# Revision History

The following table shows the revision history for this document.

<table>
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<th>Revision</th>
</tr>
</thead>
<tbody>
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<td>• Corrections to Bitstream Tables.</td>
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</tr>
</tbody>
</table>
Table of Contents

Revision History .................................................................................................................. 2

Chapter 1: Introduction

Getting Started .................................................................................................................. 7
Debug Terminology ............................................................................................................. 8

Chapter 2: Vivado Lab Edition

Installation ......................................................................................................................... 10
Using the Vivado Lab Edition ........................................................................................... 11
Vivado Lab Edition Project ................................................................................................. 12
Programming Features ...................................................................................................... 15
Debug Features .................................................................................................................. 16

Chapter 3: Generating the Bitstream

Changing the Bitstream File Format Settings ................................................................... 18
Changing Device Configuration Bitstream Settings .......................................................... 18

Chapter 4: Programming the FPGA Device

Opening the Hardware Manager ......................................................................................... 20
Opening Hardware Target Connections ............................................................................ 21
Connecting to a Hardware Target Using hw_server ......................................................... 22
Opening a New Hardware Target ...................................................................................... 22
Troubleshooting a Hardware Target .................................................................................. 25
Associating a Programming File with the Hardware Device ........................................... 27
Programming the Hardware Device .................................................................................. 28
Closing the Hardware Target ............................................................................................ 29
Closing a Connection to the Hardware Server ................................................................... 30
Reconnecting to a Target Device with a Lower JTAG Clock Frequency ......................... 30
Connecting to a Server with More Than 32 Devices in a JTAG Chain ............................. 31
Remote Debugging in Vivado ............................................................................................. 32

Chapter 5: Programming Configuration Memory Devices

Generate Bitstreams for use with Configuration Memory Devices ...................................... 38
<table>
<thead>
<tr>
<th>Chapter 6: Advanced Programming Features</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Readback and Verify</td>
<td>47</td>
</tr>
<tr>
<td>Generating Encrypted and Authenticated Files for 7 Series Devices</td>
<td>51</td>
</tr>
<tr>
<td>Generating Encrypted and Authenticated Files for UltraScale and UltraScale+</td>
<td>54</td>
</tr>
<tr>
<td>Programming the AES Key for 7 Series Devices</td>
<td>58</td>
</tr>
<tr>
<td>Programming the AES Key for UltraScale and UltraScale+ Devices</td>
<td>60</td>
</tr>
<tr>
<td>eFUSE Register Access and Programming</td>
<td>63</td>
</tr>
<tr>
<td>eFUSE Register Access and Programming for 7 Series Devices</td>
<td>63</td>
</tr>
<tr>
<td>eFUSE Register Access and Programming for UltraScale and UltraScale+ Devices</td>
<td>69</td>
</tr>
<tr>
<td>System Monitor</td>
<td>76</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 7: Serial Vector Format (SVF) File Programming</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creating an SVF Target</td>
<td>78</td>
</tr>
<tr>
<td>Adding Devices to an SVF Target</td>
<td>79</td>
</tr>
<tr>
<td>Writing SVF Files</td>
<td>80</td>
</tr>
<tr>
<td>Executing SVF Files</td>
<td>83</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 8: Debugging the Design</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTL-level Design Simulation</td>
<td>84</td>
</tr>
<tr>
<td>Post-Implemented Design Simulation</td>
<td>84</td>
</tr>
<tr>
<td>In-System Logic Design Debugging</td>
<td>85</td>
</tr>
<tr>
<td>In-System Serial I/O Design Debugging</td>
<td>85</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 9: In-System Logic Design Debugging Debugging Flows</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probing the Design for In-System Debugging</td>
<td>86</td>
</tr>
<tr>
<td>Using the Netlist Insertion Debug Probing Flow</td>
<td>87</td>
</tr>
<tr>
<td>HDL Instantiation Debug Probing Overview</td>
<td>103</td>
</tr>
<tr>
<td>Using the HDL Instantiation Debug Probing Flow</td>
<td>104</td>
</tr>
<tr>
<td>Implementing the Design Containing the Debug Cores</td>
<td>115</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 10: Debugging Logic Designs in Hardware</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Using Vivado® Logic Analyzer to Debug the Design</td>
<td>116</td>
</tr>
<tr>
<td>Connecting to the Hardware Target and Programming the FPGA Device</td>
<td>116</td>
</tr>
<tr>
<td>Vivado Hardware Manager Dashboards</td>
<td>117</td>
</tr>
</tbody>
</table>
Setting up the ILA Core to Take a Measurement .......................................................... 126
Writing ILA Probes Information .................................................................................. 148
Reading ILA Probes Information ................................................................................. 149
Viewing Captured Data from the ILA Core in the Waveform Viewer ...................... 149
Saving and Restoring Captured Data from the ILA Core ........................................ 149
Enumeration of Probe Values .................................................................................... 151
Setting Up the VIO Core to Take a Measurement ...................................................... 158
Viewing the VIO Core Status ..................................................................................... 160
Interacting with VIO Core Output Probes ................................................................. 165
Hardware System Communication Using the JTAG-to-AXI Master Debug Core ....... 167
Using Vivado Logic Analyzer in a Lab Environment .................................................. 170
Description of Hardware Manager Tcl Objects and Commands .............................. 171
Using Tcl Commands to Interact with a JTAG-to-AXI Master Core ......................... 176
Using Tcl Commands to Take an ILA Measurement ............................................... 177
Trigger At Startup ..................................................................................................... 177
Memory Interface Generator (MIG) ............................................................................ 179

Chapter 11: Viewing ILA Probe Data in the Waveform Viewer

Introduction .................................................................................................................. 181
Customizing the Configuration ................................................................................... 188
Renaming Objects ....................................................................................................... 192
Bus Radixes ................................................................................................................ 194
Viewing Analog Waveforms ..................................................................................... 196
Zoom Gestures ............................................................................................................ 198

Chapter 12: Debugging Designs Post Implementation

Replacing Debug Probes on a Placed and Routed Design Checkpoint .................... 200
Incremental Compile with Debug Core (ILA) Modifications ...................................... 206

Chapter 13: In-System Serial I/O Debugging Flows

Introduction .................................................................................................................. 210
Generating an IBERT Core using the Vivado IP Catalog ........................................... 210
Generating and Implementing the IBERT Example Design ........................................ 211

Chapter 14: Debugging the Serial I/O Design in Hardware

Using Vivado® Serial I/O Analyzer to Debug the Design .............................................. 213

Appendix A: Device Configuration Bitstream Settings

7 Series Bitstream Settings .......................................................................................... 228
Zynq-7000 Bitstream Settings ..................................................................................... 235
Chapter 1

Introduction

Getting Started

After successfully implementing your design, the next step is to run it in hardware by programming the FPGA device and debugging the design in-system. All of the necessary commands to perform programming of FPGA devices and in-system debugging of the design are in the Program and Debug section of the Flow Navigator window in the Vivado® Integrated Design Environment (IDE) (see Figure 1-1).

*Figure 1-1:  Program and Debug section of the Flow Navigator panel*
Debug Terminology

ILA: The Integrated Logic Analyzer (ILA) feature allows you to perform in-system debugging of post-implemented designs on an FPGA device. This feature should be used when there is a need to monitor signals in the design. You can also use this feature to trigger on hardware events and capture data at system speeds.

The ILA core can be instantiated in your RTL code or inserted post synthesis in the Vivado design flow. Chapter 9 and Chapter 10 of this guide have more details on the ILA core and its usage methodology in the Vivado Design Suite. Detailed documentation on the ILA core IP can be found in the LogiCORE IP Integrated Logic Analyzer Product Guide (PG172) [Ref 20].

VIO: The Virtual Input/Output (VIO) debug feature can both monitor and drive internal FPGA signals in real time. In the absence of physical access to the target hardware, you can use this debug feature to drive and monitor signals that are present on the real hardware.

This debug core needs to be instantiated in the RTL code, hence you need to know up-front, what nets to drive. The IP Catalog lists this core under the Debug category. Chapter 10 of this guide has more details on the VIO core and its usage methodology in the Vivado Design Suite. Detailed documentation on the VIO core IP can be found in the LogiCORE IP Virtual Input/Output Product Guide (PG 159) [Ref 16].

IBERT: The IBERT (Integrated Bit Error Ratio Tester) Serial Analyzer design enables in-system serial I/O validation and debug. This allows you to measure and optimize your high-speed serial I/O links in your FPGA-based system. Xilinx recommends using the IBERT Serial Analyzer design when you are interested in addressing a range of in-system debug and validation problems from simple clocking and connectivity issues to complex margin analysis and channel optimization issues.

Xilinx recommends using the IBERT Serial Analyzer design when you are interested in measuring the quality of a signal after a receiver equalization has been applied to the received signal. This ensures that you are measuring at the optimal point in the TX-to-RX channel thereby ensuring real and accurate data. Users can access this design by selecting, configuring, and generating the IBERT core from the IP Catalog and selecting the Open Example Design feature of this core. Chapter 13 and Chapter 14 of this guide have more details on the IBERT core and its usage methodology in the Vivado Design Suite. Detailed documentation on the IBERT design can be found in the LogiCORE IP IBERT for 7 Series GTX Transceivers (PG132) [Ref 17], LogiCORE IP IBERT for 7 Series GTP Transceivers (PG133) [Ref 18], and LogiCORE IP IBERT for 7 Series GTH Transceivers (PG152) [Ref 19].

JTAG-to-AXI Master: JTAG-to-AXI Master debug feature is used to generate AXI transactions that interact with various AXI full and AXI lite slave cores in a system that is running in hardware. Xilinx recommends that you use this core to generate AXI transactions and debug/drive AXI signals internal to an FPGA at run time. This core can be used in designs without processors as well.
The IP Catalog lists this core under the Debug category. Chapter 10 of this guide has more details on the JTAG-to-AXI Master core and its usage methodology in the Vivado Design Suite. Detailed documentation on the JTAG-to-AXI IP core can be found in the LogiCORE IP JTAG to AXI Master v1.0 Product Guide (PG174) [Ref 21].

**Debug Hub:** The Vivado Debug Hub core provides an interface between the JTAG Boundary Scan (BSCAN) interface of the FPGA device and the Vivado Debug cores, including the following types of cores:

- Integrated Logic Analyzer (ILA)
- Virtual Input/Output (VIO)
- Integrated Bit Error Ratio Test (IBERT)
- JTAG-to-AXI
- Memory IP

**IMPORTANT:** The Vivado Debug Hub core cannot be instantiated into the design. It is inserted by Vivado during the opt_design stage.
Vivado Lab Edition

Vivado® Lab Edition is a standalone installation of the full Vivado Design Suite with all the features and capabilities required to program and debug Xilinx® FPGAs after generating the bitstream. Typical usage is for programming and debug in the lab environment where machines have a smaller amount of resources in terms of disk space, memory, and connectivity. Vivado Lab Edition has a reduced product footprint of around 1.3GB after installation and the install package size is 1GB.

Installation

You will need to use the Lab Edition Installer to install Vivado Lab Edition.

Detailed installation, licensing and release information is available in Vivado Design Suite User Guide: Release Notes, Installation, and Licensing (UG973) [Ref 5].

Launching Vivado Lab Edition on Windows

To launch Vivado Lab Edition, select the following:

Start > All Programs > Xilinx Design Tools > Vivado Lab 2016.2 > Vivado Lab 2016.2.

Launching the Vivado Lab Edition from the Command Line on Windows or Linux

Enter the following command at the command prompt:

vivado_lab

**TIP:** To run vivado_lab at the command prompt setup your environment using either of the two scripts (depending on OS platform type):

- C:\Xilinx\Vivado_Lab\2016.2\settings32.(bat|sh)
- C:\Xilinx\Vivado_Lab\2016.2\settings64.(bat|sh)
RECOMMENDED: You can open the Vivado Lab Edition from any directory. However, Xilinx recommends running it from a writable project directory, because the Vivado Lab Edition log and journal files are written to the launch directory. When running from a command prompt, launch the Vivado IDE from the project directory, or use the vivado_lab -log and journal options to specify a location. When using a Windows shortcut, you must modify the Start in folder, which is a Property of the shortcut. Failure to launch from a writable project directory results in warnings and unpredictable behavior from the tool.

Using the Vivado Lab Edition

When you launch the Vivado Lab Edition, the Getting Started page (Figure 2-1) displays and provides you with different options to help you begin working with the Vivado Lab Edition.

Starting with a Project

To program or debug your design, you can create or open a project, and connect to a target server and device. The Quick Start section of the Getting Started Page provides links for easy access to the following tasks:
Chapter 2: Vivado Lab Edition

- Create a project using the **Create New Project** dialog
- Open existing projects

*Note:* You can also open recently accessed projects from the **Recent Projects** list.

## Opening the Hardware Manager

You can open the Vivado Design Suite Hardware Manager to download your design bitstream to a device. Use the Vivado logic analyzer and Vivado serial I/O analyzer features of the Hardware Manager to debug your design. For example, you can add ILA, VIO, and JTAG-to-AXI cores to your design for debugging in the Vivado logic analyzer, or use the IBERT example design from the Xilinx IP catalog to test and configure the GTs in your design with the Vivado serial I/O analyzer.

## Reviewing Documentation and Videos

From the Getting Started page, you can use the Xilinx Documentation Navigator to access documentation, including user guides, tutorials, videos, and the release notes.

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**Vivado Lab Edition Project**

Vivado Lab Edition allows users in the lab to create projects. All the relevant programming and runtime debug preferences and settings are stored in the project. When the project is reopened, the settings and preferences are restored back into the tool. A Vivado Lab Edition project can be created in both the Vivado Lab Edition tool as well as in Vivado Design Suite.

### Create a New Project

To create a new project in Vivado Lab Edition, click the **Create New Project** icon as shown below. Enter the project name and location in the **New Vivado Lab Edition Project** dialog box. When you create a new project, Vivado Lab Edition creates a project file. The project
file has the same name as the project name entered in the New Project dialog box with the .lpr extension. See Figure 2-2 below.

![Vivado Lab Edition Creating a New Project](image)

**Figure 2-2:**  Vivado Lab Edition Creating a New Project

### Creating Projects Using Tcl Commands

You can also create a project using Tcl commands. Enter the following command in the Tcl Console of Vivado Lab Edition or source them from a Tcl file.

```tcl
create_project project_1 C:/Lab_edition/project_1
```

### Opening the Project

To open existing projects, click the open project icon as shown in Figure 2-3 or double-click a project in the Recent Projects list. This opens a browser that enables you to open any Vivado Lab Edition project file (.lpr extension). By default, the last ten previously opened projects are listed in the Recent Projects list. To change this number, click Tools > Options.
and update the General options. Vivado Lab Edition checks to ensure that the project data is available before displaying the projects.

**Opening Projects Using Tcl Commands**

You can also open a project using Tcl commands. Enter the following command in the Tcl Console of the Vivado Lab Edition or source them from a .tcl file.

```tcl
open_project C:/Lab_edition/project_1/project_1.lpr
```

**Using existing bitstream (.bit) and debug probes (.ltx) files in Vivado Lab Edition**

You can use the existing .bit file and .ltx file from a previous implementation run in the lab machine where Vivado Lab Edition is installed.

Typical flow would entail the following:

1. Create a New Vivado Lab Edition project.
2. Connect to the board.
3. Specify the .bit file and .ltx file for the project.
4. You can either manually copy these files or point to them on a network drive.

5. Program the device.

6. Debug the design in your hardware.

7. Changes are continuously saved to the project.

8. User preferences, runtime manager debug dashboard, and window settings are continuously saved to the project.

9. User preferences, runtime manager debug dashboard, and window settings are restored at project reopen.

Using existing .lpr project from Vivado Design Suite Edition

Vivado Design Suite creates an .lpr file at project startup and populates this file with appropriate details when you use the Hardware Manager to program and/or debug the design in the project. This file is located in the project_name.hw directory and is named project_name.lpr. This project file can be opened in the Vivado Lab Edition.

Typical flow would entail:

• Click the Open Project icon on the Vivado Lab Edition start page.

• Traverse to the project_name.hw directory, which is located inside the Vivado IDE project directory.

• Select the .lpr project file inside the project_name.hw directory and click OK.

• Connect to your hardware.

• Program and debug with the correct .bit file and .ltx file from the appropriate Vivado runs directory.

• User preferences, runtime manager debug dashboard, and window settings are restored at project open.

Programming Features

After the project is open and the Hardware Manager is connected with a target device, you can use all the programming features that were available in the Vivado Design Suite from the Vivado Lab Edition. All the programming related Tcl commands are supported in Vivado Lab Edition. For more details on the programming features available refer to Chapter 5, Programming Configuration Memory Devices.
Debug Features

After you open the project and connect the Hardware Manager with a target device, you can use all the debug features that were available in the Vivado Design Suite from the Vivado Lab Edition. All the debug related Tcl commands are supported in Vivado Lab Edition. For more details on the debug features available refer to Chapter 10, Debugging Logic Designs in Hardware of this user guide.
Generating the Bitstream

Before generating the bitstream data file, it is important to review the bitstream settings to make sure they are correct for your design.

There are two types of bitstream settings in Vivado® IDE:

1. Bitstream file format settings.
2. Device configuration settings.

The Bitstream Settings button in the Vivado flow navigator and the Flow > Bitstream Settings menu selection opens the Bitstream section in the Project Settings popup window (see Figure 3-1). Once the bitstream settings are correct, the bitstream data file can be generated using the write_bitstream Tcl command or by using the Generate Bitstream button in the Vivado flow navigator.

![Figure 3-1: Bitstream Settings Panel](image)
Chapter 3: Generating the Bitstream

Changing the Bitstream File Format Settings

By default, the write_bitstream Tcl command generates a binary bitstream (.bit) file only. You can optionally change the file formats written out by the write_bitstream Tcl command by using the following command switches:

- **-raw_bitfile**: (Optional) This switch causes write_bitstream to write a raw bit file (.rbt), which contains the same information as the binary bitstream file, but is in ASCII format. The output file is named `filename.rbt`.

- **-mask_file**: (Optional) Write a mask file (.msk), which has mask data where the configuration data is in the bitstream file. This file determines which bits in the bitstream should be compared to readback data for verification purposes. If a mask bit is 0, that bit should be verified against the bitstream data. If a mask bit is 1, that bit should not be verified. The output file is named `file.msk`.

- **-no_binary_bitfile**: (Optional) Do not write the binary bitstream file (.bit). Use this command when you want to generate the ASCII bitstream or mask file, or to generate a bitstream report, without generating the binary bitstream file.

- **-logic_location_file**: (Optional) Creates an ASCII logic location file (.ll) that shows the bitstream position of latches, flip-flops, LUTs, Block RAMs, and I/O block inputs and outputs. Bits are referenced by frame and bit number in the location file to help you observe the contents of FPGA registers.

- **-bin_file**: (Optional) Creates a binary file (.bin) containing only device programming data, without the header information found in the standard bitstream file (.bit).

- **-reference_bitfile <arg>**: (Optional) Read a reference bitstream file, and output an incremental bitstream file containing only the differences from the specified reference file. This partial bitstream file can be used for incrementally programming an existing device with an updated design.

Changing Device Configuration Bitstream Settings

The most common configuration settings that you can change fall into the device configuration settings category. These settings are properties on the device model and you change them by using the **Edit Device Properties** dialog for the selected synthesized or implemented design netlist. The following steps describe how to set various bitstream properties using this method:

1. Select **Tools > Edit Device Properties**.
2. In the **Edit Device Properties** dialog, select one of the categories in the left-hand column (see Figure 3-2).
TIP: You can type a property in the Search field. For example, type jtag into the Search text field to find and select properties related to JTAG programming.

3. Set the properties to the desired values, and click **OK**.

4. Select **File > Save Constraints** to save the updated properties to the target XDC file.

You can also set the bitstream properties using the `set_property` command in an XDC file. For instance, here is an example on how to change the start-up DONE cycle property:

```plaintext
set_property BITSTREAM.STARTUP.DONE_CYCLE 4 [current_design]
```

Additional examples and templates are provided in the Vivado Templates. **Appendix A, Device Configuration Bitstream Settings** describes all of the device configuration settings.
Chapter 4

Programming the FPGA Device

The next step after generating the bitstream data programming file is to download it into the target FPGA device. Vivado® IDE has native in-system device programming capabilities built in to do this.

Vivado Design Suite and Vivado Lab Edition includes functionality that allows you to connect to hardware containing one or more FPGA devices to program and interact with those FPGA devices. Connecting to hardware can be done from either the Vivado Lab Edition, or Vivado Design Suite graphical user interface or by using Tcl commands. In either case, the steps to connect to hardware and program the target FPGA device are the same:

1. Open the Hardware Manager.
2. Open a hardware target that is managed by a hardware server running on a host computer.
3. Associate the bitstream data programming file with the appropriate FPGA device.
4. Program or download the programming file into the hardware device.

Opening the Hardware Manager

Opening the Hardware Manager is the first step in programming and/or debugging your design in hardware. To open the Hardware Manager, do one of the following:

- If you have a project open, click the Open Hardware Manager button in the Program and Debug section of the Vivado flow navigator.
- Select Flow > Open Hardware Manager.
- In the Tcl Console window, run the open_hw command.
Opening Hardware Target Connections

The next step in opening a hardware target (for instance, a hardware board containing a JTAG chain of one or more FPGA devices) is connecting to the hardware server that is managing the connection to the hardware target. You can do this one of three ways:

- Use the Open Target selection under Hardware Manager in the Program and Debug section of the Vivado Flow Navigator to open new or recent hardware targets (see Figure 4-1).

![Figure 4-1: Using the Flow Navigator to Open a Hardware Target](image1)

- Use the Open Target -> Open recent target or Open Target -> Open New Target... selections on the green user assistance banner across the top of the Hardware Manager window to open recent or new hardware targets, respectively (see Figure 4-2).

![Figure 4-2: Using the User Assistance Bar to Open a Hardware Target](image2)

- Use Tcl commands to open a connection to a hardware target.

**TIP:** Use the Auto Connect selection to automatically connect to a local hardware target.
Connecting to a Hardware Target Using hw_server

The list of compatible JTAG download cables and devices that are supported by hw_server are:

- Xilinx® Platform Cable USB II (DLC10)
- Xilinx Platform Cable USB (DLC9G, DLC9LP, DLC9)
- Digilent JTAG-HS1
- Digilent JTAG-HS2
- Digilent JTAG-HS3
- Digilent JTAG-SMT1
- Digilent JTAG-SMT2

The hw_server is automatically started by Vivado when connecting to targets on the local machine. However, you can also start the hw_server manually on either local or remote machines. For instance, in a full Vivado installation on a Windows platform, at a cmd prompt run the following command:

```
C:\Xilinx\Vivado\<Vivado_version>\bin\hw_server.bat
```

If you are using a Hardware Server (Standalone) installation on a Windows platform, at a cmd prompt run the following command:

```
c:\Xilinx\HWSRVR\<Vivado_version>\bin\hw_server.bat
```

Follow the steps in the next section to open a connection to a new hardware target using this agent.

**IMPORTANT:** If Vivado Hardware Manager is connected to the hw_server, and the hw_server is stopped, the Hardware Manager detects this condition automatically and disconnects from the server.

Opening a New Hardware Target

The Open New Hardware Target wizard provides an interactive way for you to connect to a hardware server and target. The wizard process has the following steps:

1. Select a local or remote server, depending on what machine your hardware target is connected to:
   - Local server: Use this setting if your hardware target is connected to the same machine on which you are running the Vivado Lab Edition or Vivado IDE (See Figure 4-3). The
Vivado software automatically starts the Vivado hardware server (hw_server) application on the local machine.

- Remote server: Use this setting if your hardware target is connected to a different machine on which you are running the Vivado Lab Edition or Vivado IDE. Specify the host name or IP address of the remote machine and the port number for the hardware server (hw_server) application that is running on that machine (see Figure 4-4). Refer to Connecting to a Remote hw_server Running on a Lab Machine, page 170 for more details on remote debugging.

**IMPORTANT:** When using remote server, you need to manually start the Vivado hardware server (hw_server) application of the same version of Vivado software that you will use to connect to the hardware server.

**TIP:** If you only want to connect to your lab machine remotely, you do not need to install the full Vivado design suite on that remote machine. Instead, you can install the light-weight Vivado Hardware Server (Standalone) tool on the remote machine.

![Figure 4-3: Using a Local Hardware Server](image)
2. Select the appropriate hardware target from the list of targets that are managed by the hardware server. Note that when you select a target, you see the various hardware devices that are available on that hardware target (see Figure 4-5).

![Using a Remote Hardware Server](image-url)
Troubleshooting a Hardware Target

You might run into issues when trying to connect to a hardware target. Here are some common issues and recommendations on how to resolve them:

- If you are not able to correctly identify the hardware devices on your target, it might mean that your hardware is not capable of running at the default target frequency. You can adjust the frequency of the TCK pin of the hardware target or cable (see Figure 4-5). Note that each type of hardware target may have different properties. Refer to the documentation of each hardware target for more information about these properties.
• While the Vivado hardware server will attempt to automatically determine the instruction register (IR) length of all devices in the JTAG chain, in some rare circumstances it might not be able to correctly do so. You should check the IR length for each unknown device to make sure it is correct. If you need to specify the IR length, you can do so directly in the Hardware Devices table of the Open New Hardware Target wizard (see Figure 4-5).

Opening a Recent Hardware Target

The Open New Hardware Target wizard is also what populates a list of previously connected hardware targets. Instead of connecting to a hardware target by going through the wizard, you can re-open a connection to a previously connected hardware target by selecting the Open recent target link in the Hardware Manager window and selecting one of the recently connected hardware server/target combinations in the list. You can also access this list of recently used targets through the Open Target selection under Hardware Manager in the Program and Debug section of the Vivado flow navigator.

Opening a Hardware Target Using Tcl Commands

You can also use Tcl commands to connect to a hardware server/target combination. For instance, to connect to the digilent_plugin target (serial number 210203339395A) that is managed by the hw_server running on localhost 3121, use the following Tcl commands:

```tcl
connect_hw_server -url localhost:3121
current_hw_target [get_hw_targets */xilinx_tcf/Digilent/210203339395A]
set_property PARAM.FREQUENCY 15000000 [get_hw_targets */xilinx_tcf/Digilent/210203339395A]
open_hw_target
```

Once you finish opening a connection to a hardware target, the Hardware window is populated with the hardware server, hardware target, and various hardware devices for the open target (see Figure 4-6).
Chapter 4: Programming the FPGA Device

Associating a Programming File with the Hardware Device

After connecting to the hardware target and before you program the FPGA device, you need to associate the bitstream data programming file with the device. Select the hardware device in the Hardware window and make sure the Programming file property in the Properties window is set to the appropriate bitstream data (.bit) file.

Note: As a convenience, Vivado IDE automatically uses the .bit file for the current implemented design as the value for the Programming File property of the first matching device in the open hardware target. This feature is only available when using the Vivado IDE in project mode. When using the Vivado IDE in non-project mode, you need to set this property manually.

You can also use the set_property Tcl command to set the PROGRAM.FILE property of the hardware device:

```tcl
set_property PROGRAM.FILE {C:/design.bit} [lindex [get_hw_devices] 0]
```
Programming the Hardware Device

Once the programming file has been associated with the hardware device, you can program the hardware device using by right-clicking on the device in the Hardware window and selecting the Program Device menu option. You can also use the program_hw_device Tcl command. For instance, to program the first device in the JTAG chain, use the following Tcl command:

```
program_hw_devices [lindex [get_hw_devices] 0]
```

Once the progress dialog has indicated that the programming is 100% complete, you can check that the hardware device has been programmed successfully by examining the DONE status in the Hardware Device Properties view (see Figure 4-7).

You can also use the get_property Tcl command to check the DONE status. For instance, to check the DONE status of a Kintex®-7 device that is the first device in the JTAG chain, use the following Tcl command:

```
get_property REGISTER.IR.BIT5_DONE [lindex [get_hw_devices] 0]
```
If you use another means to program the hardware device (for instance, a flash device or external device programmer such as the iMPACT tool), you can also refresh the status of a hardware device by right-clicking the Refresh Device menu option or by running the refresh_hw_device Tcl command. This refreshes the various properties for the device, including but not limited to the DONE status.

**IMPORTANT:** Vivado Programmer tries to detect debug cores on the user scan chain specified in the design by default. It does the detection by issuing a JTAG_CHAIN 1 and 3 command to the device. If you have programmed a device with a design that does not have any debug cores or a debug core with a user scan chain of 2 or 4, you will see a warning as follows:

**WARNING:** [Labtools 27-3123] The debug hub core was not detected at User Scan Chain 1 or 3.

**Resolution:**
1. Make sure the clock connected to the debug hub (dbg_hub) core is a free running clock and is active OR
2. Manually launch hw_server with -e "set xsdb-user-bscan <C_USER_SCAN_CHAIN scan_chain_number>" to detect the debug hub at User Scan Chain of 2 or 4. To determine the user scan chain setting, open the implemented design and use:
   get_property C_USER_SCAN_CHAIN [get_debug_cores dbg_hub].

You can ignore this warning for designs with no debug cores. In addition, if your design does use the BSCAN primitive with JTAG_CHAIN 1 or 3 for something other than a debug core, you should be aware that the core auto detection will issue the command and you may see unexpected behavior.

## Closing the Hardware Target

You can close a hardware target by right-clicking on the hardware target in the Hardware window and selecting Close Target from the popup menu. You can also close the hardware target using a Tcl command. For instance, to close the xilinx_platformusb/USB21 target on the localhost server, use the following Tcl command:

```tcl
close_hw_target {localhost/xilinx_tcf/Digilent/210203339395A}
```

**IMPORTANT:** If the board is powered off or cable disconnected, Vivado IDE closes the hardware target in the Hardware Manager. Any Vivado operation in the main Vivado thread is also canceled. If the board is powered back on or the cable is reconnected, the Vivado IDE will attempt to re-open the hardware target in the Hardware Manager.
Chapter 4: Programming the FPGA Device

Closing a Connection to the Hardware Server

You can close a hardware server by right-clicking on the hardware server in the Hardware window and selecting Close Server from the popup menu. You can also close the hardware server using a Tcl command. For instance, to close the connection to the localhost server, use the following Tcl command:

```
disconnect_hw_server localhost
```

**IMPORTANT:** If Vivado Hardware Manager is connected to the hw_server, and the hw_server is stopped, the Hardware Manager detects this condition automatically and disconnects from the server.

Reconnecting to a Target Device with a Lower JTAG Clock Frequency

The JTAG chain is as fast as the slowest device in the chain. Therefore, to lower the JTAG clock frequency, connect to a target device whose JTAG clock frequency is less than the default JTAG clock frequency.

