
- 13.2. Upon termination of this Agreement, the rights and obligations of the parties shall cease except as expressly set forth in this Agreement. Upon termination, Customer shall ensure that all use of the affected Products ceases, and shall return hardware and either return to Mentor Graphics or destroy Software in Customer's possession, including all copies and documentation, and certify in writing to Mentor Graphics within ten business days of the termination date that Customer no longer possesses any of the affected Products or copies of Software in any form.
14. **EXPORT.** The Products provided hereunder are subject to regulation by local laws and United States government agencies, which prohibit export or diversion of certain products and information about the products to certain countries and certain persons. Customer agrees that it will not export Products in any manner without first obtaining all necessary approval from appropriate local and United States government agencies.
15. **U.S. GOVERNMENT LICENSE RIGHTS.** Software was developed entirely at private expense. All Software is commercial computer software within the meaning of the applicable acquisition regulations. Accordingly, pursuant to US FAR 48 CFR 12.212 and DFAR 48 CFR 227.7202, use, duplication and disclosure of the Software by or for the U.S. Government or a U.S. Government subcontractor is subject solely to the terms and conditions set forth in this Agreement, except for provisions which are contrary to applicable mandatory federal laws.
16. **THIRD PARTY BENEFICIARY.** Mentor Graphics Corporation, Mentor Graphics (Ireland) Limited, Microsoft Corporation and other licensors may be third party beneficiaries of this Agreement with the right to enforce the obligations set forth herein.
17. **REVIEW OF LICENSE USAGE.** Customer will monitor the access to and use of Software. With prior written notice and during Customer's normal business hours, Mentor Graphics may engage an internationally recognized accounting firm to review Customer's software monitoring system and records deemed relevant by the internationally recognized accounting firm to confirm Customer's compliance with the terms of this Agreement or U.S. or other local export laws. Such review may include FLEXlm or FLEXnet (or successor product) report log files that Customer shall capture and provide at Mentor Graphics' request. Customer shall make records available in electronic format and shall fully cooperate with data gathering to support the license review. Mentor Graphics shall bear the expense of any such review unless a material non-compliance is revealed. Mentor Graphics shall treat as confidential information all information gained as a result of any request or review and shall only use or disclose such information as required by law or to enforce its rights under this Agreement. The provisions of this Section 17 shall survive the termination of this Agreement.
18. **CONTROLLING LAW, JURISDICTION AND DISPUTE RESOLUTION.** The owners of certain Mentor Graphics intellectual property licensed under this Agreement are located in Ireland and the United States. To promote consistency around the world, disputes shall be resolved as follows: excluding conflict of laws rules, this Agreement shall be governed by and construed under the laws of the State of Oregon, USA, if Customer is located in North or South America, and the laws of Ireland if Customer is located outside of North or South America. All disputes arising out of or in relation to this Agreement shall be submitted to the exclusive jurisdiction of the courts of Portland, Oregon when the laws of Oregon apply, or Dublin, Ireland when the laws of Ireland apply. Notwithstanding the foregoing, all disputes in Asia arising out of or in relation to this Agreement shall be resolved by arbitration in Singapore before a single arbitrator to be appointed by the chairman of the Singapore International Arbitration Centre ("SIAC") to be conducted in the English language, in accordance with the Arbitration Rules of the SIAC in effect at the time of the dispute, which rules are deemed to be incorporated by reference in this section. This section shall not

restrict Mentor Graphics' right to bring an action against Customer in the jurisdiction where Customer's place of business is located. The United Nations Convention on Contracts for the International Sale of Goods does not apply to this Agreement.

19. **SEVERABILITY.** If any provision of this Agreement is held by a court of competent jurisdiction to be void, invalid, unenforceable or illegal, such provision shall be severed from this Agreement and the remaining provisions will remain in full force and effect.
20. **MISCELLANEOUS.** This Agreement contains the parties' entire understanding relating to its subject matter and supersedes all prior or contemporaneous agreements, including but not limited to any purchase order terms and conditions. Some Software may contain code distributed under a third party license agreement that may provide additional rights to Customer. Please see the applicable Software documentation for details. This Agreement may only be modified in writing by authorized representatives of the parties. Waiver of terms or excuse of breach must be in writing and shall not constitute subsequent consent, waiver or excuse.

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