You should attempt to open with a default JTAG clock frequency that is 15 MHz for the Digilent cable connection and 6 MHz for the USB cable connection. If it is not possible to connect at these speeds, Xilinx recommends that you lower the default JTAG clock frequency even further as described below.
To change the JTAG clock frequency, use the Open New Hardware Target wizard, from Vivado Design Suite, as shown in Figure 4-8.

![Open New Hardware Target](image)

**Figure 4-8:** Vivado Lower JTAG Frequency

Alternately, you can use the following sequence of Tcl commands:

```
open_hw
connect_hw_server -url machinename:3121
current_hw_target [get_hw_targets */xilinx_tcf/Digilent/210203327962A]
set_property PARAM.FREQUENCY 250000 [get_hw_targets */xilinx_tcf/Digilent/210203327962A]
open_hw_target
```

---

**Connecting to a Server with More Than 32 Devices in a JTAG Chain**

It is possible to connect to a server which has more than 32 devices in its JTAG chain in Vivado. You need to provide option `max-jtag-devices` at the startup of `hw_server` to
enable the ability to detect more devices in a scan chain. The default value for this setting is 32. Note that increasing this number will slow down the device discovery process which in turn can slow down cable access.

Specify the `max-jtag-devices` option at `hw_server` start-up as follows:

```
hw_server -e "set max-jtag-devices 64"
```

---

**Remote Debugging in Vivado**

The need for remote debugging may arise in a variety of situations. It could be required in the prototyping phase of a product, where you might want to debug a design in the lab without physical access to the lab, or where you might want to share resources across your organization. Remote debugging could also be required to perform in-the-field debug/updates to diagnose issues or extend product life cycle.

Xilinx provides multiple solutions to debug/upgrade your design remotely. This can be done using the Xilinx Hardware Server product to connect to a remote computer in the lab. You could also implement the Xilinx Virtual Cable (XVC) protocol to connect to a network-connected board. Each of these solutions are explained in detail in the sections below.

**Using Vivado Hardware Server to Debug Over Ethernet**

You can connect to a remote lab machine using Vivado Hardware Server product. This is a small sized (<100MB) standalone download available for install on the lab machine. This option requires intranet or internet access and can be used internally just within your organization as well.

![Debug via Internet/Intranet Using Hardware Server](image)
Xilinx Virtual Cable (XVC)

Vivado IDE supports the Xilinx Virtual Cable (XVC) protocol. Xilinx Virtual Cable provides a means to access and debug a Xilinx device without using a USB or parallel configuration cable. This capability helps facilitate Vivado IDE to debug for designs that:

- Have the FPGA in a hard-to-access location, where a "lab-PC" is not close by.
- Do not have direct access to the device pins on the board - e.g. the JTAG pins are only accessible via a local microprocessor interface.

XVC is an internet-based (TCP/IP) protocol that acts like a JTAG cable. It has very basic cable commands. This allows XVC to provide the ability to debug a system over an intranet, or even the internet. With this ability you can save on costly or impractical travel and reduce the time it takes to debug a remotely located system. XVC implementation is programming language and platform independent.

Rather than using a dedicated JTAG header, an existing Ethernet connection can be used to create the appropriate JTAG commands from a processor to a target device. With the XVC v1.0 Protocol, Vivado can communicate the same JTAG commands over an Ethernet connection and still support all of the existing Vivado debug and programming features.

A common use case illustrated below in Figure 4-10 is the need to debug devices in data centers. These devices are located in remote locations on boards mounted on a rack. You can run Vivado IDE and Hardware Server (hw_server) on a desktop/host machine and communicate with the data center via ethernet which in turn communicates with an XVC server running on a microprocessor using JTAG.

![Figure 4-10: Debug via Ethernet Using XVC Server](X14742-062315)

**XVC Server Implementation**

You need to implement the XVC protocol to create an XVC server on the appropriate processor.
XVC Protocol

The XVC protocol allows Vivado IDE to communicate JTAG commands over ethernet to an embedded system so that a target Xilinx device can be programmed and/or debugged. This enables a vendor agnostic solution for debugging and programming a Xilinx device. Programming capabilities include the same support as a traditional JTAG connection would provide. Debugging capabilities include operability with Xilinx System Debugger (XSDB) or with Vivado Hardware Debug IP.

The JTAG commands to the device are the same commands that would have been transferred to the device if it were natively communicating with a programming cable or using a Digilent module. This ensures functionality between all the existing Vivado Hardware Debug tools.

User XVC 1.0 Commands

The XVC 1.0 Protocol commands are summarized Table 4-1.

Table 4-1: Description of XVC commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
</table>
| getinfo | Command format:  
getinfo:  
This command gets the XVC Service version. The service returns the following string when it receives “getinfo:“  
xvcServer_v1.0:<xvc_vector_len>
<xvc_vector_len> is the max width of the vector that can be shifted into the service. |
Initializing Vivado IDE hw_server

When Vivado IDE hw_server is initialized with an XVC connection Vivado IDE discovers the XVC cable just like any USB cable. To do that, start the Vivado IDE hw_server with these arguments

```
hw_server -e "set auto-open-servers xilinx-xvc:localhost:10200"
```

The auto-open-servers option enables the XVC cable to be initialized by hw_server at start up. You can initialize the hardware server to force a connection to an existing XVC cable. The server will automatically discover the XVC cables in future connections.

The argument to auto-open-servers is as follows

```
xilinx-xvc:<xvc_host_name>::<xvc_port>
```

Multiple servers can be specified using comma separated strings. When the hardware server starts, it attempts to establish connections to the specified XVC servers.

Refer to Xilinx Virtual Cable Running on Zynq-7000 Using the PetaLinux Tools (XAPP1251) [Ref 13] for an example of this.

---

Table 4-1: Description of XVC commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
</table>
| shift   | Command format:

  ```
  shift:[num_bits][tms_vector][tdi_vector]
  ```

  This command shifts in `num_bits` using the byte vectors `tms_vector` and `tdi_vector`
  
  • `num_bits` is an integer in little-endian mode.
  
  • `tms_vector` is a byte sized vector with all the TMS shift bits.

  • Bit 0 in Byte 0 of this vector is shifted out first.

  • The vector is `num_bits` and rounds up to the nearest byte.

  • `tdi_vector` is like `tms_vector` but this represents all the tdi vectors to be shifted in.

  This command returns a byte vector of the same size as `tms_vector` with the corresponding tdo bits sampled for every bit shifted in.

  • Bit 0 in Byte 0 of this vector is the first tdo value read from the shift

| settck  | Command format:

  ```
  settck:[period]
  ```

  This command attempts to set the service tck period to `[period]`.

  • `[period]` is specified in ns.

  • This is a little-endian integer value

  This command returns the applied period when it completes `settck`.

  • Returned value is specified in ns.

  • This is a little-endian integer value
This application note shows how to get a Xilinx Virtual Cable (XVC) server running on a Zynq®-7000 device with a Linux operating system generated with the PetaLinux Tools. A reference design is provided for the Avnet MicroZed board. The target device in this application note is on an AC701 board and will be programmed and debugged by the MicroZed board running XVC on Linux.
Chapter 5

Programming Configuration Memory Devices

The Vivado device programmer feature enables you to directly program Xilinx® FPGA devices via JTAG. Vivado can also indirectly program Flash-based configuration memory devices via JTAG. Do this by first programming the Xilinx FPGA device with a special configuration that provides a data path between JTAG and the Flash device interface followed by programming the configuration memory device contents using this data path.

The Vivado device configuration feature enables you to directly configure Xilinx FPGAs or Memory Devices using either Xilinx or Digilent cables. See Connecting to a Hardware Target Using hw_server, page 22 for a list of appropriate cables. Operating in Boundary-Scan mode, Vivado can configure or program Xilinx FPGAs, and Configuration Memory Devices.

Refer to Appendix C, Configuration Memory Support for a complete list of configuration memory devices supported by Vivado.

To program and boot from a Configuration Memory Device in Vivado follow the steps below.

1. Generate bitstreams for use with configuration memory devices.
2. Create a Configuration Memory File (.mcs or .bin).
3. Connect to the Hardware target in Vivado.
4. Add the configuration memory device.
5. Program the configuration memory device using the Vivado IDE.
6. Boot the FPGA device (optional).
Generate Bitstreams for use with Configuration Memory Devices

On the synthesized or implemented design select **Tools->Edit Device Properties** to open the **Edit Device Properties** dialog as shown below.

![Edit Device Properties Dialog](image)

*Figure 5-1: Edit Device Properties: Search Field*

Use the search field in the upper left of the dialog box to search for all SPI or BPI related fields and select the appropriate option settings. See Appendix A, Device Configuration Bitstream Settings for the device configuration settings.
Creating a Configuration Memory File

Use the `write_cfgmem` Tcl command to create the `.mcs` or `.bin` programming file. This file will be used in programming the configuration memory device.

For example, to generate an `.mcs` file for a single 1Gbit BPI configuration memory device:

```
write_cfgmem -format mcs -interface bpix16 -size 128
    -loadbit "up 0x0 design.bit"-file design.mcs
```

**Note:** The `-size` argument to `write_cfgmem` is in Mbytes, different from flash device capacity which is based on Mbits. Hence, a 1Gbit sized flash device is provided as 128 Mbytes to `write_cfgmem` in the example above. Note that `write_cfgmem` automatically sizes the configuration memory file to the size of the bitstream.

Vivado IDE supports the ability to chain multiple `.bit` files together using the `write_cfgmem` command. To generate an `.mcs` file for a single 1Gbit BPI configuration memory device containing multiple bitstreams:

```
write_cfgmem -format mcs -interface bpix16 -size 128
    -loadbit "up 0 design1.bit up 0xFFFFF design2.bit" -file design1_design2.mcs
```

For more information on `write_cfgmem` command refer to the *Vivado Design Suite Tcl Command Reference* (UG835) [Ref 8].

**TIP:** You can create configuration memory files in Vivado Lab Edition.
You can also create the Configuration Memory file in Vivado IDE. Click on **Tools > Generate Memory Configuration File**. This will bring up the **Write Memory Configuration File** dialog box as shown below.

![Write Memory Configuration File](image)

**Figure 5-2:** Write Memory Configuration File

Select the relevant format and options, and click **OK** to generate the configuration memory file.
Connect to the Hardware Target in Vivado

To connect to a hardware target in Vivado, do the following:

1. Ensure the appropriate configuration mode (Master SPI or Master BPI) is selected on the FPGA mode pins of the hardware target to configure the FPGA from a configuration memory device.

   For more information, see the appropriate Configuration User Guide for the device you are targeting.

2. Follow the steps in Chapter 4, Programming the FPGA Device to connect to the hardware target.

   **IMPORTANT:** If the board is powered off or cable disconnected, Vivado IDE closes the hardware target. Any Vivado operation in the main Vivado thread is also canceled.

Adding a Configuration Memory Device

To add the configuration memory device to a hardware target in Vivado device programmer, do the following:

1. After connecting to the hardware target as outlined above, add the configuration memory device by right-clicking the hardware target as shown below and selecting **Add Configuration Memory Device**.

   ![Add Configuration Memory Device Menu Item](image)

   **Figure 5-3:** Add Configuration Memory Device Menu Item
On clicking on this menu item the **Add Configuration Memory Device** dialog box opens.

*Figure 5-4: Add Configuration Memory Device part selector*
2. Select the appropriate configuration memory part and click **OK**.

---

**TIP:** Use the **Search** field to pare down the list using Vendor, Density, or Type information.

The configuration memory device is now added to the hardware target device.

---

**Programming a Configuration Memory Device**

1. After creating the configuration memory device, Vivado device programmer prompts “Do you want to program the configuration memory device now?” as shown below.

---

Figure 5-5: Configuration Memory Device Added to Hardware Target

Figure 5-6: Prompt to Program Configuration Memory Device
Click **OK** to open the **Program Configuration Memory Device** dialog box.

![Program Configuration Memory Device Dialog Box]

**Figure 5-7: Program Configuration Memory Device Dialog**

2. Set all the fields in this dialog box appropriately.

   - **Configuration file** (.mcs or .bin) - Specifies the file to use for programming the configuration memory device. The memory configuration file is created with the `write_cfgmem` Tcl command. See Creating a Configuration Memory File, page 39 for more information.

   - State of non-config mem I/O pins:
     - **Pull-none** - Specifies that the indirect configuration bitstream programmed into the FPGA has the unused I/O pins set to **pull-none**.
     - **Pull-up** - Specifies that the indirect configuration bitstream programmed into the FPGA has the unused I/O pins set to **pull-up**.
     - **Pull-down** - Specifies that the indirect configuration bitstream programmed into the FPGA has the unused I/O pins set to **pull-down**.
Chapter 5: Programming Configuration Memory Devices

**IMPORTANT:** Ensure the state of non-config mem I/O pins matches what you set in the write_bitstream properties. The default value for this property is pull-down.

- **Program Operations** (performed on the configuration memory device):
  - **Address Range** - Specifies the address range of the configuration memory device to program. The address range values can be:
    - **Configuration File Only** - Use only the address space required by the memory configuration file to erase, blank check, program, and verify.
    - **Entire Configuration Memory Device** - Erase, blank check, program, and verify will be performed on the entire device.
  - **RS Pins** - Optional. Revision Select Pin Mapping that is used with BPI configuration memory devices only (where the upper two FPGA address pins on the flash are tied to the FPGA RS[1:0]). When the option is enabled, Vivado drives the FPGA RS[1:0] for programming. Refer to the appropriate FPGA Configuration User Guide on application usage.
  - **Erase** - Erases the contents of the configuration memory device.
  - **Blank Check** - Checks the configuration memory device to make sure the device is void of data prior to programming.
  - **Program** - Program the configuration memory device with the specified Configuration File (.mcs or .bin).
  - **Verify** - Verify that the configuration memory device contents match the Configuration File (.mcs or .bin) after programming.
  - **Verify Checksum** - Validates the data programmed in the configuration memory device. The tool calculates the checksum value based on the data programmed in the configuration memory device and compares it to the checksum value specified in the .prm file.

**TIP:** User generates cfgmem file and specifies -checksum write_cftmem option. This step creates the .prm files that contain checksum information about the cfgmem output file.

- **Create SVF Only** - Enabling this option allows for the creation of an .svf file with the program operations that you specified. Other third party tools can use the .svf file to program configuration memory devices outside of Vivado.

**IMPORTANT:** When this option is enabled, Vivado just generates the .svf file with the relevant program options. It does not actually program the configuration memory device.

3. Click **OK** to start the Erase, Blank Check, Program, and Verify operations on the configuration memory device per the selections in this dialog box. Vivado notifies you as each operation finishes.
**Note:** Pressing **Apply** will store the configuration memory settings but will not program the configuration memory device. If you press **Cancel** after pressing **Apply** the configuration memory device will be set and programming can be performed at a later time.

---

**Booting the Device**

After programming the configuration memory device, you can issue a soft boot operation (ie. JPROGRAM) to initiate the FPGA configuration from the attached configuration memory device. If you want to perform a Boot operation on the target FPGA device select the target device and right-click and select **Boot from Configuration Memory Device**.

![Figure 5-8: Boot from Configuration Memory Device](image)

*Figure 5-8: Boot from Configuration Memory Device*
Chapter 6

Advanced Programming Features

Readback and Verify

Bitstream Verify and Readback

Vivado® IDE can verify and/or readback the configuration data (i.e., .bit file) downloaded into an FPGA. When using write_bitstream to generate the .bit file, use the -mask_file option to create a corresponding mask (.msk) file. Run write_bitstream -help in the Vivado IDE Tcl Console for details on bitstream generation options.

When performing a verify operation, the verify_hw_devices Tcl command reads data back from the FPGA and uses the .msk file to determine which readback data bits to skip and which ones to compare against the corresponding bits in the .bit file.

Following is an example of a bitstream verify Tcl command sequence (the .bit and .msk files were generated by a previous call to write_bitstream):

create_hw_bitstream -hw_device [current_hw_device] \  
    -mask kcu105_cnt_ila_uncmpr.msk  kcu105_cnt_ila_uncmpr.bit  
verify_hw_devices [current_hw_device]
You can use the Vivado Hardware Manager to verify the configuration data. Right click the device, select **Verify Device...** as shown below.

![Verify Device Selection](image)

**Figure 6-1: Verify Device Selection**

This opens up the **Verify Device** dialog box.

![Verify Device Dialog](image)

**Figure 6-2: Verify Device Dialog**

You need to enter the bit file and corresponding mask (.msk) file. Click **Verify** to execute the verification.
Use the `readback_hw_device` Tcl command with at least one of the following options to read back the FPGA configuration data:

- To save readback data in ASCII format:
  
  `-readback_file <filename.rbd>`

- To save readback data in binary format:
  
  `-bin_file <filename.bin>`

Example: Readback FPGA configuration data in both ASCII and binary formats

```
readback_hw_device [current_hw_device] \ 
  -readback_file kcu105_cnt_ila_uncmpr_rb.rbd \ 
  -bin_file kcu105_cnt_ila_uncmpr_rb.bin
```

**Notes:**

1. Bitstream, and readback operations are done through the Tcl Console.

2. Verify and readback operations do not work for FPGAs programmed with encrypted bitstreams. Encrypted bitstreams contain commands that disable readback. Readback is re-enabled by pulsing the FPGA PROG pin, or if the FPGA/board is powered down and powered back up again.

3. The data readback using `readback_hw_device` contains configuration data only (no configuration commands are included).

For more information on these features, see the *UltraScale Architecture Configuration User Guide* (UG570) [Ref 11] or the *7 Series FPGAs Configuration User Guide* (UG470) [Ref 9].

### Configuration Memory Verify and Readback

You can convert a bitstream file (.bit) to an .mcs or .bin file and then program it into a configuration memory device, such as serial/SPI or parallel/BPI flash, via the `write_cfgmem` command. See the *Vivado Design Suite Tcl Command Reference* (UG835) [Ref 8] for details.
Verify the configuration memory device through the Vivado Design Suite Hardware Manager as shown in Figure 6-3.

You can also verify the configuration memory device by setting the appropriate HW_CFGMEM properties and calling `program_hw_cfgmem` as shown in the following code:

```tcl
set_property PROGRAM.ADDRESS_RANGE  {use_file} [get_property PROGRAM.HW_CFGMEM [lindex [get_hw_devices] 0]]
set_property PROGRAM.FILES [list "H:/projects/k7_led/k7_led_325t_afx_x16_33v.mcs"]
set_property PROGRAM.BPI_RS_PINS {none} [get_property PROGRAM.HW_CFGMEM [lindex [get_hw_devices] 0]]
set_property PROGRAM.UNUSED_PIN_TERMINATION {pull-none} [get_property PROGRAM.HW_CFGMEM [lindex [get_hw_devices] 0]]
set_property PROGRAM.BLANK_CHECK 0 [get_property PROGRAM.HW_CFGMEM [lindex [get_hw_devices] 0]]
set_property PROGRAM.ERASE 0 [get_property PROGRAM.HW_CFGMEM [lindex [get_hw_devices] 0]]
set_property PROGRAM.CFG_PROGRAM 0 [get_property PROGRAM.HW_CFGMEM [lindex [get_hw_devices] 0]]
set_property PROGRAM.VERIFY 1 [get_property PROGRAM.HW_CFGMEM [lindex [get_hw_devices] 0]]
startgroup
if { ![string equal [get_property PROGRAM.HW_CFGMEM_TYPE [lindex [get_hw_devices] 0]] [get_property MEM_TYPE [get_property CFGMEM_PART [get_property PROGRAM.HW_CFGMEM [lindex [get_hw_devices] 0]]]]] } {
    create_hw_bitstream -hw_device [lindex [get_hw_devices] 0] [get_property PROGRAM.HW_CFGMEM_BITFILE [lindex [get_hw_devices] 0]];
    program_hw_devices [lindex [get_hw_devices] 0];
    program_hw_cfgmem -hw_cfgmem [get_property PROGRAM.HW_CFGMEM [lindex [get_hw_devices] 0]]
} endgroup
```

The contents of the configuration memory can be readback through the Vivado Design Suite Tcl Console using the following command sequence:

```tcl
readback_hw_cfgmem -file test.bin -hw_cfgmem [get_property PROGRAM.HW_CFGMEM [lindex [get_hw_devices] 0]]
```

**Note:** Perform configuration memory readback operations through the Tcl Console only.

For more information on these features, see the *UltraScale Architecture Configuration User Guide* (UG570) [Ref 11] or the *7 Series FPGAs Configuration User Guide* (UG470) [Ref 9]
Generating Encrypted and Authenticated Files for 7 Series Devices

To generate an encrypted bitstream, open an implemented design in Vivado IDE. From the main toolbar Select **Flow > Bitstream Settings...** to make **Project Settings** dialog box appear. At the top of the dialog box click **Configure Additional Bitstream Settings**.

![Figure 6-4: 7 Series Project Settings](Image)

**Figure 6-4:** 7 Series Project Settings
This brings up the **Edit Device Properties** dialog box. Select **Encryption** in the left-hand pane.

![Edit Device Properties dialog box](image)

**Figure 6-5: 7 Series Configure Encryption Settings**

In the **Edit Device Properties** dialog box, specify the encryption and key settings:

- **Encryption Settings**
  - Set **Enable Bitstream Encryption** to **YES**.
  - Set **Select location of encryption key** to either **BBRAM** or **EFUSE**.
    - The key location will be embedded in the encrypted bitstream.
    - When the encrypted bitstream is downloaded to the device, it instructs the FPGA to use the key loaded into the BBR or the eFUSE key register to decrypt the encrypted bitstream.
Chapter 6: Advanced Programming Features

- Key Settings
  - Specify **HMAC authentication key** and **Starting cipher block chaining (CBC)** value.
    - If these values are unspecified, Vivado generates a random value for you.
    - These values will be embedded in the encrypted bitstream and do not have to be programmed into the FPGA.

  **Note:** These values will be stored in the current project constraints file unless an input encryption file is specified. To avoid storing this value in the constraints file, specify the input encryption file.

  - Specify the **AES encryption key** to use when encrypting the bitstream. You can use up to 64 hex characters to specify the 256-bit key.
    - The key will be written to a file with the `.nky` file extension. Use this file when loading the key into the BBR or when programming the key into the eFUSE key register.

  **Note:** These values will be stored in the current project constraints file unless an input encryption file is specified. To avoid storing this value in the constraints file, specify the input encryption file.

  - Specify Input encryption file.
    - Specify an existing `.nky` file to obtain the encryption key settings. This field is optional and can be omitted if specifying the AES, HMAC and CBC manually.

After specifying the encryption settings, click **OK** to apply the settings to the project and regenerate your bitstream. Upon successful completion of the `write_bitstream` operation you will have a programming file along with a `.nky`, encryption file.
Generating Encrypted and Authenticated Files for UltraScale and UltraScale+

To generate an encrypted bitstream, open an implemented design in Vivado IDE. From the main toolbar select Flow > Bitstream Settings... to make the Project Settings dialog box appear. At the top of the dialog box click Configure Additional Bitstream Settings.

![UltraScale Configure Additional Bitstream Settings](image)

*Figure 6-6: UltraScale Configure Additional Bitstream Settings*
This brings up the **Edit Device Properties** dialog box. Select **Encryption** in the left-hand pane.

![Edit Device Properties dialog box](image)

**Figure 6-7:** Ultra Scale Configure Encryption Settings

In the **Edit Device Properties** dialog box, specify the **Encryption Settings** and **Key Settings**:

- **Encryption Settings**
  - Set **Enable Bitstream Encryption** to **YES**.
  - Set **Select location of encryption key** to either **BBRAM** or **EFUSE**.
    - The key location is embedded in the encrypted bitstream.
    - When the encrypted bitstream is downloaded to the device, it instructs the FPGA to use the key loaded into the BBR or the eFUSE key register to decrypt the encrypted bitstream.
  - Set **Enable obfuscated key load** to either **ENABLE** or **DISABLE**.
    - When enabled, this user generated key is encrypted before being stored in the BBRAM. If disabled, then the key is stored “as is” in the BBRAM.
• **Key Settings**
  - Specify **HMAC authentication key** and **Starting cipher block chaining (CBC)** value.
    - If these values are unspecified, Vivado generates a random value for you.
    - These values will be embedded in the encrypted bitstream and do not have to be programmed into the FPGA.

  **Note:** These values will be stored in the current project constraints file unless an input encryption file is specified. To avoid storing this value in the constraints file, specify the input encryption file.

  - Specify the **AES encryption key (key0)** to use when encrypting the bitstream. You can use up to 64 hex characters to specify the 256-bit key.
    - The key will be written to a file with an `.nky` file extension. Use this file when loading the key into the BBR or when programming the key into the eFUSE key register.

  **Note:** This value will be stored in the current project constraints file unless an input encryption file is specified. To avoid storing this value in the constraints file, specify the input encryption file.

  - Specify **Input encryption file**.
    - Specify an existing `.nky` file to obtain the encryption key settings. This field is optional and can be omitted if specifying the AES, HMAC, and CBC manually.

  - Specify **Number of encryption blocks per key** and **Number of frames per AES-256 key**.
    - The number of encryption blocks and frames are used to specify how many sections a bitstream will be broken into with distinct keys.

  - Specify **Starting AES initial vector (IV0) value**.
    - Initialization vector for the first key. Note that each key needs a separate initialization vector value that can be supplied through the input encryption file.

  **Note:** This value will be stored in the current project constraints file. To avoid storing this value in the constraints file, specify the input encryption file.

  - Specify **Starting obfuscate initial vector (Obfuscate IV0) value**.
    - Initialization vector for the obfuscated key.

  **Note:** This value will be stored in the current project constraints file. To avoid storing this value in the constraints file, specify the input encryption file.
For authentication settings select **Authentication** in the left-hand pane.

![Edit Device Properties - Authentication](image)

**Figure 6-8: Edit Device Properties - Authentication**

In the **Edit Device Properties - Authentication** dialog box, specify the encryption and key settings as follows:

- **Authentication Settings**
  - Set **Enable Bitstream Authentication** to **YES**.
  - Specify the **Input file containing RSA Private Key**.

Provide an RSA private key file after specifying the encryption and authentication settings. Click **OK** to apply the settings to the project. Re-run Implementation and regenerate the bitstream file. Upon successful completion of the **write_bitstream** operation, the generated .nky encryption key file appears in the same directory as the encrypted bitstream file.

You can protect IP in bitstreams by encrypting the bitstreams with a 256-bit Advanced Encryption Standard (AES) key, and downloading the bitstreams to run only on authorized FPGAs. Do this by programming the 256-bit key into the BBR register of the authorized FPGAs before downloading the encrypted bitstream.
Programming the AES Key for 7 Series Devices

To program the AES key into the BBR, right-click the FPGA device in the Hardware window, and select Program BBR Key.

In the Program BBR Key dialog box, specify the AES key (.nky) file by typing the file name or navigating to the desired file. After specifying a valid .nky file, the AES key field automatically fills in. Click OK, to have the Hardware Manager program/load the key into the BBR.

After programming the key, program the FPGA with an encrypted bitstream that:

- was encrypted using the same AES key as was loaded into BBR.
- had BBRAM selected as the specified encryption key location.
Clearing the AES Key for 7 Series Devices

To clear the AES key manually, disconnect the Vbatt pins and power-cycle the board.

*Note*: Pressing or pulsing the PROG pin when the board/FPGA is powered up will *not* clear the BBR register.

Alternatively, you can clear the AES key in Vivado IDE by right-clicking the FPGA device in the Hardware window, selecting **Clear BBR Key**...

![Clear BBR Key](image)

*Figure 6-11:*

When the **Clear BBR Key** dialog box appears, click **OK** to clear the key from the device.

![Clear BBR Key Dialog Box](image)

*Figure 6-12:  Clear BBR Key Dialog Box*
Programming the AES Key for UltraScale and UltraScale+ Devices

To program the AES key into the BBR, right-click the FPGA device in the Hardware window, and select Program BBR Key.

![Program BBR Key dialog box](image)

**Figure 6-13:** Program the BBR Key

The Program BBR Key dialog box appears.

![Program BBR Key - UltraScale and UltraScale+](image)

**Figure 6-14:** Program BBR Key - UltraScale and UltraScale+
In the Program BBR Key dialog box, specify the AES key file (.nky) and Enable DPA PROTECT:

- **AES key file (.nky)**
  - Specify the AES key file (.nky) by typing the file name or navigating to the desired file. After specifying a valid .nky file, the AES key field automatically fills in.

- **Enable DPA PROTECT**
  - Check the Enable DPA PROTECT check box.
  - Specify the DPA_COUNT value. The valid range is 1-256 when enabled.
  - Specify the DPA_MODE value. The valid values are “INVALID_CONFIGURATIONS” or “ALL_CONFIGURATIONS”.

*Note:* For more details on the BBR AES key and DPA_PROTECT feature refer to the UltraScale Architecture Configuration User Guide (UG570) [Ref 11]

Click **OK**, to have the Hardware Manager program load the key into the BBR.

After programming the key, program the FPGA with an encrypted bitstream that:

- was encrypted using the same AES key as was loaded into BBR.
- had BBRAM selected as the specified encryption key location.

**IMPORTANT:** For UltraScale devices, if you download an encrypted bitstream (which uses the BBR as the key source) before programming the key into the BBR register, the FPGA device will lock up and you will not be able to load the BBR key. You can still download unencrypted bitstreams, but you will not be able to download encrypted bitstreams because the FPGA device will prevent you from downloading a key into BBR. You must power-cycle the board to unlock the UltraScale device and then reload the BBR key.

**Clearing the AES Key for UltraScale, and UltraScale+ Devices**

To clear the AES key manually, disconnect the Vbatt pins and power-cycle the board.

*Note:* Pressing or pulsing the PROG pin when the board/FPGA is powered up will **not** clear the BBR register.
Alternatively, you can clear the AES key in Vivado IDE by right-clicking the FPGA device in the Hardware window, selecting Clear BBR Key...

![Clear BBR Key Dialog Box](image)

*Figure 6-15:*

When the **Clear BBR Key** dialog box appears, click OK to clear the key from the device.

![Clear BBR Key Dialog Box](image)

*Figure 6-16:  Clear BBR Key Dialog Box*
eFUSE Register Access and Programming

7 Series, UltraScale®, and UltraScale+® devices have one-time programmable bits called 
eFUSE bits that perform specific functions. The different eFUSE bit types are as follows:

- **FUSE_DNA** - Stores unique device identifier bits (non-programmable).
- **FUSE_USER** - Stores a 32-bit user-defined code.
- **FUSE_KEY** - Stores a key for use by the AES bitstream decryptor.
- **FUSE_CNTL** - Controls key use and read/write access to eFUSE registers.
- **FUSE_SEC** - Controls special device security settings in UltraScale and UltraScale+
devices.

**IMPORTANT:** Programming eFUSE register bits is a one-time only operation. Once eFUSE register bits 
are programmed (i.e., from unprogrammed state 0 to programmed 1 state), they cannot be reset to 0 
and/or programmed again. You should take great care to double-check your settings before 
programming any eFUSE registers.

**IMPORTANT:** Xilinx recommends programming the FUSE_USER and FUSE_KEY registers first, then 
rerunning the eFUSE programming wizard to program the FUSE_CNTL bits to control read/write access 
to these eFUSE bits, then finally the FUSE_SEC bits to control the FPGA security settings.

---

eFUSE Register Access and Programming for 7 
Series Devices

**FUSE_DNA: Unique Device DNA**

Each 7 Series device has a unique device ID called device DNA that has already been 
programmed into it by Xilinx. 7 Series devices have a 64-bit DNA. You can read these bits by 
running the following Tcl command in the Vivado Design Suite Tcl Console:

```tcl
get_property [lindex [get_hw_device] 0] REGISTER.EFUSE.FUSE_DNA
```
You can also access the device DNA by viewing the eFUSE registers in the **Hardware Device Properties** window in Vivado Design Suite as shown in the following Figure.

![Figure 6-17: eFUSE DNA](image)

For more information on these features, see the *7 Series FPGAs Configuration User Guide* (UG470) [Ref 9].
Programming the eFUSE Registers

To program the eFUSE registers, right-click the FPGA device in the Hardware window, select Program eFUSE Registers.

![Select Program eFUSE Registers](image)

*Figure 6-18: Select Program eFUSE Registers*

The Program eFUSE Registers wizard appears as shown in the following figure, and guides you to set the various options for the eFUSE registers.

![Program eFUSE Registers Wizard](image)

*Figure 6-19: Program eFUSE Registers Wizard*
In the **AES Key Setup** pane, specify the following settings:

- **AES Key file**
  - Specify the **AES key file (.nky)** by typing the file name or navigating to the desired file. After specifying a valid .nky file, the **AES key** field automatically fills in.

- **USER bits [7:0] and USER bits [31:8]**
  - The USER EFUSEs bits are provided to allow users to program their own special 32-bit pattern. The lower eight FUSE_USER bits are programmed at the same time as the 256-bit Advanced Encryption Engine (AES) key. The upper 24 user bits can be programmed concurrently with AES key or at a later time.
In the **Control Register Settings** pane, specify the following settings:

- **CFG_AES_Only**: When set, forces the use of the stored AES key.
- **AES_Exclusive**: When set, disables use of partial reconfiguration.
- **W_EN_B_Key_User**: When set, disables programming of AES key and User register.
- **R_EN_B_Key**: When set, disables reading of AES key.
- **R_EN_B_User**: When set, disables reading of user code.
- **W_EN_B_Cntl**: When set, disables programming of this control register.

For more information on these features, see the 7 Series FPGAs Configuration User Guide (UG470) [Ref 9]
Review the eFUSE settings in the **Program eFUSE Registers Summary** pane.

![Program eFUSE Registers Summary](image)

**Figure 6-22: Program eFUSE Registers Summary**

All bits set in the Program eFUSE Registers wizard panels are shown in this pane. In this pane you will see individual bit settings in order to review the specific programming settings. Review this summary page carefully to ensure every bit that is intended to be programmed is set.

Click **Finish** to bring up the **Program eFUSE confirmation** dialog box:

![Program eFUSE Confirmation](image)

**Figure 6-23: Program eFUSE Confirmation**

Click **OK** the to program the specified fuse bits.
eFUSE Register Access and Programming for UltraScale and UltraScale+ Devices

**FUSE_DNA: Unique Device DNA**

Each UltraScale device has a unique device ID called device DNA that has already been programmed into it by Xilinx. The FUSE_DNA is not user programmable. UltraScale devices have a 96-bit DNA. You can read the FUSE_DNA by running the following Tcl command in the Vivado Design Suite Tcl Console:

```
get_property [lindex [get_hw_device] 0] REGISTER.EFUSE.FUSE_DNA
```

You can also access the device DNA by viewing the eFUSE registers in the **Hardware Device Properties** window in Vivado Design Suite as shown in the following figure.

![Figure 6-24: eFUSE DNA](image)
Programming the eFUSE Registers

To program the eFUSE registers, right-click the FPGA device in the Hardware window, select Program eFUSE Registers.

The Program eFUSE Registers wizard appears as shown in the following figure, and guides you to set the various options for the eFUSE registers.

![Program eFUSE Registers Wizard](image)
In the **AES Key Setup** pane, specify the following settings:

![AES Key Setup](image)

**Figure 6-27: eFUSE Cryptographic Key Setup**

In the **Cryptographic Key Setup** wizard pane, specify these key settings:

- **Cryptographic file key (.nky)**
  - Specify a `.nky` file containing eFUSE AES and RSA keys

- **AES Key (256-bit)**
  - The 256-bit AES eFUSE key read in from specified `.nky` file used to decrypt loaded encrypted bitstream.

- **RSA Key Digest (384-bit)**
  - The 384-bit RSA eFUSE key read in from specified `.nky` file used by RSA.
In the USER Register Setup wizard pane, specify the 32 bit USER or 128 bit USER register

![USER Register Setup](image)

*Figure 6-28:  eFUSE USER Register Setup*

In the USER register setup pane specify user define register bits. The 32 bit USER (FUSE_USER) and 128 bit USER register (FUSE_USER128) registers are a set of user defined one-time programmable eFUSE bits. The bits of these registers are cumulatively programmable. This means that if you program only one USER bit in an eFUSE programming session (e.g., USER = 0x0000_0001 or bit 0), then on subsequent eFUSE programming sessions you can program any of the remaining 0 bits (e.g., USER = 0x0000_0003 or bit 1).

After programming the FUSE_USER and FUSE_USER_128 registers, these registers can be read in several ways:

- Using the Tcl command

  ```tcl
  report_property [lindex [get_hw_device] 0] REGISTER.EFUSE.FUSE_USER
  report_property [lindex [get_hw_devices] 0] REGISTER.EFUSE.FUSE_USER_128
  ```

- Through the Vivado Hardware Device Properties window after running a refresh_hw_device operation.
In the **Control Register Setup** wizard pane, specify the following settings:

![Control Register Setup Pane](image)

**Figure 6-29: Control Register Setup Pane**

In the **Control Register Setup** pane, specify the eFUSE control settings.

- **R_DIS_KEY**: When set, disables reading and programming the AES FUSE_KEY.
- **R_DIS_USER**: When set, disables reading and programming the 32 bit user bits (FUSE_USER).
- **R_DIS_SEC**: When set, disables reading and programming of the security register bits (FUSE_SEC).
- **W_DIS_CNTL**: When set, disables programming this control register (FUSE_CNTL).
- **W_DIS_RSA**: When set, disables reading and programming of the RSA key register (FUSE_RSA).
- **W_DIS_USER**: When set, disables programming of the 32 bit user bits (FUSE_USER).
- **W_DIS_SEC**: When set, disables programming of the security register bits (FUSE_SEC).
- **W_DIS_RSA**: When set, disables programming of the RSA key register (FUSE_RSA).
- **W_DIS_USER_128**: When set, disables programming of the 128 bit user bits (FUSE_USER128).

For more details on the FUSE_SEC register refer to the *UltraScale Architecture Configuration User Guide* (UG570) [Ref 11].
In the **Security Register Setup** wizard pane, specify the following settings:

![Security Register Setup](image)

**Figure 6-30: eFUSE Security Register Setup**

In the **Security Register Setup** wizard pane specify security control options over the type of bitstreams allowed to load on the FPGA. The FUSE_SEC settings are:

- **CFG_AES_Only**: When set, only accept encrypted bitstreams.
- **EFUSE_KEY_Only**: When set, only the eFUSE key can be used for decryption.
- **RSA_AUTH**: When set, forces RSA Authentication of bitstreams.
- **SCAN_DISABLE**: When set, disables Xilinx access to internal test registers.
- **CRYPT_DISABLE**: When set, permanently disables the decryptor.

For more details on the FUSE_SEC register refer to the *UltraScale Architecture Configuration User Guide* (UG570) [Ref 11].
Review the eFUSE settings in the **Program eFUSE Registers Summary** pane.

![Program eFUSE Registers Summary](image)

*Figure 6-31: Program eFUSE Registers Summary*

All bits set in the Program eFUSE Registers wizard panels are shown in this pane. In this pane you will see individual bit settings in order to review the specific programming settings. Carefully review this summary page to ensure every bit that is intended to be programmed is set.

Click **Finish** to bring up the **Program eFUSE confirmation** dialog box:

![Program eFUSE Confirmation](image)

*Figure 6-32: Program eFUSE Confirmation*

Click **OK** to program the specified fuse bits.
Disabling the JTAG interface

To disable the JTAG interface through the eFUSE registers, run the following Tcl command:

```tcl
program_hw_devices -security_efuse {08} [lindex [get_hw_devices] $deviceIdx]
```

Where `$deviceIdx` is set to the index of the UltraScale or UltraScale+ device that will have its JTAG interface disabled.

**Note:** This programming step should be performed as the last and final step after all desired eFUSE bits have been programmed.

**IMPORTANT:** If the JTAG Disable bit is programmed, the JTAG interface will be disabled, preventing future test and configuration access to the device. This bit should only be programmed if JTAG access to the device is no longer required.

---

System Monitor

The System Monitor (SYSMON) Analog-to-Digital Converter (ADC) measures die temperature and voltage on the hardware device. The SYSMON monitors the physical environment via on-chip temperature and supply sensors. The ADC provides a high-precision analog interface for a range of applications.

The ADC can access up to 17 external analog input channels. Refer to *UltraScale Architecture System Monitor User Guide* (UG580) [Ref 12], or *7 Series FPGAs and Zynq-7000 All Programmable SoC XADC Dual 12-Bit 1 MSPS Analog-to-Digital Converter User Guide* (UG480) [Ref 10] for more information on a specific device architecture.

![System Monitor](image.png)

**Figure 6-33:** System Monitor
The hw_sysmon data is stored in dedicated registers called status registers accessible through the hw_sysmon_reg object. You can get the contents of the System Monitor registers by using the get_hw_sysmon_reg command.

Every device that supports the System Monitor automatically has one or more hw_sysmon objects created when refresh_hw_device is called. When the hw_sysmon object is created, it is assigned a property for all the temperature and voltage registers, as well as the control registers. On the hw_sysmon object, the values assigned to the temperature and voltage registers are already translated to Celsius/Fahrenheit and Volts.

Although you can use the get_hw_sysmon_reg command to access the hex values stored in registers of a System Monitor, you can also retrieve values of certain registers as formatted properties of the hw_sysmon object. For example, the following code retrieves the TEMPERATURE property of the specified hw_sysmon object rather than directly accessing the hex value of the register:

```plaintext
set opTemp [get_property TEMPERATURE [lindex [get_hw_sysmons] 0]]
```

Complete list of all the System Monitor commands can be found in Table 10-16.
Serial Vector Format (SVF) File Programming

An alternative way to program FPGAs and configuration memory devices is through the use of a serial vector format (SVF) file. The SVF file generated through Vivado® Design Suite and Vivado Lab Edition contains low level JTAG instructions and data required to program these devices. Once the file is generated it can be used by boundary scan test tools independent of the Vivado IDE.

The general steps to create an SVF file are as follows:

1. Create an SVF offline target.
2. Open the created SVF target.
3. Add devices to the target to define the SVF JTAG scan chain.
4. Program FPGAs or configuration memory devices.
5. Write SVF.
6. Close SVF target.
7. (Optional) Execute SVF.

In step 4, the program operations are recorded in sequential order and stored a cached file. The cached file is then written out to a target destination in step 5. After the file is created, it can be used by boundary scan tools or executed through Vivado Design Suite or Vivado Lab Edition tools.

Creating an SVF Target

The SVF target is similar to a live Xilinx Platform Cable USB or Digilent JTAG cable hardware target. The properties and Tcl commands are all the same with the main distinction being that the SVF target is not an active live cable. This means that any operations performed on this target will not affect the hardware until the SVF is executed. Note that you do not need to have a cable connected to your system to create an SVF.

Following are the steps needed to create an SVF target after initially launching Vivado or Vivado Lab Edition:
open_hw
connect_hw_server
create_hw_target my_svf_target
current_hw_target

The first two commands can be omitted if already connected to a server. When executed, the create_hw_target command defines the my_svf_target. Note that you cannot have two targets with the same name in a session. Finally, after the create_hw_target command is run, the current_hw_target is automatically set to the newly defined target. As a result, the final command shows the full hardware target handle name of the created my_svf_target.

All standard operations on the target, such as get_hw_targets and open_hw target are supported. You can use the IS_SVF hardware target property to distinguish between a live target and an SVF target. For instance, the following is a sample command line that reads the IS_SVF property from a target named "my_svf_target".

get_property IS_SVF [get_hw_targets -regexp .*my_svf_target]

Additionally, all the SVF hw_targets created in this session can be displayed by issuing the following command:

get_hw_targets -filter {IS_SVF}

To delete the created target run use the delete_hw_target command. For instance, by issuing the following command, the my_svf_target is deleted:

delete_hw_target [get_hw_targets -regexp .*my_svf_target]

IMPORTANT: When a target is deleted, all the devices created for the target are also deleted. Moreover a deleted target is also closed if it was previously opened.

Adding Devices to an SVF Target

After the SVF target is created, devices can be added to it in order to define the SVF JTAG device chain configuration. The SVF JTAG device chain configuration should match the target hardware chain to ensure proper SVF file execution.

To create the chain, perform sequential create_hw_device operations on an open SVF target. For instance, to add an xcku9p part followed by an xcvu095 part perform the following steps:

current_hw_target my_svf_target
open_hw_target
create_hw_device -part xcku9p
create_hw_device -part xcvu095
refresh_hw_target
get_hw_devices
In this example, the first two steps can be skipped if the SVF is already created and opened. The `create_hw_device` commands in the example define the devices of the JTAG chain starting with the first device on the chain and onward.

**Note:** The `create_hw_device` command only creates devices on an open SVF hardware target.

To add user defined devices to the chain, add the `-idcode`, `-irlength`, and `-mask` values along with the part type name using the `-part` options. For instance, if you have a part called "my_part" with a JTAG idcode of 1234567, an ir length of 8, mask of fffftff, then you would create the device as shown below:

```bash
open_hw_target [current_hw_target]
create_hw_device -idcode 01234567 -irlength 8 -mask ffffffff -part my_part
# print IR length for user defined devices
puts [get_property IR_LENGTH [lindex [get_hw_devices -filter {PART == my_part}] 0]]
puts $idcode_hex
close_hw_target
```

**Note:** The idcode for the `create_hw_device` should be a valid device ID code. ID code values and IR lengths are typically provided by silicon vendors through device BSDL files.

To see a report of the target and its devices, run the `report_hw_targets` command. The report shows details for all active targets in the system. Use this report to obtain properties of the server, target, and device as shown below:

```bash
report_hw_targets
INFO: Server Property Information: localhost:3121
   CLASS:  hw_server
   HOST:  localhost
   NAME:  localhost:3121
   PORT:  3121
   SID:   TCP:localhost:3121
INFO: Target Property Information: localhost:3121/xilinx_tcf/Xilinx/my_svf_target
   CLASS:  hw_target
   DEVICE_COUNT: 3
   HW_JTAG: 0
   IS_OPENED: 1
   MAX_DEVICE_COUNT: 32
   NAME:  localhost:3121/xilinx_tcf/Xilinx/my_svf_target
   FREQUENCY: 10000000
   TYPE:  xilinx_tcf
   TID:   jsn-XNC-my_svf_target
   UID:   Xilinx/my_svf_target
   SVF:   1
   Device:  xcku9p_0
   Device:  xcvu095_1
   Device:  my_part_2
```

## Writing SVF Files

After creating an SVF target and adding devices, a target may be opened to capture direct and indirect flash programming operations in an SVF file. The direct FPGA and indirect flash
programming operations are captured in a temporary file for the open offline target. When the `write_hw_svf` command is called, the temporary file is moved to the filename passed to the command. After the `write_hw_svf` command is called, the temporary file is reset and a subsequent programming operation is added to the beginning of the SVF file sequence.

The following code segment shows the Tcl commands used to create a file named `my_xcku9p.svf` containing the direct programming of a xcku9p device:

```tcl
create_hw_target my_svf_target
open_hw_target
set device0 [create_hw_device -part xcku9p]
set_property PROGRAM.FILE {my_xcku9p.bit} $device0
program_hw_devices $device0
write_hw_svf my_xcku9p.svf
close_hw_target
```

In this sample code the xcku9p device is created using `create_hw_device` command whose return value is set to a temporary variable called `device0`. This temporary value is then used to reference the object when setting the `PROGRAM.FILE` property to the file `my_xcku9p.bit` file. Next, the `program_hw_device` command is called using the `device0` reference. When this `program_hw_device` command runs, it creates a temporary SVF file with the SVF operations necessary to program the `my_xcku9p.bit` file on the xcku9p. Lastly, the `write_hw_svf` command takes the temporary file and moves it to the final target destination, `myxcku9p.svf`. At this point, the SVF file creation process is complete and the target can be closed.

Several direct and indirect programming operations can be captured in a single SVF file. You can, for instance, create a sequence of programming steps that may iterate loading several bitstreams on the same or different devices. You can also add indirect programming operations by following the same steps used in adding configuration memory devices on a live system. For instance, following is the menu that appears on the selected device attached to the SVF target:

![Device Menu](image)

**Figure 7-1:** Add Configuration Memory Device
Chapter 7: Serial Vector Format (SVF) File Programming

**IMPORTANT:** When you specify the fields for the configuration memory, only the highlighted sections shown below apply to the offline SVF target; all other fields should not be filled.

![Program Configuration Memory Device](image.png)

**Figure 7-2:** Program Configuration Memory Device

**TIP:** A final note on writing SVF files is that you should first create all the devices for the JTAG chain and then perform the programming operations. If you happen to interleave `create_hw_device` commands in between programming commands you will produce an output SVF file that has two different chain sequences.

- **Example of Incorrect SVF File Creation Steps:**

  ```bash
  create_hw_target my_svf_target
  open_hw_target
  set device0 [create_hw_device -part xcku9p]
  set_property PROGRAM.FILE {my_xcku9p1.bit} $device0
  # this program command will produce SVF instructions
  # which account for only device0 in chain
  program_hw_devices $device0
  set device1 [create_hw_device -part xcku9p]
  set_property PROGRAM.FILE {my_xcku9p2.bit} $device1
  # this program command will produce SVF instructions
  # which account for device0 and device1 in chain
  program_hw_devices $device1
  write_hw_svf my_bad_xcku9p.svf
  close_hw_target
  
  The first program command only captures the chain definition containing the first device. The second program command includes both devices in the chain when writing out the SVF instructions. Therefore, if you attempt to play this SVF file on a chain with two devices, the
Chapter 7: Serial Vector Format (SVF) File Programming

first programming operations fail because the live chain gets two devices and not one as the command expected.

To correct this problem you simply run the create_hw_device commands first. Then after the chain is completely defined, perform the program operations as shown below:

- **Example of Correct SVF File Creation Steps**

```
create_hw_target my_svf_target
open_hw_target
# create device chain first
set device0 [create_hw_device -part xcku9p]
set device1 [create_hw_device -part xcku9p]
# program device0
set_property PROGRAM.FILE {my_xcku9p1.bit} $device0
program_hw_devices $device0
# program device1
set_property PROGRAM.FILE {my_xcku9p2.bit} $device1
program_hw_devices $device1
write_hw_svf my_good_xcku9p.svf
close_hw_target
```

**Executing SVF Files**

Once the SVF file is created, you can optionally execute the SVF file through Vivado IDE. Vivado IDE can execute SVF files generated through the SVF generation feature and is intended as the validation test tool. The execute_hw_svf command is not intended as a general purpose SVF execution command; take care to only use SVF files created through Vivado IDE.

To run an svf command you run the command on an open live target as follows:

```
execute_hw_svf my_file.svf
INFO: [Labtoolstcl 44-548] Creating JTAG TCL script from SVF file
INFO: [Labtoolstcl 44-549] Re-opening target in JTAG mode
INFO: [Labtoolstcl 44-551] Sourcing JTAG TCL script: my_file.tcl
Pass: SVF Execution completed with no errors
INFO: [Labtoolstcl 44-550] Restoring target to original mode
INFO: [Labtoolstcl 44-570] Execute SVF completed successfully
```

In this example, the file my_file.svf is executed. As part of the execution flow, the input SVF file is converted via HW_JTAG Tcl operations into a temporary file. After this Tcl code is created, the file is sourced in order to execute the converted SVF instructions. To see the JTAG_TCL operations, you can run the execute_hw_svf command using the -verbose option. Once the command completes you will see either the error at the instruction where the execution failed or a “Pass” message at the end of the message log.
Debugging an FPGA design is a multistep, iterative process. Like most complex problems, it is best to break the FPGA design debugging process down into smaller parts by focusing on getting smaller sections of the design working one at a time rather than trying to get the whole design to work at once. Iterating through the design flow by adding one module at a time and getting it to function properly in the context of the whole design is one example of a proven design and debug methodology. You can use this design and debug methodology in any combination of the following design flow stages:

- RTL-level design simulation
- Post-implemented design simulation
- In-system debugging

**RTL-level Design Simulation**

The design can be functionally debugged during the simulation verification process. Xilinx provides a full design simulation feature in the Vivado® IDE. The Vivado design simulator can be used to perform RTL simulation of your design. The benefits of debugging your design in an RTL-level simulation environment include full visibility of the entire design and ability to quickly iterate through the design/debug cycle. The limitations of debugging your design using RTL-level simulation includes the difficulty of simulating larger designs in a reasonable amount of time in addition to the difficulty of accurately simulating the actual system environment. For more information about using the Vivado simulator, refer to the Vivado Design Suite User Guide: Logic Simulation (UG900) [Ref 1].

**Post-Implemented Design Simulation**

The Vivado simulator can also be used to simulate the post-implemented design. One of the benefits of debugging the post-implemented design using the Vivado simulator includes having access to a timing-accurate model for the design. The limitations of performing post-implemented design simulation include those mentioned in the previous section: long run-times and system model accuracy.
In-System Logic Design Debugging

The Vivado Design Suite also includes a logic analysis feature that enables you to perform in-system debugging of the post-implemented design an FPGA device. The benefits for debugging your design in-system include debugging your timing-accurate, post-implemented design in the actual system environment at system speeds. The limitations of in-system debugging includes somewhat lower visibility of debug signals compared to using simulation models and potentially longer design/implementation/debug iterations, depending on the size and complexity of the design.

In general, the Vivado tool provides several different ways to debug your design. You can use one or more of these methods to debug your design, depending on your needs. Chapter 9, In-System Logic Design Debugging Flows focuses on the in-system logic debugging capabilities of the Vivado Design Suite.

In-System Serial I/O Design Debugging

To enable in-system serial I/O validation and debug, the Vivado Design Suite includes a serial I/O analysis feature. This allows you to measure and optimize your high-speed serial I/O links in your FPGA-based system. The Vivado serial I/O analyzer features are designed to help you address a range of in-system debug and validation problems from simple clocking and connectivity issues to complex margin analysis and channel optimization issues. The main benefit of using the Vivado serial I/O analyzer over some other external instrumentation techniques is that you are measuring the quality of the signal after the receiver equalization has been applied to the received signal. This ensures that you are measuring at the optimal point in the TX-to-RX channel thereby ensuring real and accurate data.

The Vivado tool provides the means to generate the design used to exercise the gigabit transceiver endpoints as well as the run-time software to take measurements and help you optimize your high-speed serial I/O channels. Chapter 13, In-System Serial I/O Debugging Flows guides you through the process of generating the IBERT design. Chapter 14, Debugging the Serial I/O Design in Hardware guides you through the use of the run time Vivado serial I/O analyzer feature.
Chapter 9

In-System Logic Design Debugging Flows

The Vivado® tool provides many features to debug a design in-system in an actual hardware device. The in-system debugging flow has three distinct phases:

1. **Probing phase**: Identifying what signals in your design you want to probe and how you want to probe them.
2. **Implementation phase**: Implementing the design that includes the additional debug IP that is attached to the probed nets.
3. **Analysis phase**: Interacting with the debug IP contained in the design to debug and verify functional issues.

This in-system debug flow is designed to work using the iterative design/debug flow described in the previous section. If you choose to use the in-system debugging flow, it is advisable to get a part of your design working in hardware as early in the design cycle as possible. The rest of this chapter describes the three phases of the in-system debugging flow and how to use the Vivado logic debug feature to get your design working in hardware as quickly as possible.

---

Probing the Design for In-System Debugging

The probing phase of the in-system debugging flow is split into two steps:

1. Identifying what signals or nets you want to probe
2. Deciding how you want to add debug cores to your design

In many cases, the decision you make on what signals to probe or how to probe them can affect one another. It helps to start by deciding if you want to manually add the debug IP component instances to your design source code (called the HDL instantiation probing flow) or if you want the Vivado tool to automatically insert the debug cores into your post-synthesis netlist (called the netlist insertion probing flow). Table 9-1 describes some of the advantages and trade-offs of the different debugging approaches.
Using the Netlist Insertion Debug Probing Flow

Insertion of debug cores in the Vivado tool is presented in a layered approach to address different needs of the diverse group of Vivado users:

- The highest level is a simple wizard that creates and configures Integrated Logic Analyzer (ILA) cores automatically based on the selected set of nets to debug.
- The next level is the main Debug window allowing control over individual debug cores, ports and their properties. The Debug window can be displayed when the Synthesized Design is open by selecting the Debug layout from the Layout Selector or the Layout menu, or can be opened directly using Window>Debug.
- The lowest level is the set of Tcl XDC debug commands that you can enter manually into an XDC constraints file or replay as a Tcl script.

You can also use a combination of the modes to insert and customize debug cores.

Marking HDL Signals for Debug

You can identify signals for debugging at the HDL source level prior to synthesis by using the mark_debug constraint. Nets corresponding to signals marked for debug in HDL are automatically listed in the Debug window under the Unassigned Debug Nets folder.

Note: In the Debug window, the Debug Nets view is a more net-centric view of nets that you have selected for debug. The Debug Cores view is a more core-centric view where you can view and set core properties.
The procedure for marking nets for debug depends on whether you are working with an RTL source-based project or a synthesized netlist-based project. For an RTL netlist-based project:

- Using the Vivado synthesis feature you can optionally mark HDL signals for debug using the mark_debug constraint in VHDL and Verilog source files. The valid values for the mark_debug constraint are “TRUE” or “FALSE”. The Vivado synthesis feature does not support the “SOFT” value.

For a synthesized netlist-based project:

- Using the Synopsys® Synplify® synthesis tool, you can optionally mark nets for debug using the mark_debug and syn_keep constraints in VHDL or Verilog, or using the mark_debug constraint alone in the Synopsys Design Constraints (SDC) file. Synplify does not support the “SOFT” value, as this behavior is controlled by the syn_keep attribute.

- Using the Mentor Graphics® Precision® synthesis tool, you can optionally mark nets for debug using the mark_debug constraint in VHDL or Verilog.

The following subsections provide syntactical examples for Vivado synthesis, XST, Synplify, and Precision source files.

**Icons and ILA Core**

- The hollow green icon 🌿 indicates nets with MARK_DEBUG property set, but not connected to any ILA core.

- The full green icon 🌿 indicates nets with MARK_DEBUG property set, and connected to an ILA core.

- The yellow icon 🌿 indicates that there is no MARK_DEBUG on the net, but it is connected to an ILA core.

**Vivado Synthesis mark_debug Syntax Examples**

The following are examples of VHDL and Verilog syntax when using Vivado synthesis.

- **VHDL Syntax Example**

  ```vhdl
  attribute mark_debug : string;
  attribute mark_debug of char_fifo_dout: signal is "true";
  ```

- **Verilog Syntax Example**

  ```verilog
  (* mark_debug = "true" *)
  wire [7:0] char_fifo_dout;
  ```
Synplify mark_debug Syntax Examples

The following are examples of Synplify syntax for VHDL, Verilog, and SDC.

- **VHDL Syntax Example**
  ```vhdl
  attribute syn_keep : boolean;
  attribute mark_debug : string;
  attribute syn_keep of char_fifo_dout: signal is true;
  attribute mark_debug of char_fifo_dout: signal is "true";
  ```

- **Verilog Syntax Example**
  ```verilog
  (* syn_keep = "true", mark_debug = "true" *) wire [7:0] char_fifo_dout;
  ```

- **SDC Syntax Example**
  ```sdc
  define_attribute {n:char_fifo_din[*]} {mark_debug} {"true"}
  define_attribute {n:char_fifo_din[*]} {syn_keep} {"true"}
  ```

**IMPORTANT:** *Net names in an SDC source must be prefixed with the "n:" qualifier.*

**Note:** Synopsys Design Constraints (SDC) is an accepted industry standard for communicating design intent to tools, particularly for timing analysis. A reference copy of the SDC specification is available from Synopsys by registering for the TAP-in program at:
http://www.synopsys.com/Community/Interoperability/Pages/TapinSDC.aspx

Precision mark_debug Syntax Examples

The following are examples of VHDL and Verilog syntax when using Precision.

- **VHDL Syntax Example**
  ```vhdl
  attribute mark_debug : string;
  attribute mark_debug of char_fifo_dout: signal is "true";
  ```

- **Verilog Syntax Example**
  ```verilog
  (* mark_debug = "true" *) wire [7:0] char_fifo_dout;
  ```

Synthesizing the Design

The next step is to synthesize the design containing the debug cores by clicking **Run Synthesis** in the Vivado Design Suite or by running the following Tcl commands:

```
lunar_tests synth_1
wait_on_run synth_1
```

You can also use the synth_design Tcl command to synthesize the design. Refer to the **Vivado Design Suite User Guide: Synthesis** (UG901) [Ref 2] for more details on the various ways you can synthesize your design.
Marking Nets for Debug in the Synthesized Design

Open the synthesized design by clicking Open Synthesized Design in the Flow Navigator and select the Debug window layout to see the Debug window. Any nets that correspond to HDL signals that were marked for debugging are shown in the Unassigned Debug Nets folder in the Debug window (see Figure 9-1).

- Selecting a net in any of the design views (such as the Netlist or Schematic windows), then right-click select the Mark Debug option.
- Selecting a net in any of the design views, then dragging and dropping the nets into the Unassigned Debug Nets folder.
- Using the net selector in the Set up Debug wizard (see Using the Set Up Debug Wizard to Insert Debug Cores for details).

Using the Set Up Debug Wizard to Insert Debug Cores

The next step after marking nets for debugging is to assign them to debug cores. The Vivado Design Suite provides an easy to use Set up Debug wizard to help guide you through the process of automatically creating the debug cores and assigning the debug nets to the inputs of the cores.

To use the Set up Debug wizard to insert the debug cores:

1. Optionally, select a set of nets for debugging either using the unassigned nets list or direct net selection.
2. Select Tools > Set up Debug from the Vivado Design Suite main menu, or click Set up Debug in the Flow Navigator under the Synthesized Design section.
3. Click Next to get to the Specify Nets to Debug panel (see Figure 9-2).
4. Optionally, click Find Nets to Add to add more nets or remove existing nets from the table. You can also right-click a debug net and select Remove Nets to remove nets from the table.
5. Right-click a debug net and select **Select Clock Domain** to change the clock domain to be used to sample value on the net.

   **Note:** The **Set up Debug** wizard attempts to automatically select the appropriate clock domain for the debug net by searching the path for synchronous elements. Use the **Select Clock Domain** dialog window to modify this selection as needed, but be aware that each clock domain present in the table results in a separate ILA core instance.

   **TIP:** Refer to **ILA Core and Timing Considerations** in Configuration and Debug of the UltraFast Design Methodology Guide for the Vivado Design Suite (UG949) [Ref 3] for tips on helping to minimize timing impact of the ILA Core.

6. Once you are satisfied with the debug net selection, click **Next**.

   **Note:** The **Set up Debug** wizard inserts one ILA core per clock domain. The nets that were selected for debug are assigned automatically to the probe ports of the inserted ILA cores. The last wizard screen shows the core creation summary displaying the number of clocks found and ILA cores to be created and/or removed.

7. If you want to enable either advanced trigger mode or basic capture mode, use the corresponding check boxes to do so. Click **Next** to move to the last panel.

   **Note:** The advanced trigger mode and basic capture mode features, when used in the Vivado Hardware Manager, are described in more detail in Chapter 10, Debugging Logic Designs in Hardware.
8. If you are satisfied with the results, click **Finish** to insert and connect the ILA cores in your synthesized design netlist.

![Set Up Debug Wizard](image)

**Figure 9-2:** Set Up Debug Wizard

9. Configure the ILA core general options such as ILA data depth (C_DATA_DEPTH), number of input pipe stages (C_INPUT_PIPE_STAGES), enabling the capture control.
feature (C_EN_STRG_QUAL), and enabling the advanced trigger feature (C_ADV_TRIGGER). Refer to Table 9-2 for descriptions of these options.

10. The debug nets are now assigned to the ILA debug core, as shown in Figure 9-4.

Using the Debug Window to Add and Customize Debug Cores

The Debug Cores tab in the Debug window provides more fine-grained control over ILA core and debug core hub insertion than what is available in the Set up Debug wizard. The controls available in this window allow core creation, core deletion, debug net connection, and core parameter changes.

The Debug Cores tab of the Debug window:

• Shows the list of debug cores that are connected to the Debug Hub (dbg_hub) core.
• Maintains the list of unassigned debug nets at the bottom of the window.
You can manipulate debug cores and ports from the popup menu or the toolbar buttons on the top of the window.

**Creating and Removing Debug Cores**

To create debug cores in the Debug window, click **Create Debug Core**. Using this interface (see Figure 9-5), you can change the parent instance, debug core name, and set parameters for the core. To remove an existing debug core, right-click the core in the Debug window and select **Delete**. Refer to Table 9-2, page 97 for a description of the ILA core options found in the Create Debug Core dialog.

![Create Debug Core](image)

**Figure 9-5:** Creating a New Debug Core

**Adding, Removing, and Customizing Debug Core Ports**

In addition to adding and removing debug cores, you can also add, remove, and customize ports of each debug core to suit your debugging needs. To add a new debug port:

1. Select the debug core in the Debug window.
2. Click **Create Debug Port** to open the dialog shown in Figure 9-6.
3. Select or type in the port width
4. Click **OK**.
Chapter 9: In-System Logic Design Debugging Flows

5. To remove a debug port, first select the port on the core in the Debug window, then select Delete.

![Create Debug Port](image)

**Figure 9-6: Creating a New Debug Port**

**Connecting and Disconnecting Nets to Debug Cores**

You can select, drag, and drop nets and buses (also called bus nets) from the Schematic or Netlist windows onto the debug core ports. This expands the debug port as needed to accommodate the net selection. You can also right-click any net or bus, and select Assign to Debug Port.

To disconnect nets from the debug core port, select the nets that are connected to the debug core port, and click Disconnect Net.

**Modifying Properties on the Debug Cores**

Each debug core has properties you can change to customize the behavior of the core. To learn how to change properties on the debug_core_hub debug core, refer to Changing the BSCAN User Scan Chain of the Debug Core Hub, page 113.

You can also change properties on the ILA debug core. For instance, to change the number of samples captured by the ILA debug core (see Figure 9-7), do the following:
1. In the **Debug** window, select the desired ILA core (such as `u_ila_0`).
2. In the **Cell Properties** window, select the **Debug Core Options** view.
3. Using the C_DATA_DEPTH pull-down list, select the desired number of samples to be captured.

![Figure 9-7: Changing the Data Depth of the ILA Core](image-url)
A full description of all ILA core properties can be found in Table 9-2.

**Table 9-2: ILA Debug Core Properties**

<table>
<thead>
<tr>
<th>Debug Core Property</th>
<th>Description</th>
<th>Possible Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_DATA_DEPTH</td>
<td>Maximum number of data samples that can be stored by the ILA core. Increasing this value causes more block RAM to be consumed by the ILA core and can adversely affect design performance.</td>
<td>1024 (Default) 2048 4096 8192 16384 32768 65536 131072</td>
</tr>
<tr>
<td>C_TRIGIN_EN</td>
<td>Enables the TRIG_IN and TRIG_IN_ACK ports of the ILA core. Note that you need to use the advanced netlist change commands to connect these ports to nets in your design. If you wish to use the ILA trigger input or output signals, you should consider using the HDL instantiation method of adding ILA cores to your design.</td>
<td>false (Default) true</td>
</tr>
<tr>
<td>C_TRIGOUT_EN</td>
<td>Enables the TRIG_OUT and TRIG_OUT_ACK ports of the ILA core. Note that you need to use the advanced netlist change commands to connect these ports to nets in your design. If you wish to use the ILA trigger input or output signals, you should consider using the HDL instantiation method of adding ILA cores to your design.</td>
<td>false (Default) true</td>
</tr>
<tr>
<td>C_ADV_TRIGGER</td>
<td>Enables the advanced trigger mode of the ILA core. Refer to Chapter 10 for more details on this feature.</td>
<td>false (Default) true</td>
</tr>
<tr>
<td>C_INPUTPIPE_STAGES</td>
<td>Enables extra levels of pipe stages (for example, flip-flop registers) on the PROBE inputs of the ILA core. This feature can be used to improve timing performance of your design by allowing the Vivado tools to place the ILA core away from critical sections of the design.</td>
<td>0 (Default) 1 2 3 4 5 6</td>
</tr>
<tr>
<td>C_EN_STRG_QUAL</td>
<td>Enables the basic capture control mode of the ILA core. Refer to Chapter 10 for more details on this feature.</td>
<td>false (Default) true</td>
</tr>
</tbody>
</table>
Chapter 9: In-System Logic Design Debugging Flows

Table 9-2: ILA Debug Core Properties

<table>
<thead>
<tr>
<th>Debug Core Property</th>
<th>Description</th>
<th>Possible Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_ALL_PROBESAME_MU</td>
<td>Enables all PROBE inputs of the ILA core to have the same number of comparators (also called “match units”). This property should always be set to true.</td>
<td>true (Default)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>false (not recommended)</td>
</tr>
</tbody>
</table>
| C_ALL_PROBESAME_MU_CNT | The number of comparators (or match units) per PROBE input of the ILA core. The number of comparators that are required depends on the settings of the C_ADV_TRIGGER and C_EN_STRG_QUAL properties:  
• If C_ADV_TRIGGER is false and C_EN_STRG_QUAL is false, can be set to 1 through 16.  
• If C_ADV_TRIGGER is false and C_EN_STRG_QUAL is true, can be set to 2 through 16.  
• If C_ADV_TRIGGER is true and C_EN_STRG_QUAL is false, can be set to 1 through 16.  
• If C_ADV_TRIGGER is true and C_EN_STRG_QUAL is true, can be set to 2 through 16.  
IMPORTANT: if you do not follow the rules above, you will encounter an error during implementation when the ILA core is generated. | 1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16 |

Probe as Data or Trigger or both

You can customize a probe to be used as data or trigger or both in the Vivado Hardware Manager. Probes that participate in trigger or capture compare values are configured as "trigger" only probes. This optimizes the use of BRAMs by the ILA core. Typically, probes whose data needs to be captured are configured as "data" only probes. Probes that participate in both trigger compare values, and whose data needs to be captured should be configured as "trigger and data".
You can configure probes as data or trigger or both using the Set up Debug wizard as shown in Figure 9-8.

**Figure 9-8: Configuring Probes as Data or Trigger or Both Using the Set Up Debug Wizard**

When you program the device at runtime with a design containing probes configured as "data" only, you will not be able to use these probes to configure trigger or capture setup conditions. Conversely, you will not be able to use probes configured as "trigger" only in the **Waveform** window.

**Configuring the Number of Comparators Used**

After you have inserted the ILA core on a post-synthesized netlist it is possible for you to set the number of comparators used to anywhere from 1 to 16. To do that in the Vivado IDE,
go to **Debug Core Options** tab of the ILA core and set the **ALL_PROBESAME_MU_CNT** property to the desired number of comparators.

Alternatively you can set the **ALL_PROBESAME_MU_CNT** property in the Tcl Console as follows:

```tcl
set_property ALL_PROBESAME_MU_CNT 10 [get_debug_cores u_ila_0]
```

**TIP:** If Capture Control is enabled, you have a choice of using 1 to 15 comparators. One comparator is used by the capture control data filtering mechanism.

**IMPORTANT:** It is not possible to set different number of comparators for different probes in the ILA using the insertion flow. Xilinx recommends that you use the HDL instantiation flow to achieve that.
Using XDC Commands to Insert Debug Cores

In addition to using the Set up Debug wizard, you can also use XDC commands to create, connect, and insert debug cores into your synthesized design netlist. Follow these steps by typing the XDC commands in the Tcl Console:

1. Open the synthesized design netlist from the synthesis run called synth_1.
   ```tcl
   open_run synth_1
   ```
   **IMPORTANT:** The XDC commands in the following steps are only valid when a synthesized design netlist is open.

2. Create the ILA core black box.
   ```tcl
   create_debug_core u ila_0 ila
   ```

3. Set the various properties of the ILA core.
   ```tcl
   set_property C_DATA_DEPTH 1024 [get_debug_cores u ila_0]  
   set_property C_TRIGIN_EN false [get_debug_cores u ila_0]  
   set_property C_TRIGOUT_EN false [get_debug_cores u ila_0]  
   set_property C_ADV_TRIGGER false [get_debug_cores u ila_0]  
   set_property C_INPUT_PIPE_STAGES 0 [get_debug_cores u ila_0]  
   set_property C_EN_STRG_QUAL false [get_debug_cores u ila_0]  
   set_property ALL_PROBE_SAME_MU true [get_debug_cores u ila_0]  
   set_property ALL_PROBE_SAME_MU_CNT 1 [get_debug_cores u ila_0]
   ```

4. Set the width of the clk port of the ILA core to 1 and connect it to the desired clock net.
   ```tcl
   set_property port_width 1 [get_debug_ports u ila_0/clk]  
   connect_debug_port u ila_0/clk [get_nets [list clk]]
   ```
   **Note:** You do not have to create the clk port of the ILA core because it is automatically created by the create_debug_core command.

   **IMPORTANT:** All debug port names of the debug cores are lower case. Using upper-case or mixed-case debug port names will result in an error.

5. Set the width of the probe0 port to the number of nets you plan to connect to the port.
   ```tcl
   set_property port_width 1 [get_debug_ports u ila_0/probe0]
   ```
   **Note:** You do not have to create the first probe port (probe0) of the ILA core because it is automatically created by the create_debug_core command.

6. Connect the probe0 port to the nets you want to attach to that port.
   ```tcl
   connect_debug_port u ila_0/probe0 [get_nets [list A_or_B]]
   ```

7. Optionally, create more probe ports, set their width, and connect them to the nets you want to debug.
   ```tcl
   create_debug_port u ila_0 probe
   set_property port_width 2 [get_debug_ports u ila_0/probe1]  
   connect_debug_port u ila_0/probe1 [get_nets [list {A[0]} {A[1]}]]
   ```
For more information on these and other related Tcl commands, type `help –category ChipScope` in the Tcl Console of the Vivado Design Suite.

**Saving Constraints After Running Debug XDC Commands**

You need to save constraints after using the Set up Debug wizard, using Vivado Design Suite to create debug cores or ports, and/or running the following XDC commands:

- `create_debug_core`
- `create_debug_port`
- `connect_debug_port`
- `set_property` (on any `debug_core` or `debug_port` object)

The corresponding XDC commands are saved to the target constraints file and are used during implementation to insert and connect the debug cores.

---

**IMPORTANT:** Saving constraints to the target constraints file while in project mode may cause the synthesis and implementation steps to go out-of-date. However, you do not need to re-synthesize the design since the debug XDC constraints are only used during implementation. You can force the synthesis step up-to-date by selecting the Design Runs window, right-clicking the synthesis run (e.g., `synth_1`), and selecting **Force up-to-date**.

---

**Implementing the Design**

After inserting, connecting and customizing your debug cores, you are now ready for implementing your design (refer to Implementing the Design Containing the Debug Cores).

**Debug Core Insertion in Non-Project Mode**

Debug cores can be inserted in either Project Mode or Non-Project Mode. The following sample Tcl script shows how to create the debug core, set debug core attributes, and connect the debug core probes to the signals in the design being probed. In Non-Project Mode, the insertion of the debug core needs to happen after synthesizing the design, and prior to the opt_design step as shown below.

---

**IMPORTANT:** Debug core insertion is only supported for ILA cores.
The following Tcl script is an example of using the debug core insertion commands in a Non-Project flow.

```tcl
#read relevant design source files
read_vhdl [glob .//*.vhdl]
read_verilog [ glob ./Sources/*.v ]
read_xdc ./target.xdc

#Synthesize Design
synth_design -top top -part xc7k325tfkg900-2

#Create the debug core
create_debug_core u_ila_0 ila

#set debug core properties
set_property C_DATA_DEPTH 1024 [get_debug_cores u_ila_0]
set_property C_TRIGIN_EN false [get_debug_cores u_ila_0]
set_property C_TRIGOUT_EN false [get_debug_cores u_ila_0]
set_property C_ADV_TRIGGER false [get_debug_cores u_ila_0]
set_property C_INPUT_PIPE_STAGES 0 [get_debug_cores u_ila_0]
set_property C_EN_STRG_QUAL false [get_debug_cores u_ila_0]
set_property ALL_PROBE_SAME_MU true [get_debug_cores u_ila_0]
set_property ALL_PROBE_SAME_MU_CNT 1 [get_debug_cores u_ila_0]

#connect the probe ports in the debug core to the signals being probed in the design
set_property port_width 1 [get_debug_ports u_ila_0/clk]
connect_debug_port u_ila_0/clk [get_nets [list clk]]
set_property port_width 1 [get_debug_ports u_ila_0/probe0]
connect_debug_port u_ila_0/probe0 [get_nets [list A_or_B]]
create_debug_port u_ila_0 probe

#Optionally, create more probe ports, set their width, 
# and connect them to the nets you want to debug

#Implement design
opt_design
place_design
report_drc -file ./placed_drc_rpt.txt
report_timing_summary -file ./placed_timing_rpt.txt

route_design
report_drc -file ./routed_drc_rpt.txt
report_timing_summary -file ./routed_timing_rpt.txt

write_bitstream
```

HDL Instantiation Debug Probing Flow Overview

The HDL instantiation probing flow involves the manual customization, instantiation, and connection of various debug core components directly in the HDL design source. The new debug cores that are supported in this flow in the Vivado tool are shown in table Table 9-3.
Chapter 9: In-System Logic Design Debugging Flows

The new ILA core has two distinct advantages over the legacy ILA v1.x core:

- Works with the integrated Vivado logic analyzer feature (refer to Chapter 10, Debugging Logic Designs in Hardware).
- No ICON core instance or connection is required.

### Using the HDL Instantiation Debug Probing Flow

The steps required to perform the HDL instantiation flow are:

1. Customize and generate the ILA and/or VIO debug cores that have the right number of probe ports for the signals you want to probe.
2. (Optional) Customize and generate the JTAG-to-AXI Master debug core and connect it to an AXI slave interface of an AXI peripheral or interconnect core in your design.
3. Synthesize the design containing the debug cores.
4. (Optional) Modify debug hub core properties.
5. Implement the design containing the debug cores.

### Table 9-3: Debug Cores in Vivado IP Catalog available for use in the HDL Instantiation Probing Flow

<table>
<thead>
<tr>
<th>Debug Core</th>
<th>Version</th>
<th>Description</th>
<th>Run Time Analyzer Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILA (Integrated Logic Analyzer)</td>
<td>v6.1</td>
<td>Debug core that is used to trigger on hardware events and capture data at system speeds.</td>
<td>Vivado logic analyzer</td>
</tr>
<tr>
<td>VIO (Virtual Input/Output)</td>
<td>v3.0</td>
<td>Debug core that is used to monitor or control signals in design at JTAG chain scan rates.</td>
<td>Vivado logic analyzer</td>
</tr>
<tr>
<td>JTAG-to-AXI Master</td>
<td>v1.1</td>
<td>Debug core that is used to generate AXI transactions to interact with various AXI full and AXI lite slave cores in a system that is running in hardware.</td>
<td>Vivado logic analyzer</td>
</tr>
</tbody>
</table>
Customizing and Generating the Debug Cores

Use the **IP Catalog** button in the **Project Manager** to locate, select, and customize the desired debug core. The debug cores are located in the **Debug & Verification > Debug** category of the IP Catalog (see **Figure 9-10**). You can customize the debug core by double-clicking on the IP core or by right-click selecting the **Customize IP** menu selection.

- For more information on customizing the ILA core, refer to *LogiCORE IP Integrated Logic Analyzer (ILA) v6.1 Datasheet* (PG172) [Ref 20].
- For more information on customizing the VIO core, refer to *LogiCORE IP Virtual Input/Output (VIO) v3.0 Product Guide* (PG159) [Ref 16].
- For more information on customizing the JTAG-to-AXI Master core, refer to *LogiCORE IP JTAG to AXI Master v1.1 Product Guide* (PG174) [Ref 21].

After customizing the core, click the **Generate** button in the IP customization wizard. This generates the customized debug core and adds it to the **Sources** view of your project.

![Figure 9-10: Debug Cores in the IP Catalog](image)

*Figure 9-10: Debug Cores in the IP Catalog*
**Configuring the Number of Comparators Used**

During the process of customizing the ILA IP, it is possible for you to set the number of comparators used. The range allowed is 1 to 16. It is possible to set a common number of comparators for all the probes in the ILA IP.

![ILA IP Comparators in General Options](image)

*Figure 9-11: ILA IP Comparators in General Options*
It is also possible to set the comparators for each IP as shown below. It is possible to have multiple probes of different width within a single ILA. To do that you need to uncheck the **Same Number of Comparators for All Probe Ports** field under General Options.

*Figure 9-13: Same Number of Comparators for All Ports Field*
You then set the exact number of comparators to be use per probe by selecting the **Probe_Ports** tab and setting the **Number of Comparators** field with the desired number of comparators.

**Figure 9-14: Number of Comparators**

**TIP:** If Capture Control is enabled, you have a choice of using 1 to 15 comparators. One comparator is used by the capture control data filtering mechanism.

**TIP:** Depending on the number of comparators chosen, the tool automatically recalculates the number of probes that you can use in the ILA IP. The maximum number of comparators allowed per ILA is 1024.
Chapter 9: In-System Logic Design Debugging Flows

Probe as Data or Trigger

Probes can be configured as data or trigger or both in the ILA IP Configuration wizard as shown in Figure 9-15.

![Figure 9-15: Configuring Probes as Trigger and Data](image)

Probes that participate in trigger or capture compare values are configured as "trigger" only probes. This optimizes the use of BRAMs by the ILA core. Typically, probes whose data needs to be captured are configured as "data" only probes. Probes that participate in both trigger compare values, and whose data needs to be captured should be configured as "trigger and data".

ILA Cross Trigger

ILA Cross Triggering feature enables cross triggering between ILA cores, and between ILA cores and a processor for example, Zynq®-7000 AP SoC or MicroBlaze™ devices. This feature is useful for when you want to trigger between two ILA cores that are in different clock domains, or perform hardware/software cross triggering between a processor and an ILA core.

For using cross trigger feature, at core generation time, you should configure the ILA core to have dedicated trigger input ports (TRIG_IN and TRIG_IN_ACK) and dedicated trigger output ports (TRIG_OUT and TRIG_OUT_ACK). If you want to use the ILA trigger input or
output signals, you must use the HDL instantiation method of adding ILA cores to your design.

![ILA Cross Trigger Feature](image)

**Figure 9-16: ILA Cross Trigger Feature**

TRIG_OUT_ACK signal is an indication to the ILA core (another ILA, user design, or processor) that TRIG_OUT is properly received and causes the ILA to lower the TRIG_OUT signal on receiving TRIG_OUT_ACK.

In other words, TRIG_OUT will remain HIGH until TRIG_OUT_ACK is available. If TRIG_OUT_ACK signal is tied to LOW then TRIG_OUT remains HIGH until the user re-arms the ILA. Only then the TRIG_OUT goes LOW. You can rearm the ILA if TRIG_OUT_ACK is tied to LOW.

A typical cross trigger setup is illustrated below where ILA2 cross triggers into ILA1. The TRIG_OUT signal of ILA2 is connected to the TRIG_IN signal of ILA1. The TRIG_IN_ACK signal of ILA 1 is connected to the TRIG_OUT_ACK signal of ILA2.

(ILA 2) trig_out => (ILA 1) trig_in
(ILA 1) trig_in_ack => (ILA 2) trig_out_ack
• It is assumed that the logic driving the \texttt{trig\_in} port is synchronous to the ILA clk.
• It takes 1 clk cycle for the \texttt{trig\_in\_ack} signal to get asserted after \texttt{trig\_in} is asserted.
• It takes 9 clk cycles for the \texttt{trig\_out} signal to get asserted when \texttt{trig\_in} is used or trigger condition is met.
• The \texttt{trig\_in\_ack} and \texttt{trig\_out\_ack} signals go low only when trigger signals are de-asserted.

For a detailed tutorial that covers using the Cross Trigger feature between the FPGA fabric and the Zynq-7000 AP SoC processor, see the \textit{Vivado Design Suite Tutorial: Embedded Processor Hardware Design}, (UG940) [Ref 14].
Instantiating the Debug Cores

After generating the debug core, instantiate it in your HDL source code and connect it to the signals that you wish to probe for debugging purposes. Following is an example of the ILA instance in a Verilog HDL source file:

```verilog
u_ila_0
(
    .clk(clk),
    .probe0(counterA),
    .probe1(counterB),
    .probe2(counterC),
    .probe3(counterD),
    .probe4(A_or_B),
    .probe5(B_or_C),
    .probe6(C_or_D),
    .probe7(D_or_A)
);
```

**Note:** Unlike the legacy VIO and ILA v1.x cores, the new ILA core instance does not require a connection to an ICON core instance. Instead, a debug core hub (`dbg_hub`) is automatically inserted into the synthesized design netlist to provide connectivity between the new ILA core and the JTAG scan chain.

Synthesizing the Design Containing the Debug Cores

In the next step, synthesize the design containing the debug cores by clicking **Run Synthesis** in the Vivado Design Suite or by running the following Tcl commands:

```tcl
launch_runs synth_1
wait_on_run synth_1
```

You can also use the `synth_design` Tcl command to synthesize the design. *Refer to Vivado Design Suite User Guide: Synthesis* (UG901) [Ref 2] for more details on the various ways you can synthesize your design.

Viewing the Debug Cores in the Synthesized Design

After synthesizing your design, you can open the synthesized design to view the debug cores and modify their properties. Open the synthesized design by clicking **Open Synthesized Design** in the **Flow Navigator**, and select the **Debug** window layout to see the
Debug window that shows your ILA debug cores connected to the debug hub core (dbg_hub) (see Figure 9-19).

![Debug Window Showing ILA Core and Debug Core Hub](image)

**Figure 9-19:** Debug Window Showing ILA Core and Debug Core Hub

### Changing the BSCAN User Scan Chain of the Debug Core Hub

You can view and change the BSCAN user scan chain index of the debug core hub by selecting the `dbg_hub` in the **Debug** window, selecting the **Debug Core Options** view in the **Properties** window, then changing the value of the **C_USER_SCAN_CHAIN** property (see Figure 9-20).

**IMPORTANT:** The default values for C_USER_SCAN_CHAIN are 1 or 3 for the debug hub core. If using a scan chain value other than 1 or 3 for the debug hub core, you must manually change them on the device. For instance to see the setting on the current device run:

```
hw_server -e "set xsdb-user-bscan <C_USER_SCAN_CHAIN scan_chain_number>"
```
IMPORTANT: If you plan to use the Microprocessor Debug Module (MDM) or other IP that uses the BSCAN primitive with the Vivado logic debug cores, you need to set the C_USER_SCAN_CHAIN property of the dbg_hub to a user scan chain that does not conflict with the other IPs Boundary Scan Chain setting. Failure to do so results in errors later in the implementation flow.

Figure 9-20: Changing the User Scan Chain Property of the Debug Core Hub
Implementing the Design Containing the Debug Cores

The Vivado software creates the debug core hub initially a black box. This core must be implemented prior to running the placer and router.

Implementing the Design

Implement the design containing the debug core by clicking Run Implementation in the Vivado Design Suite or by running the following Tcl commands:

```
launch_runs impl_1
wait_on_run impl_1
```

You can also implement the design using the implementation commands opt_design, place_design, and route_design. Refer to the Vivado Design Suite User Guide: Implementation (UG904) [Ref 4] for more details on the various ways you can implement your design.
Debugging Logic Designs in Hardware

Once you have the debug cores in your design, you can use the run time logic analyzer features to debug the design in hardware.

Using Vivado® Logic Analyzer to Debug the Design

The Vivado® logic analyzer feature is used to interact with new ILA, VIO, and JTAG-to-AXI Master debug cores that are in your design. To access the Vivado logic analyzer feature, click the Open Hardware Manager button in the Program and Debug section of the Flow Navigator.

The steps to debug your design in hardware using an ILA debug core are:

1. Connect to the hardware target and program the FPGA device with the .bit file
2. Set up the ILA debug core trigger and capture controls.
3. Arm the ILA debug core trigger.
4. View the captured data from the ILA debug core in the Waveform window.
5. Use the VIO debug core to drive control signals and/or view design status signals.
6. Use the JTAG-to-AXI Master debug core to run transactions to interact with various AXI slave cores in your design.

Connecting to the Hardware Target and Programming the FPGA Device

Programming an FPGA device prior to debugging are exactly the same steps described in Programming the FPGA Device. After programming the device with the .bit file that contains the new ILA, VIO, and JTAG-to-AXI Master debug cores, the Hardware window now shows the debug cores that were detected when scanning the device (see Figure 10-1).
Chapter 10: Debugging Logic Designs in Hardware

For more information on using the ILA core, refer to Setting up the ILA Core to Take a Measurement. For more information on using the VIO core, refer to Setting Up the VIO Core to Take a Measurement.

**IMPORTANT:** Ensure the JTAG clock is slower than the clocks input to the debug cores. You can modify the JTAG frequency using the Open New Hardware Target wizard or the following Tcl command:

```
set_property PARAM.FREQUENCY 250000 [get_hw_targets */xilinx_tcf/Digilent/210203327962A]
```

---

**Vivado Hardware Manager Dashboards**

The Vivado Hardware Manager Dashboards help you manage the various windows for your System Monitor, ILA, and VIO Debug cores. The dashboards enable you to create, modify, and save the configuration of these windows in your Vivado Design Suite project.

**Default Dashboards**

When debug cores are detected upon refreshing a hardware device, the default dashboard for each debug core is automatically opened.
Default Dashboard Windows

Every default dashboard contains windows relevant to the debug core the dashboard is created for. The default dashboard created for the ILA debug core contains five windows:

- **Settings** window
- **Status** window,
- **Trigger Setup** window,
- **Capture Setup** window
- **Waveform** window

An example of the default ILA Dashboard can be seen below.

*Figure 10-2: Default ILA Dashboard*
You can start adding probes to the **Trigger Setup** window by clicking the green "+" button in the center of the window, and selecting probes from the **Add Probes** window as seen in **Figure 10-3**.

![Add Probes Window](image1)

**Figure 10-3: Add Probes Window**

The VIO Default dashboard starts out empty to which you can add VIO probes to as shown in **Figure 10-4**.

![Adding VIO Probes](image2)

**Figure 10-4: Adding VIO Probes**

To view a dashboard associated with a debug core, right-click the debug core object in the Hardware window, select the Dashboard option, and click the dashboard name.
Double-clicking a debug core in the hardware window will pop up the dashboards associated with that debug core.

![Hardware Manager window](image)

*Figure 10-5: Associated Dashboards*

**Window Controls within a Dashboard**

Each window has the following title bar controls, which enable you to manipulate the window:

- Minimize
- Maximize
- Close

**Moving Windows**

To move windows:

1. Select the window tab or title bar, and drag the window. A gray outline indicates where the window will be located after the move.
2. To commit to the placement, release the mouse button.

**Note:** Dropping one window onto an existing window places the two window tabs in the same region.
**Chapter 10:** Debugging Logic Designs in Hardware

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**IMPORTANT:** You cannot move windows into or out of the workspace. However, you can resize and move the windows within the workspace.

---

**Resizing Windows**

- To resize windows, click and drag a window border.

  **Note:** The mouse cursor changes to a resize cursor when positioned over a window border or drag handle, indicating that you can click and drag the window border to resize the window.

- To expand a window to use the all of the viewing environment, click the Maximize button in the upper right corner of the window.

- To restore a window to its original size, double-click the window title bar or tab.

---

**Closing Windows**

- To close windows, click the Close button in the upper right corner of the window.

  **Note:** In some cases, this button is also available in the window tab.

- Right-click a window tab or title bar, and select **Close** from the popup menu.

---

**Window Tabs**

Each window has a tab that you can select to make that the window is active. The tab is at the bottom of some windows, such as the Trigger Setup and Capture Setup windows.

**TIP:** To make the next tab active, press Ctrl+Tab. To make the previous tab active, press Ctrl+Shift+Tab. To maximize or minimize the window, double-click the window tab, or press Alt-q.

---

**Customizing Dashboards**

Typically the windows in the default dashboards should be enough to debug your design and view the results. However there are times when you might want to move windows around (i.e. customize your dashboards). For example you may want to be able to view both the ILA status and Waveform window in addition to controlling VIO probes in the same dashboard. In those situations Xilinx recommends customizing the dashboard to fit your needs.

**Dashboard Options**

Every dashboard has a **Dashboard Options** slideout on the left. Use the “>>” button on the left side of a dashboard to open its Dashboard Options settings. The Dashboard Options settings allow you to control the windows that appear in a specific dashboard. For example you may want to customize the ILA dashboard to include one of the VIO windows as well. As shown below you click on the VIO window to include it in the Dashboard Options and the
VIO window shows up in the ILA Dashboard. You can now add the VIO probes you are interested in and trigger the ILA window.

Figure 10-6: Adding Dashboard Options

Click the Dashboard Options tab on the left side of a dashboard to open and close the Dashboard Options slideout.
Creating New Dashboards

In addition to customizing Default Dashboards using the Dashboard Options, you can also create brand new dashboards. To do that right-click the debug core object in the Hardware window and select the Dashboard > New Dashboard option as shown in Figure 10-7.

![Figure 10-7: Creating New Dashboard](image-url)
When the **New Dashboard** dialog appears, you can customize the dashboard as necessary and click **OK**.

![New Dashboard Dialog](image)

**Figure 10-8: New Dashboard Dialog**

You can also use the **Dashboard** toolbar button to create new dashboards as shown below.

![Dashboard Toolbar Button](image)

**Figure 10-9: Dashboard Toolbar Button**

**TIP:** To view all the dashboards associated with a debug core, right click the debug core in the **Hardware** view and click on **Dashboard**. Alternatively double-click the debug core in the **Hardware** view and the list of dashboards associated with the debug core pop-up.
**TIP:** To float a single window in a dashboard, Xilinx recommends that you create a dashboard with just that window and float the dashboard.

### ILA Waveform window in dashboards

Each ILA Waveform window can only appear in a single dashboard. If you click a Waveform window that is located in another dashboard you will get a notification that the window is being relocated as shown in **Figure 10-10**.

![ILA Waveform Confirmation](image)

**Figure 10-10:** ILA Waveform Confirmation

Click **OK**, and the Waveform window relocates to the specified dashboard.

**TIP:** Save ILA data when closing Waveform window.

### System Monitor Dashboards

You can also include the XADC/System Monitor window into another dashboard or its own dashboard.

![System Monitor Dashboard](image)

**Figure 10-11:** System Monitor Dashboard
Chapter 10: Debugging Logic Designs in Hardware

Resetting to Default Dashboards

You can reset the dashboards back to their default state by clicking Dashboard on the toolbar and selecting Reset to Default.

![Image](image.png)

Figure 10-12: Resetting to Default Dashboard

Closing Dashboards

You can close all the Dashboards by clicking Dashboard on the toolbar and selecting Close All. This will delete all of the dashboards and the user settings in those dashboards.

You can also close a single dashboard by clicking the "X" button on the upper right hand corner. This will delete the dashboard and all of the user settings in the dashboard.

Saving User Dashboard Preferences and Settings

User Dashboard settings and preferences are saved automatically by Vivado IDE. Upon closing and reopening the project the user settings and preferences are restored back into the Hardware Manager.

Setting up the ILA Core to Take a Measurement

The ILA cores that you add to your design appear in the Hardware window under the target device. If you do not see the ILA cores appear, right-click the device and select Refresh Device. This re-scans the FPGA device and refreshes the Hardware window.

**Note:** If you still do not see the ILA core after programming and/or refreshing the FPGA device, check to make sure the device was programmed with the appropriate .bit file and check to make sure the implemented design contains an ILA core. Also, check to make sure the appropriate .ltx probes file that matches the .bit file is associated with the device.

Click the ILA core (called hw_ila_1 in Figure 10-1) to see its properties in the ILA Core Properties window. You can see all the probes corresponding to the ILA core by using the
Windows -> Debug Probes menu option, which displays the Debug Probes window as shown in Figure 10-13.

Adding Probes

You can add relevant probes to specific windows in an ILA Dashboard by clicking on the green "+" button on the window toolbar or workspace.

Writing Debug Probes Information

The Debug Probes window contains information about the nets that you probed in your design using the ILA and/or VIO cores. This debug probe information is extracted from your design and is stored in a data file that typically has an .ltx file extension.

Normally, the debug probes file is automatically created during the implementation process. However, you can also use the write_debug_probes Tcl command to write out the debug probes information to a file:

1. Open the Synthesized or Netlist Design.
2. Run the write_debug_probes filename.ltx Tcl command.
IMPORTANT: If you are using non-project mode, you must manually call the `write_debug_probes` command immediately following the `opt_design` command.

---

**Reading Debug Probes Information**

The debug probes file is automatically associated with the hardware device if the Vivado IDE is in project mode and a probes file is called `debug_nets.ltx` is found in the same directory as the bitstream programming (.bit) file that is associated with the device.

You can also specify the location of the probes file:

1. Select the hardware device in the **Hardware** window.
2. Set the Probes file location in the **Hardware Device Properties** window.
3. Right-click the hardware device in the **Hardware** window and select **Refresh Device** to read the contents of the debug probes file and associate and validate the information with the debug cores found in the design running in the hardware device.

You can also set the location using the following Tcl commands to associate a debug probes file called `C:\myprobes.ltx` with the first device on the target board:

```tcl
% set_property PROBES.FILE {C:/myprobes.ltx} [lindex [get_hw_devices] 0]
% refresh_hw_device [lindex [get_hw_devices] 0]
```

**Renaming Debug Probes**

You can use the **Debug Probes** window to rename debug probes that belong to an ILA or VIO core. You can rename the debug probes and add them to an existing Waveform Viewer for the core, or you can add them to the various trigger and/or capture windows of the ILA Dashboard. These names could be the custom, long or short name associated with the debug probe.

To perform these operations, right-click an ILA/VIO core’s debug probe(s) and select one of the following:

- **Rename**: Prompts you to rename the probe to a custom name.
- **Name**: Allows you to select the long, short, or custom name of the debug probe. Subsequent references to the debug probe in the Vivado IDE window will use the name that you selected.
  - **Long**: Displays the full hierarchical name of the signal or bus being probed.
  - **Short**: Displays the name of the signal or bus being probed.
  - **Custom**: Displays the custom name given to the signal or bus when renamed.
Using Multiple Comparators

If you have customized the probes and/or ILA debug cores to use more than 1 comparator in the Basic/Advanced mode - you can use these comparators both in the Basic and Advanced Trigger Setup window.

You can add the probe into the Basic trigger setup window and set up the trigger conditions. The comparator usage column gives you information on the comparator used within the probe for the specific compare condition out of the total number of comparators associated with the probe.

![Image of Trigger Setup - Comparator Usage](image-url)

*Figure 10-14: Basic Trigger Setup - Comparator Usage*

Using the ILA Default Dashboard

The ILA Dashboard (see Figure 10-15) is a central location for all status and control information pertaining to a given ILA core. When an ILA core is first detected upon refreshing a hardware device, the Default ILA Dashboard for the core is automatically
opened. If you need to manually open or re-open the dashboard, just right-click the ILA core object in the Hardware window and select Default Dashboard.

You can use the **ILA Dashboard** to interact with the ILA debug core in several ways:

- Set the trigger mode to trigger on various events in hardware:
  - **BASIC_ONLY**: The ILA Basic Trigger Mode can be used to trigger the ILA core when a basic AND/OR functionality of debug probe comparison result is satisfied.
  - **ADVANCED_ONLY**: The ILA Advanced Trigger Mode can be used to trigger the ILA core as specified by a user defined state machine.
  - **TRIG_IN_ONLY**: The ILA TRIG_IN Trigger Mode can be used to trigger the ILA core when the TRIG_IN pin of the ILA core transitions from a low to high.
  - **BASIC_OR_TRIG_IN**: The ILA BASIC_OR_TRIG_IN Trigger Mode can be used to trigger the ILA core when a logical OR-ing of the TRIG_IN pin of the ILA core and BASIC_ONLY trigger mode is desired.
  - **ADVANCED_OR_TRIG_IN**: The ILA ADVANCED_OR_TRIG_IN Trigger Mode can be used to trigger the ILA core when a logical OR-ing of the TRIG_IN pin of the ILA core and ADVANCED_ONLY trigger mode is desired.
- Set the trigger output mode.
- Use **ALWAYS** and **BASIC** capture modes to control filtering of data to be captured.
- Set the number of ILA capture windows.
• Set the data depth of the ILA capture window.
• Set the trigger position to any sample within the capture window.
• Monitor the trigger and capture status of the ILA debug core.

**User-Defined Debug Probes**

Using user-defined debug probes (also called hw_probes) in the Hardware Manager allows you the ability to create probes from combinations of physical ILA probe ports and constant values. You can then use these probes in the Trigger Setup or Waveform windows in the Hardware Manager. On successful creation of these probes, they are listed in the Debug Probes window as part of the debug core they were associated with during creation.

You can create the following types of user defined probes:

• An ILA probe port.
• One or more constant values of 0 and/or 1.
• A mix of ILA probe port and constant values.

**IMPORTANT:** User-defined probes that involve constant values can only be used in the Waveform window. They cannot be used in the Trigger Setup window.

**TIP:** You can only create user-defined probes on ILA debug cores. Creating user-defined debug probes for VIO cores is not currently supported.

### Creating a User-Defined Debug Probe

To create a user-defined debug probe use the `create_hw_probe` Tcl command.

```
create_hw_probe [-verbose] [-map <arg>] <name> <core>
```

Where:

• **name** is the name of the `hw_probe`. Must be unique for `hw_probes` belonging to the same device. Bus probes must have their range specified. For example, `myNewProbe[31:0]`
• **core** is the `hw_ila` to associate the probe with.
• **map** is the declaration of bits to base the user-defined probe on.
Chapter 10: Debugging Logic Designs in Hardware

Examples of creating user-defined debug probes:

```bash
# Given a 512-bit counter "counterA[511:0]": Connects [255:223] to
# ILA probe port 0 [31:0]
# Create a user-defined probe called foobar pointing at the
# ILA buffer specified range [255:223]
create_hw_probe -map {probe0[31:0]} {foobar [255:223]} [get_hw_ilas hw_ila_1]

# Constant only probe. NO triggering allowed on constant ONLY probes.
create_hw_probe -map {0} {my_constant_gnd[0:0]} [get_hw_ilas hw_ila_1]

# Create a user-defined probe as a mix of constants and ILA probe ports
create_hw_probe -map {0000 probe0[31:0] 1010} {my_mixed_probe[47:8]} [get_hw_ilas hw_ila_1]

# Creating scalar hw_probe called "foobar" from probe1:
create_hw_probe -map {probe1} foobar [get_hw_ilas hw_ila_1]

# Creating scalar hw_probe called "foobar" from bit 3 of probe0:
create_hw_probe -map {probe0[3]} foobar [get_hw_ilas hw_ila_1]

# Creating vector hw_probe called "foobar[0:0]" from probe1:
create_hw_probe -map {probe1} foobar[0:0] [get_hw_ilas hw_ila_1]

# Creating vector probe called "foobar[3:0]" from probe0:
create_hw_probe -map {probe0[3:0]} foobar[3:0] [get_hw_ilas hw_ila_1]

# Creating vector probe called "foobar[3:2]" from probe0[1:0]:
create_hw_probe -map {probe0[1:0]} foobar[3:2] [get_hw_ilas hw_ila_1]
```

Deleting a User-Defined Debug Probe

You can delete user-defined debug probes using the `delete_hw_probe` Tcl command.

For example, to delete a probe `foobar` created earlier using `create_hw_probe` do the following:

```bash
delte_hw_probe [get_hw_probes foobar -of_objects [get_hw_ilas -of_objects [get_hw_devices xc7k325t_0] -filter {CELL_NAME=~"i_fast_ila"}]]
```

Persistence of User-Defined Debug Probes

Any of the user-defined probes created in the Hardware Manager in the project flow are automatically persisted by the tool. The next time the project is opened and you connect to the hardware target using Vivado Hardware Manager, these user-defined probes are resurrected. If these user-defined debug probes participated in Basic triggering or were added to the Waveform window, on project open and connecting to the target in the Hardware Manager, you will see the probe setup in all the windows exactly as when you closed the project earlier.

Interacting with a User-Defined Probe

Any of the user-defined debug probes created in the Hardware Manager can participate in Basic triggering, Advanced Triggering, and/or the Waveform window. The only exception are user-defined debug probes that involve constant values. These types of debug probes can only be used in the Waveform window.
Using Basic Trigger Mode

Use the basic trigger mode to describe a trigger condition that is a global Boolean equation of participating debug probe comparators. Basic trigger mode is enabled when the Trigger Mode is set to either BASIC_ONLY or BASIC_OR_TRIG_IN. Use the Basic Trigger Setup window (see Figure 10-16) to create this trigger condition and debug probe compare values.

You can also use the set_property Tcl command to change the trigger mode of the ILA core. For instance, to change the trigger mode of ILA core hw ila_1 to BASIC_ONLY, use the following command:

```
set_property CONTROL.TRIGGER_MODE BASIC_ONLY [get_hw_ilas hw ila_1]
```

Adding Probes to Basic Trigger Setup Window

The first step in using the basic trigger mode is to decide what ILA debug probes you want to participate in the trigger condition. Do this by selecting the desired ILA debug probes from the Debug Probes window and either right-click selecting Add Probes to Basic Trigger Setup or by dragging and dropping the probes into the Basic Trigger Setup window.

**Note:** You can drag-and-drop the first probe anywhere in the Basic Trigger Setup window, but you must drop the second and subsequent probes on top of the first probe. The new probe is always added above the previously added probe in the table. You can also use drag-and-drop operations in this manner to re-arrange probes in the table.

**IMPORTANT:** Only probes that are in the Basic Trigger Setup window participate in the trigger condition. Any probes that are not in the window are set to "don't care" values and are not used as part of the trigger condition.

You can remove probes from the Basic Trigger Setup window by selecting the probe and hitting the Delete key or by right-click selecting the Remove option.

Setting Basic Trigger Compare Values

Use the ILA debug probe trigger comparators to detect specific equality or inequality conditions on the probe inputs to the ILA core. The trigger condition is the result of a Boolean "AND", "OR", "NAND", or "NOR" calculation of each of the ILA probe trigger comparator results. To specify the compare values for a given ILA probe, select the Compare...
Value cell in for a given ILA debug probe in the **Basic Trigger Setup** window to open the **Compare Value** dialog box (see **Figure 10-17**).

![ILA Probe Compare Value Dialog Box](image)

**Figure 10-17: ILA Probe Compare Value Dialog Box**

**TIP:** Prior to changing the **Radix** ensure that the value is set to a string that applies to the new **Radix**.

**ILA Probe Compare Value Settings**

The **Compare Value** dialog box contains three fields that you can configure:

1. **Operator:** This is the comparison operator that you can set to the following values:
   - `==` (equal)
   - `!=` (not equal)
   - `<` (less than)
   - `<=` (less than or equal)
   - `>` (greater than)
   - `>=` (greater than or equal)

2. **Radix:** This is the radix or base of the Value that you can set to the following values:
   - `[B]` Binary
   - `[H]` Hexadecimal
   - `[O]` Octal
   - `[U]` Unsigned Decimal
   - `[S]` Signed Decimal
3. **Value**: This is the comparison value that will be compared (using the **Operator**) with the real-time value on the net(s) in the design that are connected to the probe input of the ILA debug core. Depending on the Radix settings, the Value string is as follows:

- **Binary**
  - 0: logical zero
  - 1: logical one
  - X: don’t care
  - R: rising or low-to-high transition
  - F: falling or high-to-low transition
  - B: either low-to-high or high-to-low transitions
  - N: no transition (current sample value is the same as the previous value)
- **Hexadecimal**
  - X: All bits corresponding to the value string character are "don't care" values
  - 0-9: Values 0 through 9
  - A-F: Values 10 through 15
- **Octal**
  - X: All bits corresponding to the value string character are "don't care" values
  - 0-7: Values 0 through 7
- **Unsigned Decimal**
  - Any non-negative integer value
- **Signed Decimal**
  - Any integer value

**Setting Basic Trigger Condition**

You can set up the trigger condition using the toolbar button on the left side of the **Basic Trigger Setup** window that has an icon the shape of a logic gate on it (see **Figure 10-18**). You can also use the `set_property` Tcl command to change the trigger condition of the ILA core:

```
set_property CONTROL.TRIGGER_CONDITION AND [get_hw_ilas hw_ila_1]
```
The meaning of the four possible values is shown in Table 10-1.

![Setting the Basic Trigger Condition](image)

**Table 10-1: Basic Trigger Condition Setting Descriptions**

<table>
<thead>
<tr>
<th>Trigger Condition Setting in GUI</th>
<th>CONTROL.TRIGGER_CONDITION property value</th>
<th>Trigger Condition Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global AND</td>
<td>AND</td>
<td>Trigger condition is “true” if all participating probe comparators evaluate “true”, otherwise trigger condition is “false.”</td>
</tr>
<tr>
<td>Global OR</td>
<td>OR</td>
<td>Trigger condition is “true” if at least one participating probe comparator evaluates “true”, otherwise trigger condition is “false.”</td>
</tr>
<tr>
<td>Global NAND</td>
<td>NAND</td>
<td>Trigger condition is “true” if at least one participating probe comparator evaluates “false”, otherwise trigger condition is “false.”</td>
</tr>
<tr>
<td>Global NOR</td>
<td>NOR</td>
<td>Trigger condition is “true” if all participating probe comparators evaluate “false”, otherwise trigger condition is “false.”</td>
</tr>
</tbody>
</table>

**IMPORTANT:** If the ILA core has two or more debug probes that concatenated together to share a single physical probe port of the ILA core, then only the “Global AND” (AND) and “Global NAND” (NAND) trigger condition settings are supported. The “Global OR” (OR) and “Global NOR” (NOR) functions are not supported due to limitations of the probe port comparator logic. If you want to use the “Global OR” (OR) or “Global NOR” (NOR) trigger condition settings, then make sure you assign each unique net or bus net to separate probe ports of the ILA core.
Using Advanced Trigger Mode

The ILA core can be configured at core generation or insertion time to have advanced trigger capabilities that include the following features:

- Trigger state machine consisting of up to 16 states.
- Each state can consist of one-, two-, or three-way conditional branching.
- Up to four counters can be used in a trigger state machine program to keep track of multiple events.
- Up to four flags can be used in a trigger state machine program to indicate when certain branches are taken.
- The state machine can execute "goto", "trigger", and various counter- and flag-related actions.

If the ILA core in the design that is running in the hardware device has advanced trigger capabilities, the advanced trigger mode features can be enabled by setting the Trigger mode control in the ILA Properties window of the ILA Dashboard to ADVANCED_ONLY or ADVANCED_OR_TRIG_IN.

Specifying the Trigger State Machine Program File

When you set the Trigger mode to ADVANCED_ONLY or ADVANCED_OR_TRIG_IN, two changes happen in the ILA Dashboard:

1. A new control called Trigger State Machine appears in the ILA Properties window
2. The Basic Trigger Setup window is replaced by a Trigger State Machine code editor window.

If you are specifying an ILA trigger state machine program for the first time, the Trigger State Machine code editor window will appear as the one shown in Figure 10-19.

![Figure 10-19: Creating or Opening a Trigger State Machine Program File](image)

To create a new trigger state machine, click the Create new trigger state machine link, otherwise click the Open existing trigger state machine link to open a trigger state machine program file (.tsm extension). You can also open an existing trigger state machine program file using the Trigger state machine text field and/or browse button in the ILA Properties window of the ILA Dashboard.
Editing the Trigger State Machine Program

If you created a new trigger state machine program file, the Trigger State Machine code editor window will be populated with a simple trigger state machine by default (see Figure 10-20).

The simple default trigger state machine program is designed to be valid for any ILA core configuration regardless of debug probe or trigger settings. This means that you can click the Run Trigger for the ILA core without modifying the trigger state machine program.

However, it is likely that you will want to modify the trigger state machine program to implement some advanced trigger condition. The comment block at the top of the simple state machine shown in Figure 10-20 gives some instructions on how to use the built-in language templates in the Vivado IDE to construct a trigger state machine program (see Figure 10-21). A full description of the ILA trigger state machine language, including examples, is found in the section of this document called Appendix B, Trigger State Machine Language Description.
Chapter 10:  Debugging Logic Designs in Hardware

Compiling the Trigger State Machine

The trigger state machine is compiled every time you run the ILA trigger. If you would like to compile the trigger state machine without running or arming the ILA trigger, click the Compile trigger state machine button in the ILA Dashboard (see Figure 10-22).

---

Figure 10-21:  Trigger State Machine Language Templates
Enabling Trigger In and Out Ports

The ILA core can be configured at core generation-time to have dedicated trigger input ports (TRIG_IN and TRIG_IN_ACK) and dedicated trigger output ports (TRIG_OUT and TRIG_OUT_ACK). If the ILA core has trigger input ports enabled, then you can use the following Trigger Mode settings to trigger on events on the TRIG_IN port:

- **BASIC_OR_TRIG_IN**: used to trigger the ILA core when a logical OR-ing of the TRIG_IN pin of the ILA core and BASIC_ONLY trigger mode is desired.
- **ADVANCED_OR_TRIG_IN**: used to trigger the ILA core when a logical OR-ing of the TRIG_IN pin of the ILA core and ADVANCED_ONLY trigger mode is desired.
- **TRIG_IN_ONLY**: used to trigger the ILA core when the TRIG_IN pin of the ILA core transitions from a low to high.

If the ILA core has trigger output ports enabled, then you can use the following TRIG_OUT Mode to control the propagation of trigger events to the TRIG_OUT port:

- **DISABLED**: disables the TRIG_OUT port.
- **TRIGGER_ONLY**: enables the result of the basic/advanced trigger condition to propagate to the TRIG_OUT port.
- **TRIG_IN_ONLY**: propagates the TRIG_IN port to the TRIG_OUT port.
- **TRIGGER_OR_TRIG_IN**: enables the result of a logical OR-ing of the basic/advanced trigger condition and TRIG_IN port to propagate to the TRIG_OUT port.
Configuring Capture Mode Settings

The ILA core can capture data samples when the core status is Pre-Trigger, Waiting for Trigger, or Post-Trigger (refer to the section called Viewing Trigger and Capture Status for more details). The Capture mode control is used to select what condition is evaluated before each sample is captured:

- **ALWAYS**: store a data sample during a given clock cycle regardless of any capture conditions
- **BASIC**: store a data sample during a given clock cycle only if the capture condition evaluates "true"

You can also use the `set_property` Tcl command to change the capture mode of the ILA core. For instance, to change the capture mode of ILA core `hw ila_1` to BASIC, use the following command:

```
set_property CONTROL.CAPTURE_MODE BASIC [get_hw_ilas hw ila_1]
```

**Using BASIC Capture Mode**

Use the basic capture mode to describe a capture condition that is a global Boolean equation of participating debug probe comparators. Use the Basic Capture Setup window (see Figure 10-23) to create this capture condition and debug probe compare values.

![Basic Capture Setup Window](image)

*Figure 10-23: Setting the Basic Capture Condition*

**Configuring the Basic Capture Setup Window**

The process for configuring debug probes and basic capture condition in the Basic Capture window is very similar to working with debug probes in the Basic Trigger Setup window:

- For information on adding probes to the Basic Capture Setup window, refer to the section called Adding Probes to Basic Trigger Setup Window.
- For information on setting the compare values on each probe in the Basic Capture Setup window, refer to the section called ILA Probe Compare Value Settings
• For information on setting the basic capture condition in the **Basic Capture Setup** window, refer to the section called **Setting Basic Trigger Condition**. One key difference is the ILA core property used to control the capture condition is called **CONTROL.CAPTURE_CONDITION**.

### Setting the Number of Capture Windows

The ILA capture data buffer can be subdivided into one or more capture windows, the depth each of which is a power of 2 number of samples from 1 to \(((\text{buffer size}) / (\text{number of windows})) - 1\). For example, if the ILA data buffer is 1024 samples deep and is segmented into four capture windows, then each window can be up to 256 samples deep. Each capture window has its own trigger mark corresponding to the trigger event that caused the capture window to fill.

**TIP:** Clicking **Stop Trigger** before the entire ILA data capture buffer is full will upload and display all capture windows that have been filled. For example, if the ILA data buffer is segmented into four windows and three of them have filled with data, clicking **Stop Trigger** will halt the ILA core and upload and display the three filled capture windows.

The table below illustrates the interaction between the Vivado runtime software and hardware when a you set the **Number of Capture Windows** to more than 1 and the **Trigger Position** to 0.

**Table 10-2: Number of Capture Windows > 1 and Trigger Position = 0**

<table>
<thead>
<tr>
<th>Software</th>
<th>Hardware</th>
</tr>
</thead>
<tbody>
<tr>
<td>User Runs Trigger on the ILA core</td>
<td>• Window 0: ILA is armed</td>
</tr>
<tr>
<td></td>
<td>• Window 0: ILA triggers</td>
</tr>
<tr>
<td></td>
<td>• Window 0: ILA fills capture window 0</td>
</tr>
<tr>
<td></td>
<td>• Window 1: ILA is rearmed</td>
</tr>
<tr>
<td></td>
<td>• Window 1: ILA triggers</td>
</tr>
<tr>
<td></td>
<td>• Window 1: ILA fills capture window 1</td>
</tr>
<tr>
<td></td>
<td>• Window n-1: ILA is rearmed</td>
</tr>
<tr>
<td></td>
<td>• Window n-1: ILA triggers</td>
</tr>
<tr>
<td></td>
<td>• Window n-1: ILA fills capture window n</td>
</tr>
<tr>
<td>Data is uploaded and displayed</td>
<td>Entire ILA Capture Buffer is Full</td>
</tr>
<tr>
<td></td>
<td>The ILA core is rearmed such that it is ready to trigger on the clock cycle immediately following the last sample captured of the previous window.</td>
</tr>
</tbody>
</table>
Chapter 10: Debugging Logic Designs in Hardware

The table below illustrates the interaction between the Vivado runtime software and hardware when you set the **Number of Capture Windows** to more than 1 and the **Trigger Position** to greater than 0.

**Table 10-3: Number of Capture Windows > 1 and Trigger Position > 0**

<table>
<thead>
<tr>
<th>Software</th>
<th>Hardware</th>
</tr>
</thead>
</table>
| User Runs Trigger on the ILA core | • Window 0: ILA is armed  
• Window 0: ILA fills capture buffer up to trigger position  
• Window 0: ILA triggers  
• Window 0: ILA fills the rest of capture window 0  
• Window 1: ILA is rearmed  
• Window 1: ILA fills capture buffer up to trigger position  
• Window 1: ILA triggers  
• Window 1: ILA fills capture buffer  
• Window 1: ILA fills window 1  
...  
• Window n-1: ILA is rearmed  
• Window n-1: ILA fills capture buffer up to trigger position  
• Window n-1: ILA triggers  
• Window n-1: ILA fills capture buffer  
• Window n-1: ILA fills window n  
Entire ILA Capture Buffer is Full |

Data is uploaded and displayed | Triggers could be missed between two windows since the ILA now has to fill the capture data up to the trigger position. |

**Setting the Trigger Position in the Capture Window**

Use the **Trigger position** control in the **Capture Mode Settings** window (or the **Trigger Position** property in the **ILA Core Properties** window) to set the position of the trigger marker in the captured data window. You can set the trigger position to any sample number in the captured data window. For instance, in the case of a captured data window that is 1024 samples deep:

- Sample number 0 corresponds to the first (left-most) sample in the captured data window.
- Sample number 1023 corresponds to the last (right-most) sample in the captured data window.
- Samples numbers 511 and 512 correspond to the two "center" samples in the captured data window.
You can also use the `set_property` Tcl command to change the ILA core trigger position:

    set_property CONTROL.TRIGGER_POSITION 512 [get_hw_ilas hw ila_1]

**Setting the Data Depth of the Capture Window**

Use the Data Depth control in the Capture Mode Settings window (or the Capture data depth property in the ILA Core Properties window) to set the data depth of the ILA core's captured data window. You can set the data depth to any power of two from 1 to the maximum data depth of the ILA core (set during core generation or insertion time).

*Note:* Refer to the section called Modifying Properties on the Debug Cores for more details on how to set the maximum capture buffer data depth on ILA cores that are added to the design using the Netlist Insertion probing flow.

You can also use the `set_property` Tcl command to change the ILA core data depth:

    set_property CONTROL.DATA_DEPTH 512 [get_hw_ilas hw ila_1]

**Running the Trigger**

You can run or arm the ILA core trigger in two different modes:

- **Run Trigger**: Selecting the ILA core(s) to be armed followed by clicking the Run Trigger button on the ILA Dashboard or Hardware window toolbar arms the ILA core to detect the trigger event that is defined by the ILA core basic or advanced trigger settings.

- **Run Trigger Immediate**: Selecting the ILA core(s) to be armed followed by clicking the Run Trigger Immediate button on the ILA Dashboard or Hardware window toolbar arms the ILA core to trigger immediately regardless of the ILA core trigger settings. This command is useful for detecting the "aliveness" of the design by capturing any activity at the probe inputs of the ILA core.

You can also arm the trigger by selecting and right-clicking on the ILA core and selecting Run Trigger or Run Trigger Immediate from the popup menu (see Figure 10-24).
Chapter 10:  Debugging Logic Designs in Hardware

**TIP:** You can run or stop the triggers of multiple ILA cores by selecting the desired ILA cores, then using the Run Trigger, Run Trigger Immediate, or Stop Trigger buttons in the Hardware window toolbar. You can also run or stop the triggers of all ILA cores in a given device by selecting the device in the Hardware window and click the appropriate button in the Hardware window toolbar.

**Stopping the Trigger**

You can stop the ILA core trigger by selecting the appropriate ILA core followed by clicking on the Stop Trigger button on the ILA Dashboard or Hardware window toolbar. You can also stop the trigger by selecting and right-clicking on the appropriate ILA core(s) and selecting Stop Trigger from the popup menu (see Figure 10-24).

**Using Auto Re-Trigger**

Select the Enable Auto Re-Trigger right-click menu option (or corresponding button on the ILA Dashboard toolbar) on the ILA core to enable Vivado IDE to automatically re-arm the ILA core trigger after a successful trigger+upload+display operation has completed. The captured data displayed in the waveform viewer corresponding to the ILA core will be overwritten upon each successful trigger event. The Auto Re-Trigger option can be used with the Run Trigger and Run Trigger Immediate operations. Click Stop Trigger to stop the trigger currently in progress.

![ILA Core Trigger Commands](image-url)
The table below illustrates the interaction between the Vivado IDE runtime software and hardware when you invoke the **Auto Re-Trigger** option.

**Table 10-4: Auto Re-Trigger**

<table>
<thead>
<tr>
<th>Software</th>
<th>Hardware</th>
</tr>
</thead>
</table>
| Click the Auto Re-trigger option on the ILA core | • ILA is armed  
• ILA triggers  
• ILA fills capture buffer  
• ILA is full |
| Data is uploaded and displayed | • ILA is rearmed  
• ILA triggers  
• ILA fills capture buffer  
• ILA is full  
Lots of cycles are missed between the ILA “full” event and display of the ILA data |

**IMPORTANT:** As there is a delay between the time the ILA data is full and the data is uploaded and displayed in the GUI, there is a very high probability of missing cycles between these events where the ILA could have triggered.

### Viewing Trigger and Capture Status

The ILA debug core trigger and capture status is displayed in two places in Vivado IDE:

- In the **Hardware** window **Status** column of the row(s) corresponding to the ILA debug core(s).
- In the **Trigger Capture Status** window of the **ILA Dashboard**.

The **Status** column in the **Hardware** window indicates the current state or status of each ILA core (see **Table 10-5**).
Chapter 10: Debugging Logic Designs in Hardware

The contents of the Trigger Capture Status window in the ILA Dashboard depend on the Trigger Mode setting of the ILA core.

Partial Buffer Capture

Clicking Stop Trigger before the entire ILA data capture buffer is full uploads and displays all capture windows that have been filled. For example, if the ILA data buffer is segmented into four windows and three of them have filled with data, clicking Stop Trigger halts the ILA core and uploads and displays the three filled capture windows. In addition, clicking Stop Trigger will halt the ILA core and display a partially filled capture window so long as the trigger event occurred in that capture window.

Basic Trigger Mode Trigger and Capture Status

The Trigger Capture Status window contains two status indicators when the Trigger Mode is set to BASIC (see Figure 10-25):

- **Core status**: indicates the status of the ILA core trigger/capture engine (see Table 10-5 for a description of the status indicators)

- **Capture status**: indicates the current capture window, the current number of samples captured in the current capture window, and the total number of samples captured by the ILA core. These values are all reset to 0 once the ILA core status is Idle.

<table>
<thead>
<tr>
<th>ILA Core Status</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idle</td>
<td>The ILA core is idle and waiting for its trigger to be run. If the trigger position is 0, then the ILA core will transition to the Waiting for Trigger status once the trigger is run, otherwise the ILA core will transition to the Pre-Trigger status.</td>
</tr>
<tr>
<td>Pre-Trigger</td>
<td>The ILA core is capturing pre-trigger data into its data capture window. Once the pre-trigger data has been captured, the ILA core will transition to the Waiting for Trigger status.</td>
</tr>
<tr>
<td>Waiting for Trigger</td>
<td>The ILA core trigger is armed and is waiting for the trigger event to occur as described by the basic or advanced trigger settings. Once the trigger occurs, the ILA core will transition to the Full status if the trigger position is set to the last data sample in the capture window, otherwise it will transition to the Post-Trigger status.</td>
</tr>
<tr>
<td>Post-Trigger</td>
<td>The ILA core is capturing post-trigger data into its data capture window. Once the post-trigger data has been captured, the ILA core will transition to the Full status.</td>
</tr>
<tr>
<td>Full</td>
<td>The ILA core capture buffer is full and is being uploaded to the host for display. The ILA core will transition to the Idle status once the data has been uploaded and displayed.</td>
</tr>
</tbody>
</table>

Table 10-5: ILA Core Status Description
Chapter 10: Debugging Logic Designs in Hardware

Advanced Trigger Mode Trigger and Capture Status

The Trigger Capture Status window contains four status indicators when the Trigger Mode is set to ADVANCED (see Figure 10-26):

- **Core status**: indicates the status of the ILA core trigger/capture engine (see Table 10-5 for a description of the status indicators)
- **Trigger State Machine Flags**: indicates the current state of the four trigger state machine flags.
- **Trigger State**: when the core status is Waiting for Trigger, this field indicates the current state of the trigger state machine.
- **Capture status**: indicates the current capture window, the current number of samples captured in the current capture window, and the total number of samples captured by the ILA core. These values are all reset to 0 once the ILA core status is Idle.

Writing ILA Probes Information

The ILA Cores tab view in the Debug Probes window contains information about the nets that you probed in your design using the ILA core. This ILA probe information is extracted from your design and is stored in a data file that typically has an .ltx file extension.

Normally, the ILA probe file is automatically created during the implementation process. However, you can also use the write_debug_probes Tcl command to write out the debug probes information to a file:
1. If you are in project mode, open the Synthesized or Netlist Design. If you are in non-project mode, open the synthesized design checklist.

2. Run the `write_debug_probes filename.ltx` Tcl command.

---

Reading ILA Probes Information

The ILA probe file is automatically associated with the FPGA hardware device if the probes file is called `debug_nets.ltx` and is found in the same directory as the bitstream programming (`.bit`) file that is associated with the device.

You can also specify the location of the probes file:

1. Select the FPGA device in the Hardware window.
2. Set the Probes file location in the Hardware Device Properties window.
3. Click Apply to apply the change.

You can also set the location using the `set_property` Tcl command:

```
set_property PROBES.FILE {C:/myprobes.ltx} [lindex [get_hw_devices] 0]
```

---

Viewing Captured Data from the ILA Core in the Waveform Viewer

Once the ILA core captured data has been uploaded to the Vivado IDE, it is displayed in the Waveform Viewer. See Chapter 11, Viewing ILA Probe Data in the Waveform Viewer for details on using the Waveform Viewer to view captured data from the ILA core.

---

Saving and Restoring Captured Data from the ILA Core

In addition to displaying the captured data that is directly uploaded from the ILA core, you can also write the captured data to a file then read the data from a file and display it in the waveform viewer.
Chapter 10: Debugging Logic Designs in Hardware

Saving Captured ILA Data to a File

Currently, the only way to upload captured data from an ILA core and save it to a file is to use the following Tcl command:

```
write_hw_ila_data my_hw_ila_data_file.ila [upload_hw_ila_data hw_ila_1]
```

This Tcl command sequence uploads the captured data from the ILA core and writes it to an archive file called `my_hw_ila_data_file.ila`. The archive file contains the waveform database file, the waveform configuration file, a waveform comma separated value file, and a debug probes file.

**TIP:** Use the `-csv_file` option to generate a comma-separated values (CSV) file. This configures the `write_hw_ila_data` command to export the ILA data in the form of a CSV file that can be used to import into a spreadsheet or third-party application, rather than the default binary ILA file format.

**TIP:** Use the `-vcd_file` option to generate a value change dump (VCD) file. This configures the `write_hw_ila_data` command to export the ILA data in the form of a VCD file that can be used to import into a third-party application or viewer, rather than the default binary ILA file format.

**Probe Data Radix**

Every probe has a DISPLAY_RADIX property associated with it. This property is set to HEX for a multi-bit probe and BINARY for a one-bit probe by default. The exported probe data in the `.csv` files use probe radix.

You can change the DISPLAY_RADIX probes of all the probes of all ILAs in the design as follows in the Vivado Hardware Manager Tcl Console:

```
foreach probe [get_hw_probes -of [get_hw_ilas]] {
    set_property DISPLAY_RADIX binary $probe
    set_property DISPLAY_AS_ENUM false $probe
}
```

**Note:** Here we are changing the radix of all the probes in all the ILAs to BINARY. To change the radix to HEX, use the script below.

```
foreach probe [get_hw_probes -of [get_hw_ilas]] {
    set_property DISPLAY_RADIX hex $probe
    set_property DISPLAY_AS_ENUM false $probe
}
```

**Listing data samples associated with a single probe**

You can also list data samples associated with individual probes using the `list_hw_samples` Tcl command.
An example of listing the samples associated with probe `fast_cnt_incr_val_1` on ILA named `i_fast_ila` is shown below:

```tcl
list_hw_samples [get_hw_probes fast_cnt_incr_val_1 -of_objects [get_hw_ilas -of_objects [get_hw_devices xc7k325t_0] -filter {CELL_NAME="i_fast_ila"}]]
```

```text
00000001 00000001 00000001 00000001 00000001 00000001 00000001 00000001
00000001 00000001 00000001 00000001 00000001 00000001 00000001 00000001
00000001 00000001 00000001 00000001 00000001 00000001 00000001 00000001
...```

Restoring Captured ILA Data from a File

Currently, the only way to restore captured data from a file and display it in the waveform viewer is to use the following Tcl command:

```tcl
display_hw_ila_data [read_hw_ila_data my_hw_ila_data_file.ila]
```

This Tcl command sequence reads the previously saved captured data from the ILA core and displays it in the Waveform window.

**Note:** The waveform configuration settings (dividers, markers, colors, probe radices, etc.) for the ILA Data Waveform window is also saved in the ILA captured data archive file. Restoring and displaying any previously saved ILA data uses these stored waveform configuration settings.

**IMPORTANT:** Do NOT use the `open_wave_config` command to open a waveform created from ILA captured data. This is a simulator-only command and will not function correctly with ILA captured data waveforms.

Enumeration of Probe Values

This feature provides a way to refer to probe values, both during Trigger/Capture Setup to compare values, and in the **Waveform** window, by symbolic names.

Some common use cases include the following.

- state machine state values
- op codes
- any probe match value, that you want to refer to by name, instead of value.

The process involves entering enumeration name-value pairs and associating them with a probe. The enumeration name-value pair associations are available using Tcl commands and are stored between sessions.

Probe compare values can be set using enumeration names in the **Trigger Setup** and **Capture Control Setup** windows. Probes and their enumeration names corresponding to values can be displayed in the **Waveform** window as well.
Add/Edit Enumerations

Define new Enumerations using the Hardware Manager

To associate a new enumeration name-value pair to a debug probe, right-click the debug probe either in the Debug Probes window or the Trigger/Capture Setup window and select Edit Enumeration.

![Figure 10-27: Edit Enumeration from Trigger Setup Window](image)

Editing Enumeration Associated with a Debug Probe in the Trigger Setup Window

You can also associate a new enumeration name-value pair to a debug probe by selecting the debug probe in the Debug Probes window or Trigger Setup window. The
Enumeration tab of the Debug Probe Properties window also allows you to associate a new enumeration name-value pair to the probe.

Click Edit Enumeration, to open the Edit Enumeration dialog box.
Select the name-value pair and use the green “+” and red “−” buttons on the left to add or delete enumerations. You can change the **name**, **radix**, and **values** fields in the table.

### Add Enumerations Using Tcl Commands

The `add_hw_probe_enum` command, associates an enumeration name-value pair to a debug probe. You can add `add_hw_probe` commands to a Tcl file, to have the definitions appear in a separate file. The enumeration names maintain the case they were entered in, but lookup is case-insensitive.

**Example:**

```tcl
set probe  [get_hw_probes fast_cnt_count -of_objects [get_hw_ilas -of_objects [get_hw_devices xc7k325t_0] -filter {CELL_NAME=~"i_fast_ila"}]]
add_hw_probe_enum  ZERO      eq5'h00 $probe
add_hw_probe_enum  TWELVE    eq5'u12 $probe
add_hw_probe_enum  THIRTEEN  eq5'u13 $probe
add_hw_probe_enum  FOURTEEN  eq5'u14 $probe
add_hw_probe_enum  FIFTEEN   eq5'u15 $probe
add_hw_probe_enum  SIXTEEN   eq5'u16 $probe
add_hw_probe_enum  SEVENTEEN eq5'u17 $probe
```

### Delete Enumerations using Tcl commands

Use the `remove_hw_probe_enum` command to remove explicitly named enumerations entries, or all enumerations for a `hw_probe`.

**Example:**

```tcl
remove_hw_probe_enum -list {zero } [get_hw_probes U_SINEGEN/sel -of_objects [get_hw_ilas -of_objects [get_hw_devices xc7k325t_0] -filter {CELL_NAME=~"u_ila_0"}]]
```

**TIP:** Using the `-remove_all` option on `remove_hw_probe_enum` removes all of the enumerations associated with the probe.

### Access Enumeration

Enumerations are stored as `hw_probe` properties, so `set_property`, `get_property`, and `report_property` commands can be used on these properties.
The enumeration properties have a prefix `ENUM`, which needs to be used when using it with `set_property` and `get_property` commands. See the following example.

```
get_property ENUM.FIFTEEN -of_objects [get_hw_ilas -of_objects [get_hw_devices xc7k325t_0] -filter {CELL_NAME=~"i_fast_ila"}]
eq5'u15
```

```
report_property [get_hw_probes fast_vio_slice5_fb -of_objects [get_hw_ilas hw_ila_1]] ENUM*
```

<table>
<thead>
<tr>
<th>Property</th>
<th>Type</th>
<th>Read-only</th>
<th>Visible</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENUM.FIFTEEN</td>
<td>string</td>
<td>true</td>
<td>true</td>
<td>eq5'u15</td>
</tr>
<tr>
<td>ENUM.FOURTEEN</td>
<td>string</td>
<td>true</td>
<td>true</td>
<td>eq5'u14</td>
</tr>
<tr>
<td>ENUM.SEVENTEEN</td>
<td>string</td>
<td>true</td>
<td>true</td>
<td>eq5'u17</td>
</tr>
<tr>
<td>ENUM.SIXTEEN</td>
<td>string</td>
<td>true</td>
<td>true</td>
<td>eq5'u16</td>
</tr>
<tr>
<td>ENUM.THIRTEEN</td>
<td>string</td>
<td>true</td>
<td>true</td>
<td>eq5'u13</td>
</tr>
<tr>
<td>ENUM.TWELVE</td>
<td>string</td>
<td>true</td>
<td>true</td>
<td>eq3'u12</td>
</tr>
<tr>
<td>ENUM.ZERO</td>
<td>string</td>
<td>true</td>
<td>true</td>
<td>eq5'h00</td>
</tr>
</tbody>
</table>

```
set_property ENUM.FIFTEEN eq5'h0F [get_hw_probes fast_vio_slice5_fb -of_objects [get_hw_ilas hw_ila_1]]
```

**Using Enumerations in Trigger Setup window**

Setting compare values with enumerations in the **Trigger Setup** window, has similar syntax to numeric compare values. The radix char is 'e'. Only the operators 'eq' and 'neq' are supported for enumeration compare values.

```
set_property TRIGGER_COMPARE_VALUE eq2'ethree [get_hw_probes U_SINEGEN/sel -of_objects [get_hw_ilas -of_objects [get_hw_devices xc7k325t_0] -filter {CELL_NAME=~"u_ila_0"}]]
```

![Figure 10-30: Enumerations in Trigger Setup Window](image-url)
Using Enumerations in Capture Setup window

You can also compare values using enumeration in the Capture Setup window in the Vivado IDE or using Tcl commands.

```
set_property CAPTURE_COMPARE_VALUE eq2'eone [get_hw_probes locked -of_objects [get_hw_ilas -of_objects [get_hw_devices xc7k325t_0] -filter {CELL_NAME=~"u_ila_0_0"}]]
```

Advanced Trigger

You can compare values using enumeration in the Advanced Trigger State Machine scripts as in the following example.

```
state my_state0:
    if (fast_ila_slice5_fb == 5'eFIFTEEN) then
        set_flag $flag1;
        goto my_state0;
    elseif (fast_ila_slice5_fb == 5'eTWELVE) then
        trigger;
    else
        clear_flag $flag1;
        goto my_state0;
    endif
```

Using Enumerations in the Waveform window

You can show enumerations in the Waveform window by choosing the Show as Enumeration option for each signal. Right-click the signal in the Waveform window and
select **Show as Enumeration** in the menu that appears. When not shown as an enumeration, bus values are displayed according to regular radix selection.

---

**Figure 10-32**: Show as Enumeration option in the Waveform Window
Enumeration information is saved to waveform data files and is used in subsequent displays of waveform data. The default for waveform probes that have Enumerations defined is to have the Enumerations displayed.

When a waveform object has **Show as Enumeration** selected, enumeration names are displayed. If there is no matching Enumeration for the waveform value, it will instead be displayed according to the selected radix.

**IMPORTANT:** If the waveform has been created prior to creating the enumerations, you can apply new enumerations to the waveform by saving the waveform ILA data using the Tcl commands below:

```tcl
write_hw_ila_data -force data_ila_3.ila
[upload_hw_ila_data hw_ila_3]
display_hw_ila_data [read_hw_ila_data ./data_ila_3.ila]
```

### Setting Up the VIO Core to Take a Measurement

The VIO cores that you add to your design appear in the **Hardware** window under the target device. If you do not see the VIO cores appear, right-click the device and select **Refresh Hardware**. This re-scans the FPGA device and refreshes the **Hardware** window.

**Note:** If you still do not see the VIO core after programming and/or refreshing the FPGA device, check to make sure the device was programmed with the appropriate .bit file and check to make
sure the implemented design contains an VIO core. Also, check to make sure the appropriate `.ltx` probes file that matches the `.bit` file is associated with the device.

Click the VIO core (called hw_vio_1 in Figure 10-34) to see its properties in the **VIO Core Properties** window. By selecting the VIO core, you should also see the probes corresponding to the VIO core in the **Debug Probes** window as well as the corresponding **VIO Dashboard** in the **Vivado IDE** workspace (see Figure 10-35).

![Figure 10-34: VIO Core in the Hardware Window](image)
Chapter 10: Debugging Logic Designs in Hardware

The VIO core can become out-of-sync with the Vivado IDE. Refer to Viewing the VIO Core Status for more information on how to interpret the VIO status indicators.

The VIO core operates on an object property-based set/commit and refresh/get model:

- To read VIO input probe values, first refresh the hw_vio object with the VIO core values. Observe the input probe values by getting the property values of the corresponding hw_probe object. Refer to the section called Interacting with VIO Core Input Probes for more information.

- To write VIO output probe values, first set the desired value as a property on the hw_probe object. These property values are then committed to the VIO core in hardware in order to write these values to the output probe ports of the core. Refer to the section called Interacting with VIO Core Output Probes for more information.

Viewing the VIO Core Status

The VIO core can have zero or more input probes and zero or more output probes (note that the VIO core must have at least one input or output probe). The VIO core status shown
in the Hardware window is used to indicate the current state of the VIO core output probes. The possible status values and any action that you need to take are described in Table 10-6.

### Table 10-6: VIO Core Status and Required User Action

<table>
<thead>
<tr>
<th>VIO Status</th>
<th>Description</th>
<th>Required User Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>OK – Outputs Reset</td>
<td>The VIO core outputs are in sync with the Vivado IDE and the outputs are in their initial or “reset” state.</td>
<td>None</td>
</tr>
<tr>
<td>OK</td>
<td>The VIO core outputs are in sync with the Vivado IDE, however, the outputs are not in their initial or “reset” state.</td>
<td>None</td>
</tr>
<tr>
<td>Outputs out-of-sync</td>
<td>The VIO core outputs are not in sync with the Vivado IDE.</td>
<td>You must choose one of two user actions:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Write the values from the Vivado IDE to the VIO core by right-clicking the VIO core in the Hardware window and selecting the Commit VIO Core Outputs option.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Update the Vivado IDE with the current values of the VIO core output probe ports by right-clicking the VIO core in the Hardware window and selecting the Refresh Input and Output Values from VIO Core option.</td>
</tr>
</tbody>
</table>

### Viewing VIO Cores in the Debug Probes Window

The “+” button in the VIO Dashboard window is used to view, add, and delete the debug probes that belong to VIO core.

### Using the VIO Dashboard

The VIO Default Dashboard starts out empty to which you can add VIO probes to as shown
The **VIO Dashboard** is a central location for all status and control information pertaining to a given VIO core. When a VIO core is first detected upon refreshing a hardware device, the **VIO Dashboard** for the core is automatically opened. If you need to manually open or re-open the dashboard, right-click the VIO core object in either the **Hardware** or **Debug Probes** windows and select **Open Dashboard**.

**Interacting with VIO Core Input Probes**

The VIO core input probes are used to read values from a design that is running in an FPGA in actual hardware. The VIO input probes are typically used as status indicators for a design-under-test. VIO debug probes need to be added manually to the **VIO Probes** window in the **VIO Dashboard**. Refer to the section called **Viewing VIO Cores in the Debug Probes Window** on how to do this. An example of what VIO input probes look like in the VIO Probes window of the VIO Dashboard is shown in **Figure 10-37**.
Chapter 10: Debugging Logic Designs in Hardware

Reading VIO Inputs Using the VIO Cores View

The VIO input probes can be viewed using the VIO Probes window of the VIO Dashboard window. Each input probe is viewed as a separate row in the table. The value of the VIO input probes are shown in the Value column of the table (see Figure 10-37). The VIO core input values are periodically updated based on the value of the refresh rate of the VIO core. You can set the refresh rate by changing the Refresh Rate (ms) in the VIO Properties window or by running the following Tcl command:

```
set_property CORE_REFRESH_RATE_MS 1000 [get_hw_vios hw_vio_1]
```

Note: Setting the refresh rate to 0 causes all automatic refreshes from the VIO core to stop. Also note that very small refresh values may cause your Vivado IDE to become sluggish. Xilinx recommends a refresh rate of 500 ms or longer.

If you want to manually read a VIO input probe value, you can use Tcl commands to do so. For instance, if you wanted to refresh and get the value of the input probe called BUTTON_IBUF of the VIO core hw_vio_1, run the following Tcl commands:

```
refresh_hw_vio [get_hw_vios {hw_vio_1}]
get_property INPUT_VALUE [get_hw_probes BUTTON_IBUF]
```

Setting the VIO Input Display Type and Radix

The display type of VIO input probes can be set by right-clicking a VIO input probe in the VIO Probes window of the VIO Dashboard window and selecting:

- **Text** to display the input as a text field. This is the only display type for VIO input probe vectors (more than one bit wide).
- **LED** to display the input as a graphical representation of a light-emitting diode (LED). This display type is only applicable to VIO input probe scalars and individual elements of VIO input probe vectors. You can set the high and low values to one of four colors:
  - Gray (off)
  - Red
  - Green
  - Blue
When the display type of the VIO input probe is set to **Text**, you can change the radix by right-clicking a VIO input probe in the **VIO Probes** window of the **VIO Dashboard** window and selecting:

- **Radix > Binary** to change the radix to binary.
- **Radix > Octal** to change the radix to octal.
- **Radix > Hex** to change the radix to hexadecimal.
- **Radix > Unsigned** to change the radix to unsigned decimal.
- **Radix > Signed** to change the radix to signed decimal.

You can also set the radix of the VIO input probe using a Tcl command. For instance, to change the radix of a VIO input probe called “BUTTON_IBUF”, run the following Tcl command:

```tcl
set_property INPUT_VALUE_RADIX HEX [get_hw_probes BUTTON_IBUF]
```

**Observing and Controlling VIO Input Activity**

In addition to reading values from the VIO input probes, you can also monitor the activity of the VIO input probes. The activity detectors are used to indicate when the values on the VIO inputs have changed in between periodic updates to the Vivado IDE.

The VIO input probe activity values are shown as arrows in the activity column of the **VIO Probes** window of the **VIO Dashboard** window:

- An up arrow indicates that the input probe value has transitioned from a 0 to a 1 during the activity persistence interval.
- A down arrow indicates that the input probe value has transitioned from a 1 to a 0 during the activity persistence interval.
- A double-sided arrow indicates that the input probe value has transitioned from a 1 to a 0 and from a 0 to a 1 at least once during the activity persistence interval.

The persistence of how long the input activity status is displayed can be controlled by right-clicking a VIO input probe in the **VIO Probes** window of the **VIO Dashboard** window and selecting:

- **Activity Persistence > Infinite** to accumulate and retain the activity value until you reset it.
- **Activity Persistence > Long (80 samples)** to accumulate and retain the activity for a longer period of time.
- **Activity Persistence > Short (8 samples)** to accumulate and retain the activity for a shorter period of time.
You can also set the activity persistence using a Tcl command. For instance, to change the activity persistence on the VIO input probe called BUTTON_IBUF to a long interval, run the following Tcl command:

```
set_property ACTIVITY_PERSISTENCE LONG [get_hw_probes BUTTON_IBUF]
```

The activity for all input probes for a given core can be reset by right-clicking the VIO core in the Hardware window and selecting **Reset All Input Activity**. You can also do this by running the following Tcl command:

```
reset_hw_vio_activity [get_hw_vios {hw_vio_1}]
```

**TIP:** You can change the type, radix, and/or activity persistence of multiple scalar members of a VIO input probe vector by right-clicking the whole probe or multiple members of the probe, then making a menu choice. The menu choice applies to all selected probe scalars.

---

### Interacting with VIO Core Output Probes

The VIO core output probes are used to write values to a design that is running in an FPGA device in actual hardware. The VIO output probes are typically used as low-bandwidth control signals for a design-under-test. VIO debug probes need to be added manually to the VIO Probes window in the VIO Dashboard. Refer to the section called **Viewing VIO Cores in the Debug Probes Window** on how to do this. An example of what VIO output probes look like in the VIO Probes window of the VIO Dashboard is shown in Figure 10-38.

![VIO Outputs in the VIO Probes window of the VIO Dashboard](image)

**Figure 10-38:** VIO Outputs in the VIO Probes window of the VIO Dashboard

### Writing VIO Outputs Using the VIO Cores View

The VIO output probes can be set using the VIO Probes window of the VIO Dashboard window. Each output probe is viewed as a separate row in the table. The value of the VIO output probes are shown in the Value column of the table (see Figure 10-38). The VIO core output values are updated whenever a new value is entered into the Value column. Clicking on the Value column causes a pull-down dialog to appear. Type the desired value into the Value text field and click OK.
You can also write out a new value to the VIO core using Tcl commands. For instance, if you wanted to write a binary value of “11111” to the VIO output probe called vio_slice5_fb_2 whose radix is already set to BINARY, run the following Tcl commands:

```
set_property OUTPUT_VALUE 11111 [get_hw_probes vio_slice5_fb_2]
commit_hw_vio [get_hw_probes {vio_slice5_fb_2}]
```

### Setting the VIO Output Display Type and Radix

The display type of VIO output probes can be set by right-clicking a VIO output probe in the VIO Probes window of the VIO Dashboard window and selecting:

- **Text** to display the output as a text field. This is the only display type for VIO input probe vectors (more than one bit wide).
- **Toggle Button** to display the output as a graphical representation of a toggle button. This display type is only applicable to VIO output probe scalars and individual elements of VIO input probe vectors.

When the display type of the VIO output probe is set to “Text”, you can change the radix by right-clicking a VIO output probe in the VIO Cores tabbed view of the Debug Probes window and selecting:

- **Radix > Binary** to change the radix to binary.
- **Radix > Octal** to change the radix to octal.
- **Radix > Hex** to change the radix to hexadecimal.
- **Radix > Unsigned** to change the radix to unsigned decimal.
- **Radix > Signed** to change the radix to signed decimal.

You can also set the radix of the VIO output probe using a Tcl command. For instance, to change the radix of a VIO output probe called “vio_slice5_fb_2” to hexadecimal, run the following Tcl command:

```
set_property OUTPUT_VALUE_RADIX HEX [get_hw_probes vio_slice5_fb_2]
```

### Resetting the VIO Core Output Values

The VIO v2.0 core has a feature that allows you to specify an initial value for each output probe port. You can reset the VIO core output probe ports to these initial values by right-clicking the VIO core in the Hardware window and selecting the **Reset VIO Core Outputs** option. You can also reset the VIO core outputs using a Tcl command:

```
reset_hw_vio_outputs [get_hw_vios {hw_vio_1}]
```

**Note:** Resetting the VIO output probes to their initial values may cause the output probe values to become out-of-sync with the Vivado IDE. Refer to the section called Synchronizing the VIO Core Output Values to the Vivado IDE on how to handle this situation.
Synchronizing the VIO Core Output Values to the Vivado IDE

The output probes of a VIO core can become out-of-sync with the Vivado IDE after resetting the VIO outputs, re-programming the FPGA, or by another Vivado tool instance setting output values before the current instance has started. In any case, if the VIO status indicates “Outputs out-of-sync”, you need to take one of two actions:

- Write the values from the Vivado IDE to the VIO core by right-clicking the VIO core in the Hardware window and selecting the Commit VIO Core Outputs option. You can also do this running a Tcl command:
  
  ```tcl
  commit_hw_vio [get_hw_vios {hw_vio_1}]
  ```

- Update the Vivado IDE with the current values of the VIO core output probe ports by right-clicking the VIO core in the Hardware window and selecting the Refresh Input and Output Values from VIO Core option. You can also do this running a Tcl command:
  
  ```tcl
  refresh_hw_vio -update_output_values 1 [get_hw_vios {hw_vio_1}]
  ```

---

Hardware System Communication Using the JTAG-to-AXI Master Debug Core

The JTAG-to-AXI Master debug core is a customizable core that can generate the AXI transactions and drive the AXI signals internal to an FPGA at run time. The core supports all memory mapped AXI and AXI-Lite interfaces and can support 32- or 64-bit wide data interfaces.

The JTAG-to-AXI Master (JTAG-AXI) cores that you add to your design appear in the Hardware window under the target device. If you do not see the JTAG-AXI cores appear, right-click the device and select Refresh Hardware. This re-scans the FPGA device and refreshes the Hardware window.

**Note:** If you still do not see the ILA core after programming and/or refreshing the FPGA device, check to make sure the device was programmed with the appropriate .bit file and check to make sure the implemented design contains an ILA core.

Click to select the JTAG-AXI core (called hw_axi_1 in Figure 10-39) to see its properties in the AXI Core Properties window.
Interacting with the JTAG-to-AXI Master Debug Core in Hardware

The JTAG-to-AXI Master debug core can only be communicated with using Tcl commands. You can create and run AXI read and write transactions using the `create_hw_axi_txn` and `run_hw_axi` commands, respectively.

Resetting the JTAG-to-AXI Master Debug Core

Before creating and issuing transactions, it is important to reset the JTAG-to-AXI Master core using the following Tcl command:

```
reset_hw_axi [get_hw_axis hw_axi_1]
```

Creating and Running a Read Transaction

The Tcl command used to create an AXI transaction is called `create_hw_axi_txn`. For more information on how to use this command, type "help create_hw_axi_txn" at the Tcl Console in the Vivado IDE. Here is an example on how to create a 4-word AXI read burst transaction from address 0:

```
create_hw_axi_txn read_txn [get_hw_axis hw_axi_1] -type READ -address 00000000 -len 4
```

where:
- `read_txn` is the user-defined name of the transaction
- `[get_hw_axis hw_axi_1]` returns the `hw_axi_1` object
- `-address 00000000` is the start address
- `-len 4` sets the AXI burst length to 4 words
Chapter 10: Debugging Logic Designs in Hardware

The next step is to run the transaction that was just created using the `run_hw_axi` command. Here is an example on how to do this:

```
run_hw_axi [get_hw_axi_txns read_txn]
```

The last step is to get the data that was read as a result of running the transaction. You can use either the `report_hw_axi_txn` or `report_property` commands to print the data to the screen or you can use the `get_property` command to return the value for use elsewhere.

```
report_hw_axi_txn [get_hw_axi_txns read_txn]
```

```
0  00000000 00000000  
8  00000000 00000000  
```

```
report_property [get_hw_axi_txns read_txn]
```

```
Property    Type    Read-only  Visible  Value
CLASS       string  true       true     hw_axi_txn 
CMD.ADDR    string  false      true     00000000 
CMD.BURST   enum    false      true     INCR  
CMD.CACHE   int     false      true     3     
CMD.ID      int     false      true     0     
CMD.LEN     int     false      true     4     
CMD.SIZE    enum    false      true     32    
DATA        string  false      true     00000000000000000000000000000000
HW_AXI      string  true       true     hw_axi_1 
NAME        string  true       true     read_txn 
TYPE        enum    false      true     READ  
```

Creating and Running a Write Transaction

Here is an example on how to create a 4-word AXI write burst transaction from address 0:

```
create_hw_axi_txn write_txn [get_hw_axis hw_axi_1] -type WRITE -address 00000000 
                   -len 4 -data {11111111_22222222_33333333_44444444} 
```

where:

- `write_txn` is the user-defined name of the transaction
- `[get_hw_axis hw_axi_1]` returns the `hw_axi_1` object
- `-address 00000000` is the start address
- `-len 4` sets the AXI burst length to 4 words
- `-data {11111111_22222222_33333333_44444444}`- The `-data` direction is LSB to the left (i.e., address 0) and MSB to the right (i.e., address 3).
Chapter 10: Debugging Logic Designs in Hardware

The next step is to run the transaction that was just created using the `run_hw_axi` command. Here is an example on how to do this:

```
run_hw_axi [get_hw_axi_txns write_txn]
```

**IMPORTANT:** If you reprogram the device, all the existing `jtag_axi` transactions will be deleted. You may need to recreate these transactions again.

**TIP:** The `-queue` optional argument to the `run_hw_axi` Tcl command allows you to specify `hw_axi` transactions in queue mode.

Queued operation allows up to 16 read and 16 write transactions to be queued in the JTAG to AXI Master FIFO and issued back-to-back for low latency and higher performance between the transactions. Non-queued transactions are simply run as submitted.

---

**Using Vivado Logic Analyzer in a Lab Environment**

The Vivado logic analyzer feature is integrated into the Vivado IDE and Vivado Lab Edition. To use Vivado logic analyzer feature to debug a design that is running on a target board that is in a lab environment, you need to do one of three things:

- Install and run the Vivado Lab Edition on your lab machine. For more details refer to Chapter 2, of this user guide.
- Install and run the full Vivado IDE on your lab machine.
- Install latest version of the Vivado Design Suite or Vivado Hardware Server (Standalone) on your remote lab machine, and use the Vivado logic analyzer feature on your local machine to connect to a remote instance of the Vivado Hardware Server (`hw_server`).

**Connecting to a Remote hw_server Running on a Lab Machine**

If you have a network connection to your lab machine, you can also connect to the target board by connecting to a Hardware Server that is running on that remote lab machine. Here are the steps to using the Vivado logic analyzer feature to connect to a Vivado Hardware Server (`hw_server.bat` on Windows platforms or `hw_server` on Linux platforms) that is running on the lab machine:

1. Install the latest version of the Vivado Design Suite or Vivado Hardware Server (Standalone) on the lab machine.
**IMPORTANT:** You do NOT need to install the full Vivado Design Suite or Vivado Lab Edition on the lab machine to only use the remote hardware server feature. However, if you do want to use the Vivado Hardware Manager features (such as the Vivado logic analyzer or Vivado serial I/O analyzer) on the lab machine, then you will need to install the Vivado Lab Edition on the lab machine. Also, you do NOT need any software licenses to run the Hardware Server, any of the Hardware Manager features of the Vivado Design Suite, or the Vivado Lab Edition.

2. Start up the hw_server application on the remote lab machine. Assuming you installed the Vivado Hardware Server (Standalone) to the default location and your lab machine is a 64-bit Windows machine, here is the command line:

   ```
   C:\Xilinx\VivadoHWSRV\vivado_release.version\bin\hw_server.bat
   ```

3. Start Vivado IDE in GUI mode on a different machine than your lab machine.

4. Follow the steps in the Connecting to the Hardware Target and Programming the FPGA Device section to open a connection to the target board that is connected to your lab machine. However, instead of connecting to a Vivado CSE server running on localhost, use the host name of your lab machine.

5. Follow the steps in the Setting up the ILA Core to Take a Measurement section and beyond to debug your design in hardware.

---

**Description of Hardware Manager Tcl Objects and Commands**

You can use Tcl commands to interact with your hardware under test. The hardware is organized in a set of hierarchical first class Tcl objects (see Table 10-7).

<table>
<thead>
<tr>
<th>Tcl Object</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>hw_server</td>
<td>Object referring to hardware server. Each hw_server can have one or more hw_target objects associated with it.</td>
</tr>
<tr>
<td>hw_target</td>
<td>Object referring to JTAG cable or board. Each hw_target can have one or more hw_device objects associated with it.</td>
</tr>
<tr>
<td>hw_device</td>
<td>Object referring to a device in the JTAG chain, including Xilinx FPGA devices. Each hw_device can have one or more hw_ila objects associated with it.</td>
</tr>
<tr>
<td>hw_ila</td>
<td>Object referring to an ILA core in the Xilinx FPGA device. Each hw_ila object can have only one hw_ila_data object associated with it. Each hw_ila object can have one or more hw_probe objects associated with it.</td>
</tr>
<tr>
<td>hw_ila_data</td>
<td>Object referring to data uploaded from an ILA debug core.</td>
</tr>
</tbody>
</table>
Table 10-7: Hardware Manager Tcl Objects (Cont’d)

<table>
<thead>
<tr>
<th>Tcl Object</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>hw_probe</td>
<td>Object referring to the probe input of an ILA debug core.</td>
</tr>
<tr>
<td>hw_vio</td>
<td>Object referring to a VIO core in the Xilinx FPGA device.</td>
</tr>
</tbody>
</table>

For more information about the Hardware Manager commands, run the `help -category hardware` Tcl command in the Tcl Console.

Description of hw_server Tcl Commands

Table 10-8 contains descriptions of all Tcl commands used to interact with hardware servers.

Table 10-8: Descriptions of hw_server Tcl Commands

<table>
<thead>
<tr>
<th>Tcl Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>connect_hw_server</td>
<td>Open a connection to a hardware server.</td>
</tr>
<tr>
<td>current_hw_server</td>
<td>Get or set the current hardware server.</td>
</tr>
<tr>
<td>disconnect_hw_server</td>
<td>Close a connection to a hardware server.</td>
</tr>
<tr>
<td>get_hw_servers</td>
<td>Get list of hardware server names for the hardware servers.</td>
</tr>
<tr>
<td>refresh_hw_server</td>
<td>Refresh a connection to a hardware server.</td>
</tr>
</tbody>
</table>

Description of hw_target Tcl Commands

Table 10-9 contains descriptions of all Tcl commands used to interact with hardware targets.

Table 10-9: Descriptions of hw_target Tcl Commands

<table>
<thead>
<tr>
<th>Tcl Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>close_hw_target</td>
<td>Close a hardware target.</td>
</tr>
<tr>
<td>current_hw_target</td>
<td>Get or set the current hardware target.</td>
</tr>
<tr>
<td>get_hw_targets</td>
<td>Get list of hardware targets for the hardware servers.</td>
</tr>
<tr>
<td>open_hw_target</td>
<td>Open a connection to a hardware target on the hardware server.</td>
</tr>
<tr>
<td>refresh_hw_target</td>
<td>Refresh a connection to a hardware target.</td>
</tr>
</tbody>
</table>
Chapter 10: Debugging Logic Designs in Hardware

Description of hw_device Tcl Commands

Table 10-10 Descriptions of hw_device Tcl Commands contains descriptions of all Tcl commands used to interact with hardware devices.

<table>
<thead>
<tr>
<th>Tcl Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>current_hw_device</td>
<td>Get or set the current hardware device.</td>
</tr>
<tr>
<td>get_hw_devices</td>
<td>Get list of hardware devices for the target.</td>
</tr>
<tr>
<td>program_hw_device</td>
<td>Program Xilinx FPGA devices.</td>
</tr>
<tr>
<td>refresh_hw_device</td>
<td>Refresh a hardware device.</td>
</tr>
</tbody>
</table>

Description of hw_ila Tcl Commands

Table 10-11 Descriptions of hw_ila Tcl Commands contains descriptions of all Tcl commands used to interact with ILA debug cores.

<table>
<thead>
<tr>
<th>Tcl Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>current_hw_ila</td>
<td>Get or set the current hardware ILA.</td>
</tr>
<tr>
<td>get_hw_ilas</td>
<td>Get list of hardware ILAs for the target.</td>
</tr>
<tr>
<td>reset_hw_ila</td>
<td>Reset hw_ila control properties to default values.</td>
</tr>
<tr>
<td>run_hw_ila</td>
<td>Arm hw_ila triggers.</td>
</tr>
<tr>
<td>wait_on_hw_ila</td>
<td>Wait until all data has been captured.</td>
</tr>
</tbody>
</table>

Description of hw_ila_data Tcl Commands

Table 10-12 Descriptions of hw_ila_data Tcl Commands contains descriptions of all Tcl commands used to interact with captured ILA data.

<table>
<thead>
<tr>
<th>Tcl Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>current_hw_ila_data</td>
<td>Get or set the current hardware ILA data.</td>
</tr>
<tr>
<td>display_hw_ila_data</td>
<td>Display hw_ila_data in waveform viewer.</td>
</tr>
<tr>
<td>get_hw_ila_data</td>
<td>Get list of hw_ila_data objects.</td>
</tr>
<tr>
<td>list_hw_samples</td>
<td>Lists data samples associated with an individual hardware probe.</td>
</tr>
<tr>
<td>read_hw_ila_data</td>
<td>Read hw_ila_data from a file.</td>
</tr>
<tr>
<td>upload_hw_ila_data</td>
<td>Stop the ILA core from capturing data and upload any captured data.</td>
</tr>
<tr>
<td>write_hw_ila_data</td>
<td>Write hw_ila_data to a file.</td>
</tr>
</tbody>
</table>
Description of hw_probe Tcl Commands

Table 10-13 contains descriptions of all Tcl commands used to interact with captured ILA data.

Table 10-13: Descriptions of hw_probe Tcl Commands

<table>
<thead>
<tr>
<th>Tcl Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>create_hw_probes</td>
<td>Creates a new hardware probe from physical ILA probe ports and/or constant values.</td>
</tr>
<tr>
<td>delete_hw_probes</td>
<td>Deletes a user-defined hardware probe creating using the create_hw_probe command</td>
</tr>
<tr>
<td>get_hw_probes</td>
<td>Get list of hardware probes.</td>
</tr>
</tbody>
</table>

Description of hw_vio Tcl Commands

Table 10-14 contains descriptions of all Tcl commands used to interact with VIO cores.

Table 10-14: Descriptions of hw_vio Tcl Commands

<table>
<thead>
<tr>
<th>Tcl Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>commit_hw_vio</td>
<td>Write hw_probe OUTPUT_VALUE properties values to VIO cores.</td>
</tr>
<tr>
<td>get_hw_vios</td>
<td>Get a list of hw_vios</td>
</tr>
<tr>
<td>refresh_hw_vio</td>
<td>Update hw_probe INPUT_VALUE and ACTIVITY_VALUE properties with values read from VIO cores.</td>
</tr>
<tr>
<td>reset_hw_vio_activity</td>
<td>Reset VIO ACTIVITY_VALUE properties, for hw_probes associated with specified hw_vio objects.</td>
</tr>
<tr>
<td>reset_hw_vio_outputs</td>
<td>Reset VIO core outputs to initial values.</td>
</tr>
</tbody>
</table>
Chapter 10: Debugging Logic Designs in Hardware

Description of hw_axi and hw_axi_txn Tcl Commands

Table 10-15 contains descriptions of all Tcl commands used to interact with JTAG-to-AXI Master cores.

Table 10-15: Description of hw_axi and hw_axi_txn Tcl Commands

<table>
<thead>
<tr>
<th>Tcl Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>create_hw_axi_txn</td>
<td>Creates hardware AXI transaction object.</td>
</tr>
<tr>
<td>delete_hw_axi_txn</td>
<td>Deletes hardware AXI transaction objects.</td>
</tr>
<tr>
<td>get_hw_axi_txns</td>
<td>Gets a list of hardware AXI transaction objects.</td>
</tr>
<tr>
<td>get_hw_axis</td>
<td>Gets a list of hardware AXI objects.</td>
</tr>
<tr>
<td>refresh_hw_axi</td>
<td>Refreshes hardware AXI object status.</td>
</tr>
<tr>
<td>report_hw_axi_txn</td>
<td>Reports formatted hardware AXI transaction data.</td>
</tr>
<tr>
<td>reset_hw_axi</td>
<td>Resets hardware AXI core state.</td>
</tr>
<tr>
<td>run_hw_axi</td>
<td>Runs hardware AXI read/write transactions and update transaction status in the corresponding hw_axi object.</td>
</tr>
</tbody>
</table>

Description of hw_sysmon Tcl Commands

Table 10-16 contains descriptions of all Tcl commands used to interact with System Monitor core.

Table 10-16: Descriptions of hw_sysmon Tcl commands

<table>
<thead>
<tr>
<th>Tcl Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>commit_hw_sysmon</td>
<td>Commits the current property values defined on a hw_sysmon object to the System Monitor registers on the hardware device.</td>
</tr>
<tr>
<td>get_hw_sysmon_reg</td>
<td>Returns the hex value of the System Monitor register defined at the specified address of the specified hw_sysmon object.</td>
</tr>
<tr>
<td>get_hw_sysmons</td>
<td>Returns the list of Sysmon debug core objects defined on the current hardware device.</td>
</tr>
<tr>
<td>refresh_hw_sysmon</td>
<td>Refreshes the properties of the hw_sysmon object with the values on the System Monitor from the current hw_device.</td>
</tr>
<tr>
<td>set_hw_sysmon_reg</td>
<td>Sets the System Monitor register at the specified address to the hex value specified.</td>
</tr>
</tbody>
</table>

Note: Detailed help for each of these commands can be obtained by typing `<command name> -help` on the Vivado Tcl Console.
Using Tcl Commands to Interact with a JTAG-to-AXI Master Core

Below is an example Tcl command script that interacts with the following example system:

- One KC705 board's Digilent JTAG-SMT1 cable (serial number 12345) accessible via a Vivado hw_server running on localhost:3121.
- Single JTAG-to-AXI Master core in a design running in the XC7K325T device on the KC705 board.
- JTAG-to-AXI Master core is in an AXI-based system that has an AXI BRAM Controller Slave core in it.

Example Tcl Command Script

```
# Connect to the Digilent Cable on localhost:3121
connect_hw_server -url localhost:3121
current_hw_target [get_hw_targets */xilinx_tcf/Digilent/12345]
open_hw_target

# Program and Refresh the XC7K325T Device
current_hw_device [lindex [get_hw_devices] 0]
refresh_hw_device -update_hw_probes false [lindex [get_hw_devices] 0]
set_property PROGRAM.FILE {C:/design.bit} [lindex [get_hw_devices] 0]
set_property PROBES.FILE {C:/design.ltx} [lindex [get_hw_devices] 0]
program_hw_devices [lindex [get_hw_devices] 0]
refresh_hw_device [lindex [get_hw_devices] 0]

# Reset the JTAG-to-AXI Master core
reset_hw_axi [get_hw_axis hw_axi_1]

# Create a read transaction bursts 128 words starting from address 0
create_hw_axi_txn read_txn [get_hw_axis hw_axi_1] -type read
  -address 00000000 -len 128

# Create a write transaction bursts 128 words starting at address 0
# using a repeating fill value of 11111111_22222222_33333333_44444444 _22
# (where LSB is to the left)
create_hw_axi_txn write_txn [get_hw_axis hw_axi_1] -type write
  -address 00000000 -len 128 -data {11111111_22222222_33333333_44444444}

# Run the write transaction
run_hw_axi [get_hw_axi_txns write_txn]

# Run the read transaction
run_hw_axi [get_hw_axi_txns read_txn]
```
Using Tcl Commands to Take an ILA Measurement

Below is an example Tcl command script that interacts with the following example system:

- One KC705 board’s Digilent JTAG-SMT1 cable (serial number 12345) accessible via a Vivado CSE server running on localhost:3121.
- Single ILA core in a design running in the XC7K325T device on the KC705 board.
- ILA core has a probe called counter[3:0].

Example Tcl Command Script

```tcl
# Connect to the Digilent Cable on localhost:3121
connect_hw_server -url localhost:3121
current_hw_target [get_hw_targets */xilinx_tcf/Digilent/12345]
open_hw_target

# Program and Refresh the XC7K325T Device
current_hw_device [lindex [get_hw_devices] 0]
refresh_hw_device -update_hw_probes false [lindex [get_hw_devices] 0]
set_property PROGRAM.FILE {C:/design.bit} [lindex [get_hw_devices] 0]
set_property PROBES.FILE {C:/design.ltx} [lindex [get_hw_devices] 0]
program_hw_devices [lindex [get_hw_devices] 0]
refresh_hw_device [lindex [get_hw_devices] 0]

# Set Up ILA Core Trigger Position and Probe Compare Values
set_property CONTROL.TRIGGER_POSITION 512 [get_hw_ilas hw_ila_1]
set_property COMPARE_VALUE.0 eq4'b0000 [get_hw_probes counter]

# Arm the ILA trigger and wait for it to finish capturing data
run_hw_ila hw_ila_1
wait_on_hw_ila hw_ila_1

# Upload the captured ILA data, display it, and write it to a file
current_hw ila_data [upload_hw ila_data hw ila_1]
display_hw ila_data [current_hw ila_data]
write_hw ila_data my ila_data [current_hw ila_data]
```

Trigger At Startup

The Trigger at Startup feature is used to configure the trigger settings of an ILA core in a design .bit file so that it is pre-armed to trigger immediately after device startup. You do this by taking the various trigger settings that ordinarily get applied to an ILA core running in a design in hardware, and applying them to the ILA core in the implemented design.
Chapter 10: Debugging Logic Designs in Hardware

**IMPORTANT:** The following process for using Trigger at Startup assumes that you have a valid ILA design working in hardware, and that the ILA core has NOT been flattened during the synthesis flow.

To use the Trigger at Startup feature perform the following steps:

1. Run through the first pass of the ILA flow as usual to set up the trigger condition.
   a. Open the target, configure the device, and bring up the ILA Dashboard.
   b. Enter the trigger equations for the ILA core in the ILA Dashboard.

2. From the Vivado Tcl command line, export the trigger register map file for the ILA core. This file contains all of the register settings to "stamp" back on to the implemented netlist. The output from this is a single file.
   ```
   % run_hw_ila -file ila_trig.tas [get_hw_ilas hw_ila_1]
   ```

3. Go back and open the previously implemented routed design in Vivado IDE. There are two ways to do this depending on your project flow.
   a. Project Mode: Use the **Flow Navigator** to open the implemented design.
   b. Non-Project Mode: Open your routed checkpoint:
      ```
      %open_checkpoint <file>.dcp
      ```

4. At the Implemented Design Tcl Console, apply the trigger settings to the current design in memory, which is your routed netlist.
   ```
   %apply_hw_ila_trigger ila_trig.tas
   ```

   **Note:** If you see an ERROR indicating that the ILA core has been flattened during synthesis, you will need to regenerate your design and force synthesis to preserve hierarchy for the ILA core. Ensure that you have a valid ILA design working in hardware, and that the ILA core has NOT been flattened during the synthesis flow.

5. At the Implemented Design Tcl Console, write the bitstream with Trigger at Startup settings.
   ```
   IMPORTANT: To pick up the routed design changes do this at the Tcl command console only:
   write_bitstream trig_at_startup.bit
   ```

6. Go back to the **Hardware Manager** and reconfigure with the new .bit file that you generated in the previous step. You will have to set the property for the updated .bit file location either through the GUI or through a Tcl command. Make sure you set the new .bit file as the one to use for configuration in the hardware tool.
   a. Select the device in the hardware tree.
   b. Assign the .bit file generated in step 5.

7. Program the device using the new .bit file.
Once programmed, the new ILA core should immediately arm at startup. You should see an indication in the Trigger Capture Status for the ILA core. If trigger or capture events have occurred, the ILA core is now populated with captured data samples.

Memory Interface Generator (MIG)

Vivado Memory Interface Generator (MIG) includes debug support. The MIG IP stores useful core configuration, calibration, and data window information within an internal BRAM. The MIG Debug interface can be used at any point to read out this information and get valuable statistics and feedback from the MIG IP. The information can be viewed through a MIG Debug GUI in the Vivado Hardware Manager or through available MIG Debug Tcl commands.

MIG Debug GUI Usage

Upon configuring the device, the MIG debug core and contents are visible in the Vivado Hardware Manager.

MIG designs include a debug interface that can be used to very quickly identify calibration status, and read and write window margin. This debug interface is always included in the generated MIG (UltraScale® and 7 Series) designs.

MIG Debug Tcl Usage

Use the following Tcl commands in the Vivado Tcl Console when connected to the hardware in Vivado Hardware Manager to output all debug MIG content that is displayed in the Vivado IDE.
• **get_hw_migs**
  - Displays what MIG cores exist in the design.

• **refresh_hw_mig [lindex [get_hw_migs] 0]**
  - Refreshes only the MIG core denoted by index (index begins with 0).

• **report_property[lindex [get_hw_migs] 0]**
  - Reports all of the parameters available for the MIG core.
  - Where 0 is the index of the MIG core to be reported (index begins with 0).

For more specific details see the UltraScale or 7 Series MIG debug commands in the following answer records:

• Xilinx Answer 43879, *MIG 7 Series DDR3/DDR2 - Hardware Debug Guide.*
• Xilinx Answer 60305, *MIG UltraScale DDR4/DDR3 - Hardware Debug Guide.*
Chapter 11

Viewing ILA Probe Data in the Waveform Viewer

Introduction

The ILA waveform viewer in the Vivado® Integrated Design Environment (IDE) provides a powerful way to analyze data captured from the ILA Debug Core. After successfully triggering an ILA core and capturing data, Vivado automatically populates a corresponding waveform viewer with data collected from the ILA core. When using Vivado in project mode, configurable waveform settings such as coloring, radix selection, and signal ordering persist and are conveniently remembered between Vivado sessions.

ILA Data and Waveform Relationship

It is useful to understand the relationship between the hw_ila_data captured ILA data object and the waveform, as shown in Figure 11-1.

![Figure 11-1: ILA Data and Waveform Relationship](image)

The `hw_ila` Tcl object represents the ILA core in hardware. Every time an ILA core uploads captured data, it is stored in memory in a corresponding Tcl `hw_ila_data` object. These objects are named predictably so the first ILA core in hardware 'hw_ila_1' produces data in a corresponding Tcl data object named 'hw_ila_data_1' after trigger and upload. When working online with hardware, every waveform is backed by the in-memory `hw_ila_data` object and has a 1:1 correspondence with this object illustrated by the diagram in Figure 11-1. For each Tcl `hw_ila_data` object, a wave database (WDB) file and
wave configuration (WCFG) file are created and automatically tracked in a directory of the Vivado project. Figure 11-1 illustrates the flow of data from the hardware hw_ila on the left through to the waveform display on the right.

The combination of the wave configuration, WCFG, file and wave transition database, WDB, file contain the waveform database and customizations displayed in the Vivado waveform user interface. These waveform files are automatically managed in the Vivado ILA flow and users are not expected to modify the WDB or WCFG files directly. The wave configuration can be modified by changing objects in the waveform viewer (such as signal color, bus radix, signal order, markers, etc) then clicking the **Save** button. This automatically saves the wave configuration changes to the appropriate WCFG file in the Vivado project.

It is possible to archive waveform configurations and data for later viewing by using the Tcl command `write_hw ila_data`. This stores the hw ila_data, wave database and wave configuration in an archive for later viewing offline. See the section, **Saving and Restoring Captured Data from the ILA Core** for details on using `read_hw ila_data` and `write_hw ila_data` for offline storage and retrieval of waveforms.

### Waveform Viewer Layout

The ILA waveform viewer (sometimes referred to as waveform configuration) is composed of several dynamic objects working together to provide a complete visualization tool for the captured ILA data, as shown in Figure 11-2.
The description for the labeled objects in Figure 11-2 is as follows:

1. Net or Bus Name from the ILA probes file (.ltx)
2. Net or Bus Value at the cursor
3. Trigger Markers (red lines)
4. Cursor (yellow line)
5. Markers (blue line)
6. ILA capture window transitions (alternating clear/grey regions)
7. Floating measurement ruler (yellow bar)

**Waveform Viewer Operation**

The scalars and buses shown in the **Name** column of the wave viewer represent the names of the probe design objects in the waveform (see Figure 11-3). These correspond to the hardware probes of the ILA core (see the `get_hw_probes` Tcl command).

Immediately after triggering and uploading ILA data for the first time, the waveform viewer populates with all probes connected to the ILA core. It is possible to customize probes in
the viewer in addition to removing existing probes or adding new probes to the viewer. This section covers the basic operation of the waveform viewer.

Removing Probes from the Waveform

All probes by default are added to the waveform during the first trigger and upload operation. If you do not want the waveform to contain all probes, it is simple to remove probes from the viewer.

To remove a probe from the waveform viewer, right-click the scalar or bus to delete in the Name column and select Delete from the pop up menu. Alternatively, select the signal or bus to delete and press the Delete key. Probe transition data is not actually deleted from memory it is just hidden from view when probes are removed.

Adding Probes to the Waveform

To add probes to the waveform, select the Probes to add for the associated ILA core in the Debug Probes window, right-click, and select Add Probes to Waveform from the pop-up menu.

To add another copy of a signal or bus to the Waveform window, select the signal or bus in the Waveform window. Then select Edit > Copy or type Ctrl+C. This copies the object to the clipboard. Select Edit > Paste or type Ctrl+V to paste a copy of the object in the waveform.
Using Waveform ILA Trigger and Export Features

Enable Auto Re-Trigger: Select the Enable Auto Re-Trigger button on the Waveform window toolbar to enable Vivado IDE to automatically re-arm the ILA core associated with the Waveform window trigger after a successful trigger+upload+display operation has completed.

The captured data displayed in the Waveform window corresponding to the ILA core is overwritten upon each successful trigger event. The Auto Re-Trigger option can be used with the Run Trigger and Run Trigger Immediate operations. Click the Stop Trigger button to stop the trigger currently in progress.

Run Trigger: Arms the ILA core associated with the Waveform window to detect the trigger event that is defined by the ILA core basic or advanced trigger settings.

Run Trigger Immediate: Arms the ILA core associated with the Waveform window to trigger immediately regardless of the ILA core trigger settings. This command is useful for detecting the “aliveness” of the design by capturing any activity at the probe inputs of the ILA core.

Stop Trigger: Stops the ILA core trigger of the ILA associated with the Waveform window.
Chapter 11: Viewing ILA Probe Data in the Waveform Viewer

**Export ILA Data:** Captures data from an ILA core and saves it to a file. The data can be captured in either native, .csv, or .vcd format. On clicking this icon on the Waveform window toolbar the following dialog box appears.

![Export ILA Data Dialog](Image)

*Figure 11-5: Export ILA Data Dialog*

The ILA core is the name of the ILA debug core to export data for. The format is a selection among Native, CSV, and VCD formats.

- **Native format** configures the `write_hw_ila_data` command to export the ILA data in the form of a default ILA file format file that can be used to import into Vivado and back again at another point in time so that you can view previously captured ILA data.
- **CSV format** configures the `write_hw_ila_data` command to export the ILA data in the form of a .csv file that can be used to import the data into a spreadsheet or third-party application.
- **VCD file format** configures the `write_hw_ila_data` command to export the ILA data in the form of a .vcd file that can be used to import into a third-party application or viewer.

**IMPORTANT:** While ILA data can be exported in the CSV, VCD, and native ILA format, only the native ILA format can be imported into Vivado. Also, native ILA data imported into Vivado is supported only for offline viewing of previously captured data. The probe signals cannot be used for other purposes such as triggering, etc.

**Using the Zoom Features**

Toolbar buttons provide quick access to waveform zooming features (see Figure 11-6). Alternatively, use the mouse wheel combined with the CTRL key to zoom in and out of the
currently selected waveform. It is important to note the zoom level is not persistent and will be reset between Vivado sessions.

![Waveform Zoom Buttons](image)

*Figure 11-6: Waveform Zoom Buttons*

**Waveform Options Dialog Box**

The waveform viewer allows you to customize the way objects are displayed.

When you select the **Waveforms Options** button the **Waveform Options** dialog box in *Figure 11-7* opens:

![Waveform Options Dialog Box](image)

*Figure 11-7: Waveform Options Dialog Box*

The options are as follows:

- **Colors Tab**: Lets you choose custom colors for waveform objects
• **Default Radix**: Sets the default radix for bus probes

• **Draw Waveform Shadow**: Displays a light green shadow under scalar '1' to help differentiate between '1' and '0'

• **Show signal indices**: Display index position number to the left side of scalar and bus names

• **Show trigger markers**: Show (or hide) the red trigger markers in the wave viewer

---

### Customizing the Configuration

You can customize the Waveform configuration using the features that are listed and briefly described in Table 11-1; the feature name links to the subsection that fully describes the feature.

**Table 11-1:** Customization Features in the Waveform Configuration

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cursors</strong></td>
<td>The main cursor and secondary cursor in the Waveform window let you display and measure time, and they form the focal point for various navigation activities.</td>
</tr>
<tr>
<td><strong>Markers</strong></td>
<td>You can add markers to navigate through the waveform, and to display the waveform value at a particular time.</td>
</tr>
<tr>
<td><strong>Dividers</strong></td>
<td>You can add a divider to create a visual separator of signals.</td>
</tr>
<tr>
<td><strong>Using Groups</strong></td>
<td>You can add a group, that is a collection to which signals and buses can be added in the wave configuration as a means of organizing a set of related signals.</td>
</tr>
<tr>
<td><strong>Using Virtual Buses</strong></td>
<td>You can add a virtual bus to your wave configuration, to which you can add logic scalars and arrays.</td>
</tr>
<tr>
<td><strong>Renaming Objects</strong></td>
<td>You can rename objects, signals, buses, and groups.</td>
</tr>
<tr>
<td><strong>Radixes</strong></td>
<td>The default radix controls the bus radix that displays in the wave configuration, Objects panel, and the Console panel.</td>
</tr>
<tr>
<td><strong>Bus Bit Order</strong></td>
<td>You can change the Bus bit order from Most Significant Bit (MSB) to Least Significant Bit (LSB) and vice versa.</td>
</tr>
</tbody>
</table>

### Cursors

Cursors are used primarily for temporary indicators of sample position and are expected to be moved frequently, as in the case when you are measuring the distance (in samples) between two waveform edges.

**TIP:** For more permanent indicators, used in situations such as establishing a time-base for multiple measurements, add markers to the Wave window instead. See **Markers** for more information.
You can place the main cursor with a single click in the Waveform window.

To place a secondary cursor, Ctrl+Click and hold the waveform, and drag either left or right. You can see a flag that labels the location at the top of the cursor.

Alternatively, you can hold the SHIFT key and click a point in the waveform. The main cursor remains the original position, and the other cursor is at the point in the waveform that you clicked.

**Note:** To preserve the location of the secondary cursor while positioning the main cursor, hold the Shift key while clicking. When placing the secondary cursor by dragging, you must drag a minimum distance before the secondary cursor appears.

To move a cursor, hover over the cursor until you see the grab symbol, and click and drag the cursor to the new location.

As you drag the cursor in the Waveform window, you see a hollow or filled-in circle if the Snap to Transition button is selected, which is the default behavior.

- A hollow circle ○ indicates that you are between transitions in the waveform of the selected signal.
- A filled-in circle ● indicates that you are hovering over the waveform transition of the selected signal. A secondary cursor can be hidden by clicking anywhere in the Waveform window where there is no cursor, marker, or floating ruler.

**Markers**

Use a marker when you want to mark a significant event within your waveform in a permanent fashion. Markers allow you to measure distance (in samples) relevant to that marked event.

You can add, move, and delete markers as follows:

- You add markers to the wave configuration at the location of the main cursor.
  
  a. Place the main cursor at the sample number where you want to add the marker by clicking in the Waveform window at the sample number or on the transition.
  
  b. Select Edit > Markers > Add Marker, or click the Add Marker button. A marker is placed at the cursor, or slightly offset if a marker already exists at the location of the cursor. The sample number of the marker displays at the top of the line.

- You can move the marker to another location in the waveform using the drag and drop method. Click the marker label (at the top of the marker) and drag it to the location.
  
  - The drag symbol ✂️ indicates that the marker can be moved. As you drag the marker in the Waveform window, you see a hollow or filled-in circle if the Snap to Transition button is selected, which is the default behavior.
Chapter 11: Viewing ILA Probe Data in the Waveform Viewer

- A filled-in circle ⬤ indicates that you are hovering over a transition of the waveform for the selected signal or over another marker.
- For markers, the filled-in circle is white.
- A hollow circle ◯ indicates that you are between transitions in the waveform of the selected signal.
- Release the mouse key to drop the marker to the new location.
- You can delete one or all markers with one command. Right-click over a marker, and do one of the following:
  - Select **Delete Marker** from the popup menu to delete a single marker.
  - Select **Delete All Markers** from the popup menu to delete all markers.
    
    **Note:** You can also use the Delete key to delete a selected marker.
  - Use **Edit > Undo** to reverse a marker deletion.

**Trigger Markers**

The red trigger marker (whose label is a red letter ‘T’) a special marker that indicates the occurrence of the trigger event in the capture buffer. The position of the trigger marker in the buffer directly corresponds to the Trigger Position setting (see Using the ILA Default Dashboard).

**Note:** The trigger markers are not movable using the same technique as regular markers. Set their position using the ILA core’s Trigger Position property setting.

**Dividers**

Dividers create a visual separator between signals. You can add a divider to your wave configuration to create a visual separator of signals, as follows:

1. In a **Name** column of the **Waveform** window, click a signal to add a divider below that signal.
2. From the popup menu, select **Edit > New Divider**, or right-click and select **New Divider**.

The change is visual and nothing is added to the HDL code. The new divider is saved with the wave configuration file when you save the file.

You can move or delete Dividers as follows:

- Move a Divider to another location in the waveform by dragging and dropping the divider name.
- To delete a Divider, highlight the divider, and click the **Delete** key, or right-click and select **Delete** from the popup menu.

You can also rename Dividers; see Renaming Objects.
Using Groups

A Group is a collection of expandable and collapsible categories, to which you can add signals and buses in the wave configuration to organize related sets of signals. The group itself displays no waveform data but can be expanded to show its contents or collapsed to hide them. You can add, change, and remove groups.

To add a Group:

1. In a wave configuration, select one or more signals or buses to add to a group.
   
   **Note:** A group can include dividers, virtual buses, and other groups.

2. Select Edit > New Group, or right-click and select New Group from the popup menu.

A Group that contains the selected signal or bus is added to the wave configuration.

A Group is represented with the Group button.

The change is visual and nothing is added to the ILA core.

You can move other signals or buses to the group by dragging and dropping the signal or bus name.

You can move or remove Groups as follows:

• Move Groups to another location in the Name column by dragging and dropping the group name.

• Remove a group, by highlighting it and selecting Edit > Wave Objects > Ungroup, or right-click and select Ungroup from the popup menu. Signals or buses formerly in the group are placed at the top-level hierarchy in the wave configuration.

Groups can be renamed also; see Renaming Objects.

---

**CAUTION!** The Delete key removes the group and its nested signals and buses from the wave configuration.

---

Using Virtual Buses

You can add a virtual bus to your wave configuration, which is a grouping to which you can add logic scalars and arrays. The virtual bus displays a bus waveform, which shows the signal waveforms in the vertical order that they appear under the virtual bus, flattened to a one-dimensional array. You can then change or remove virtual buses after adding them.
Chapter 11: Viewing ILA Probe Data in the Waveform Viewer

To add a virtual bus:

1. In a wave configuration, select one or more signals or buses you want to add to a virtual bus.
2. Select Edit > New Virtual Bus, or right-click and select New Virtual Bus from the popup menu.

   The virtual bus is represented with the Virtual Bus button.

   The change is visual and nothing is added to the HDL code.

You can move other signals or buses to the virtual bus by dragging and dropping the signal or bus name. The new virtual bus and its nested signals or buses are saved when you save the wave configuration file. You can also move it to another location in the waveform by dragging and dropping the virtual bus name.

You can rename a virtual bus; see Renaming Objects.

To remove a virtual bus, and ungroup its contents, highlight the virtual bus, and select Edit > Wave Objects > Ungroup, or right-click and select Ungroup from the popup menu.

**CAUTION!** The Delete key removes the virtual bus and its nested signals and buses from the wave configuration.

---

### Renaming Objects

You can rename any object in the Waveform window, such as signals, dividers, groups, and virtual buses.

1. Select the object name in the Name column.
2. Select Rename from the popup menu.
3. Replace the name with a new one.
4. Press Enter or click outside the name to make the name change take effect.

You can also double-click the object name and then type a new name. The change is effective immediately. Object name changes in the wave configuration do not affect the names of the nets attached to the ILA core probe inputs.

### Radixes

Understanding the type of data on your bus is important. You need to recognize the relationship between the radix setting and the data type to use the waveform options of
Chapter 11: Viewing ILA Probe Data in the Waveform Viewer

Digital and Analog effectively. See Bus Radixes for more information about the radix setting and its effect on Analog waveform analysis.

You can change the radix of an individual signal (ILA probe) in the Waveform window as follows:

1. Right-click a bus in the Waveform window.
2. Select Radix and the format you want from the drop-down menu:
   - Binary
   - Hexadecimal
   - Unsigned Decimal
   - Signed Decimal
   - Octal

**IMPORTANT:** Changes to the radix of an item in the Objects window do not apply to values in the Waveform window or the Tcl Console. To change the radix of an individual signal (ILA probe) in the Waveform window, use the Waveform window popup menu.

- Maximum bus width of 64 bits on real. Incorrect values are possible for buses wider than 64 bits.
- Floating point supports only 32- and 64-bit arrays.

**Using the Floating Ruler**

The floating ruler assists with sample measurements using a sample number base other than the absolute sample numbers shown on the standard ruler at the top of the Waveform window.

You can display (or hide) a floating ruler and move it to a location in the Waveform window. The sample base (sample 0) of the floating ruler is the secondary cursor, or, if there is no secondary cursor, the selected marker.

The floating ruler button and the floating ruler itself are visible only when the secondary cursor (or selected marker) is present.

1. Do either of the following to display or hide a floating ruler:
   - Place the secondary cursor.
   - Select a marker.
2. Select View > Floating Ruler, or click the Floating Ruler button.

   You only need to follow this procedure the first time. The floating ruler displays each time the secondary cursor is placed or a marker is selected.

   Select the command again to hide the floating ruler.
Chapter 11: Viewing ILA Probe Data in the Waveform Viewer

### Bus Bit Order

You can reverse the bus bit order in the wave configuration to switch between MSB-first and LSB-first signal representation.

To reverse the bit order:

1. Select a bus.
2. Right-click and select **Reverse Bit Order**.

The bus bit order is reversed. The **Reverse Bit Order** command is marked to show that this is the current behavior.

---

### Bus Radixes

Bus values are interpreted as numeric values, which are determined by the radix setting on the bus wave object, as follows:

- Binary, octal, hexadecimal, ASCII, and unsigned decimal radices cause the bus values to be interpreted as unsigned integers. The format of data on the bus must match the radix setting.
- Any non-0 or -1 bits cause the entire value to be interpreted as 0.
- The signed decimal radix causes the bus values to be interpreted as signed integers.
- Real radices cause bus values to be interpreted as fixed point or floating point real numbers, as determined by the settings of the **Real Settings** dialog box, shown in Figure 11-8.
The options are as follows:

- **Fixed Point**: Specifies that the bits of the selected bus wave objects is interpreted as a fixed point, signed, or unsigned real number.

- **Binary Point**: Specifies how many bits to interpret as being to the right of the binary point. If **Binary Point** is larger than the bit width of the wave object, wave object values cannot be interpreted as fixed point, and when the wave object is shown in Digital waveform style, all values show as <Bad Radix>. When shown as analog, all values are interpreted as 0.

- **Floating Point**: Specifies that the bits of the selected bus wave objects should be interpreted as an IEEE floating point real number.

  **Note**: Only single precision and double precision (and custom precision with values set to those of single and double precision) are supported.

  Other values result in <Bad Radix> values as in **Fixed Point**. **Exponent Width** and **Fraction Width** must add up to the bit width of the wave object, or else <Bad Radix> values result.
Viewing Analog Waveforms

To convert a digital waveform to analog, do the following:

1. In the Name area of a Waveform window, right-click the bus.
2. Select Waveform Style and then Analog Settings to choose an appropriate drawing setting.

The digital drawing of the bus converts to an analog format.

You can adjust the height of either an analog waveform or a digital waveform by selecting and then dragging the rows.

Figure 11-9 shows the Analog Settings dialog box with the settings for analog waveform drawing.

![Figure 11-9: Analog Settings Dialog Box](https://www.xilinx.com)

The Analog Settings dialog box options are as follows:

- **Row Height**: Specifies how tall to make the select wave objects, in pixels. Changing the row height does not change how much of a waveform is exposed or hidden vertically, but rather stretches or contracts the height of the waveform.
Chapter 11: Viewing ILA Probe Data in the Waveform Viewer

When switching between Analog and Digital waveform styles, the row height is set to an appropriate default for the style (20 for digital, 100 for analog).

- **Y Range**: Specifies the range of numeric values to be shown in the waveform area.
  - **Auto**: Specifies that the range should continually expand whenever values in the visible time range of the window are discovered to lie outside the current range.
  - **Fixed**: Specifies that the time range is to remain at a constant interval.
  - **Min**: Specifies the value displays at the bottom of the waveform area.
  - **Max**: Specifies the value displays at the top.

  Both values can be specified as floating point; however, if radix of the wave object radix is integral, the values are truncated to integers.

- **Interpolation Style**: Specifies how the line connecting data points is to be drawn.
  - **Linear**: Specifies a straight line between two data points.
  - **Hold**: Specifies that of two data points, a horizontal line is drawn from the left point to the X-coordinate of the right point, then another line is drawn connecting that line to the right data point, in an L shape.
  - **Off Scale**: Specifies how to draw waveform values that lie outside the Y range of the waveform area.
    - **Hide**: Specifies that outlying values are not shown, such that a waveform that reaches the upper or lower bound of the waveform area disappears until values are again within the range.
    - **Clip**: Specifies that outlying values be altered so that they are at the top or bottom of the waveform area, such that a waveform that reaches the upper- or lower-bound of the waveform area follows the bound as a horizontal line until values are again within the range.
    - **Overlap**: Specifies that the waveform be drawn wherever its values are, even if they lie outside the bounds of the waveform area and overlap other waveforms, up to the limits of the wave window itself.

- **Horizontal Line**: Specifies whether to draw a horizontal rule at the given value. If the check-box is on, a horizontal grid line is drawn at the vertical position of the specified Y value, if that value is within the Y range of the waveform.

  As with Min and Max, the Y value accepts a floating point number but truncates it to an integer if the radix of the selected wave objects is integral.

---

**IMPORTANT:** Analog settings are saved in a wave configuration; however, because control of zooming in the Y dimension is highly interactive, unlike other wave object properties such as radix, they do not affect the modification state of the wave configuration. Consequently, zoom settings are not saved with the wave configuration.
Zoom Gestures

In addition to the zoom gestures supported for zooming in the X dimension, when over an analog waveform, additional zoom gestures are available, as shown in Figure 11-10.

To invoke a zoom gesture, hold down the left mouse button and drag in the direction indicated in the diagram, where the starting mouse position is the center of the diagram.

The additional Zoom gestures are as follows:

- **Zoom Out Y**: Zooms out in the Y dimension by a power of 2 determined by how far away the mouse button is released from the starting point. The zoom is performed such that the Y value of the starting mouse position remains stationary.

- **Zoom Y Range**: Draws a vertical curtain which specifies the Y range to display when the mouse is released.

- **Zoom In Y**: Zooms in toward the Y dimension by a power of 2 determined by how far away the mouse button is released from the starting point.

  The zoom is performed such that the Y value of the starting mouse position remains stationary.

- **Reset Zoom Y**: Resets the Y range to that of the values currently displayed in the wave window and sets the Y Range mode to **Auto**.

All zoom gestures in the Y dimension set the Y Range analog settings. **Reset Zoom Y** sets the Y Range to **Auto**, whereas the other gestures set Y Range to **Fixed**.

*Figure 11-10: Analog Zoom Options*
Chapter 12

Debugging Designs Post Implementation

You might want to modify, add, or delete your debug cores post implementation. There are two ways to do it in Vivado Design Suite.

If you want to replace the existing connections to the ILA cores, Xilinx recommends that you use the ECO flow. The ECO flow operates on an implemented checkpoint (DCP) and could save you time that could otherwise be spent in a complete re-route of the design.

If you want to add new ILA cores, delete existing ILA cores, or modify existing ILA cores (e.g., resizing probe width, changing the data depth etc.), Xilinx recommends that you use the Incremental Compile flow. The Incremental flow for debug cores operates on a synthesized design or checkpoint (DCP) and uses a reference implemented checkpoint (ideally from a previous run of implementation). This could save you time that could otherwise be spent in a complete re-implementation of the design.

The sections below discuss each of these debug related flows in detail.

Using Vivado ECO Flow to replace existing Debug Probes

It is possible to replace debug nets connected to an ILA core in a placed and routed design checkpoint. You can do this by using the Engineering Change Order (ECO) flow. This is an advanced design flow used for designs that are nearing completion, where you need to swap nets connected to an ILA probe port. This method serves two purposes:

- **It saves you time.** This feature lets you swap existing debug nets that are being probed for different nets.
- **It is minimally invasive.** After replacing probed nets, it is necessary to route those nets to the inputs of the debug core. The rest of the design remains intact, thereby not only preserving previous implementation results, but also reducing the possibility that a re-implementation will hide the bug you are trying to find.

**IMPORTANT:** This flow is only applicable to designs where ILA cores have already been instantiated or inserted.
Figure 12-1 shows the process of replacing debug nets using the ECO design flow.

Replacing Debug Probes on a Placed and Routed Design Checkpoint

When using the Vivado® Hardware Manager to debug a design that has been programmed on a device, the nets being probed for debug sometimes need to be swapped for other alternative nets. Instead of going back and changing your RTL code, or changing the nets being probed in the inserted debug cores, you can use the ECO flow to replace the debug nets.
To use the ECO flow, open the placed and routed design checkpoint (DCP), in the Vivado IDE, and change the layout to ECO.

Figure 12-2: Selecting the ECO Layout
The **Flow Navigator** window now changes to **ECO Navigator** with a different set of options.

*Figure 12-3: ECO Navigator*
In the **ECO Navigator**, click **Replace Debug Probes** to bring up the **Replace Debug Probes** dialog box.

![Replace Debug Probe Dialog Box](image)

**Figure 12-4:** Replace Debug Probe Dialog Box

In the **Replace Debug Probes** dialog box, highlight the probes whose nets you want to change, and click the **Edit Probes** button. Use the **Edit Probes** button to the right of each
probe to change individual nets. Alternatively, you can use the **Edit Probes** button on the left edge of the window to change the nets for multiple probes.

![Edit Probes Button](image.png)

*Figure 12-5: Edit Probes Button*
Click the **Edit Probes** button to bring up the **Choose Nets** dialog box, where you can choose nets to replace the existing ones.

![Choose Nets Dialog Box](Figure 12-6)

**IMPORTANT:** Once you have completed replacing all the debug probes necessary, rerouted them, and regenerated the bitstream, you must regenerate the debug probes file (*.ltx).

**TIP:** You can also choose multiple nets or a bus by clicking on the **Edit Probes** button on the left in the **Replace Debug Probes** dialog box.

After you replace all the desired nets on the debug cores, click **OK** to bring up a confirmation dialog box to confirm the changes about to be made.
Chapter 12: Debugging Designs Post Implementation

IMPORTANT: Check the Tcl Console to ensure that there are noWarnings/Errors.

Deleting any net segment on the path of a net being probed could have an impact on the probe names displayed in the Hardware Manager. Vivado IDE picks the net segment closest to the net being probed with a MARK_DEBUG attribute on it. If there is no net segment with a MARK_DEBUG attribute, then the top level net is picked. If there is more than one net segment with a MARK_DEBUG attribute, the tool randomly selects one of those nets.

After you have replaced all the debug probe ports, you can perform an incremental route of the modifications made to the design by routing the specific nets impacted. You can save your modifications to a new checkpoint using the “Save Checkpoint As” option in the ECO Navigator. The Replace Debug Probes command in the ECO Navigator needs to be run to generate a new *.ltxt file for the debug probes. You should then generate a new bit file to program the device. You can then connect to the Vivado Hardware Manager to debug the design with the new changes.

Incremental Compile with Debug Core (ILA) Modifications

Incremental Compile is an advanced design flow for designs that are nearing completion, where small changes are required. After resynthesizing these small changes, the flow:

- Speeds up place and route run time.
- Preserves QoR predictability by reusing prior placement and routing from a reference design. The flow is most effective when synthesis changes result in at least 95 percent similarity to the reference design.

Incremental Debug changes are applied to a placed and routed design by re-implementing the design using the Incremental Compile design flow. This flow is recommended in situations where:

- The debug cores are absent from the existing implemented design or,
- You need to modify existing debug cores by changing probe widths, data depth, etc. or,
- You need to delete debug cores from the design.
Incremental Compile Flow Designs

The Incremental Compile flow involves two different designs, the reference design and the current design with debug core modifications.

Reference Design

The reference design is usually an earlier iteration or variation of the current design that has been synthesized, placed, and routed. However, you can use a checkpoint that has any amount of placement, routing, or both. The reference design checkpoint (DCP) might be the product of many design iterations involving code changes, floorplanning, and revised constraints necessary to close timing. After the current design is loaded, load the reference design checkpoint using the `read_checkpoint -incremental <dcp>` command. Loading the reference design checkpoint with the `-incremental` option enables the Incremental Compile design flow for subsequent place and route operations.

Current Design

The current design incorporates small debug related design changes or variations from the reference design. These changes or variations can include:

- Debug core RTL instantiation changes
- Debug core insertion changes
- Both debug core related RTL changes and insertion changes

To insert, delete, or modify debug cores to an existing design that has been implemented, open the synthesized DCP or design, and use the debug insertion flow. Details on the debug insertion flow can be found in Using the Netlist Insertion Debug Probing Flow in Chapter 9.

You can also modify existing debug cores or instantiate new debug cores into your existing RTL design. The Incremental Compile flow reuses placement and routing from the reference design along with the new debug related modifications. Details on the debug instantiation flow can be found in HDL Instantiation Debug Probing Flow Overview in Chapter 9.

Using Incremental Compile

In both Project Mode and Non-Project Mode, incremental place and route mode is entered when you load the reference design checkpoint using the `read_checkpoint -incremental <reference_dcp_file>` command where `<reference_dcp_file>` specifies the path and file name of the reference design checkpoint. Loading the reference design checkpoint with the `-incremental` option enables the Incremental Compile design flow for subsequent place and route operations. In Non-Project Mode, `read_checkpoint -incremental should:: (1) follow opt_design and; (2) precede
place_design. If using the debug insertion flow the debug core related XDC commands should precede opt_design.

Using Incremental Compile in Non-Project Mode

To specify a design checkpoint file (DCP) to use as the reference design, and to run incremental place in Non-Project Mode:

1. Load the current design.
2. Run debug core commands.
3. Run opt_design.
5. Run place_design.
6. Run phys_opt_design (optional).
7. Run phys_opt_design if it was used in the reference design.
8. Run route_design.

```plaintext
# to load the current design
link_design;

#Create the debug core
create_debug_core u_ila_0 ila
#set debug core properties
set_property C_DATA_DEPTH 1024 [get_debug_cores u_ila_0]
set_property C_TRIGIN_EN false [get_debug_cores u_ila_0]
set_property C_TRIGOUT_EN false [get_debug_cores u_ila_0]
set_property C_ADV_TRIGGER false [get_debug_cores u_ila_0]
set_property C_INPUT_PIPE_STAGES 0 [get_debug_cores u_ila_0]
set_property C_EN_STRG_QUAL false [get_debug_cores u_ila_0]
set_property ALL_PROBE_SAME_MU true [get_debug_cores u_ila_0]
set_property ALL_PROBE_SAME_MU_CNT 1 [get_debug_cores u_ila_0]
set_property port_width 1 [get_debug_ports u_ila_0/clk]
connect_debug_port u_ila_0/clk [get_nets [list clk ]]
set_property port_width 1 [get_debug_ports u_ila_0/probe0]
connect_debug_port u_ila_0/probe0 [get_nets [list A_or_B]]
create_debug_port u_ila_0 probe

opt_design
read_checkpoint -incremental <reference_dcp_file>
place_design
phys_opt_design; #if used in reference design
route_design
```

**IMPORTANT:** You must open the synthesized checkpoint to modify the debug cores in the design. Insertion of debug cores by opening a post-routed checkpoint is not supported.
Using Incremental Compile in Project Mode

In Project Mode, you can set the incremental compile option in the Design Runs window.

To set the incremental compile option:

1. Select a run in the Design Runs window.
2. Click Set Incremental Compile from the context menu.
3. In the Set Incremental Compile window, select a reference design checkpoint. This enables incremental compile mode for the run.
4. Open the Synthesized netlist and optionally modify/add the debug cores instantiated in the RTL.
5. Use the SetUp Debug wizard to insert/delete/modify debug cores inserted into the design.
6. Implement Design.

**IMPORTANT:** You must open the synthesized design to modify the debug cores in the design. Insertion of debug cores by opening a post-routed design is not supported.

For more information on the Incremental Compile feature, see this link in the Vivado Design Suite User Guide: Implementation (UG904) [Ref 4].
In System Serial I/O Debugging Flows

Introduction

The Vivado® IDE provides a quick and easy way to generate a design that helps you debug and verify your system that uses Xilinx high-speed gigabit transceiver (GT) technology. The in-system serial I/O debugging flow has three distinct phases:

1. IBERT Core generation phase: Customizing and generating the IBERT core that best meets your hardware high-speed serial I/O requirements.
2. IBERT Example Design Generation and Implementation phase: Generating the example design for the IBERT core generated in the previous step.
3. Serial I/O Analysis phase: Interacting with the IBERT IP contained in the design to debug and verify issues in your high-speed serial I/O links.

The rest of this chapter shows how to complete the first two phases. The third phase is covered in the chapter Chapter 14, Debugging the Serial I/O Design in Hardware.

Generating an IBERT Core using the Vivado IP Catalog

The first phase of getting a suitable hardware design to help debug and validate your system’s high-speed serial I/O interfaces is to generate the IBERT core. The following steps outline how to do this:

1. Open the Vivado IDE
2. On the first panel, choose Manage IP > New IP Location, then click Next when the Open IP Catalog wizard opens.
3. Select the desired part, target language, target simulator, and IP location. Click Finish.
4. In the IP Catalog under Debug and Verification > Debug, you will find one or more available IBERT cores as shown in Figure 13-1, depending on the device selected in the previous step.
5. Double-click the IBERT architecture desire to open the Customize IP Wizard for that core.
Customize the IBERT core for your given hardware system requirements. For details on the various IBERT cores available, see the following IP Documents: LogiCORE IP IBERT for 7 Series GTX Transceivers, (PG132) [Ref 17], LogiCORE IP IBERT for 7 Series GTP Transceivers, (PG133) [Ref 18], LogiCORE IP IBERT for 7 Series GTH Transceivers, (PG152) [Ref 19].

Generating and Implementing the IBERT Example Design

After generating the IBERT IP core, it appears in the Sources window as "ibert_7series_gtx" or something similar. To generate the example design, right-click the IBERT IP in the Sources window and select Open IP Example Design, then specify the desired location of the example design project in the resulting dialog window. This command opens a new Vivado project window for the example design and adds the proper top-level wrapper and constraints file to the project, as shown in Figure 13-2.
Once the example design is generated, you can implement the IBERT example design through bitstream creation core by clicking **Generate Bitstream** in the **Program and Debug** section of the Vivado IDE flow navigator or by running the following Tcl commands:

```tcl
launch_runs impl_1 -to_step write_bitstream
wait_on_run impl_1
```

Refer to the *Vivado Design Suite User Guide: Design Flows Overview* (UG892) [Ref 6] for more details on the various ways you can implement your design.

![IBERT Example Design](image-url)

**Figure 13-2:** IBERT Example Design
Debugging the Serial I/O Design in Hardware

Once you have IBERT core implemented, you can use the run time serial I/O analyzer features to debug the design in hardware. Only IBERT cores version v3.0 and later can be accessed using the serial I/O analyzer feature.

Using Vivado® Serial I/O Analyzer to Debug the Design

The Vivado® serial I/O analyzer feature is used to interact with IBERT debug IP cores that are in your design. To access the Vivado serial I/O analyzer feature, click the Open Hardware Manager button in the Program and Debug section of the Flow Navigator.

The steps to debug your design in hardware are:

1. Connect to the hardware target and programming the FPGA device with the bit file.
2. Create Links.
3. Modify link settings and examine status.
4. Run scans as needed.

Connecting to the Hardware Target and Programming the FPGA Device

Programming an FPGA device prior to debugging involves exactly the same steps described in Programming the FPGA Device7. After programming the device with the .bit file that contains the IBERT core, the Hardware window now shows the components of the IBERT core that were detected when scanning the device (see Figure 14-1).
Chapter 14: Debugging the Serial I/O Design in Hardware

Creating Links and Link Groups

The IBERT core present in the design appears in the Hardware window under the target device. If you do not see the core appear, right-click the device and select the Refresh Hardware command. This re-scans the FPGA device and refreshes the Hardware window.

Note: If you still do not see the IBERT core after programming and/or refreshing the FPGA device, check to make sure the device was programmed with the appropriate .bit file. Also check to make sure the implemented design contains an IBERT v3.0 core.

The Vivado serial I/O analyzer feature is built around the concept of links. A link is analogous to a channel on a board, with a transmitter and a receiver. The transmitter and receiver may or may not be the same GT, on the same device, or be the same architecture.

To create one or more links, go to the Links tab in Vivado, and click either the Create Links button, or right-click and choose Create Links. This causes the Create Links dialog window to appear, as shown in Figure 14-2.

When an IBERT core is detected, the Hardware Manager notes that there are no links present, and show a green banner at the top. Click *Create Links* to open the Create Links dialog window, as shown in Figure 14-2.
Choose a TX and/or an RX from the list available. Or type in a string into the search field to narrow down the list. Then click the Add (+) button to add the link to the list. Repeat for all links desired.

**IMPORTANT:** A given TX or RX endpoint can only belong to one link.

Links can also be a part of a link group. By default, all new links are grouped together. You can choose not to add the links to a group by unchecking **Create link group** check box. The name of the link group is specified in the Link group description field.

**Viewing and Changing Links Settings Using the Links Window**

Once links are created, they are added to the **Links** view (see **Figure 14-3**) which is the primary and best way to change link settings and view status.
Each row in the Links window represents a link. Common and useful status and controls are enabled by default, so the health of the links can be quickly seen. The various settings that can be viewed in the Links window’s table columns are shown in Table 14-1.

Table 14-1: Links Window Settings

<table>
<thead>
<tr>
<th>Link View Column Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>The name of the link</td>
</tr>
<tr>
<td>TX</td>
<td>The GT location of the transmitter</td>
</tr>
<tr>
<td>RX</td>
<td>The GT location of the receiver</td>
</tr>
<tr>
<td>Status</td>
<td>If linked (meaning the incoming RX data as expected). Status displays the measured line rate. Otherwise, it displays “No Link”.</td>
</tr>
<tr>
<td>Bits</td>
<td>The measured number of bits received.</td>
</tr>
<tr>
<td>Errors</td>
<td>The measured number of bit errors by the receiver.</td>
</tr>
<tr>
<td>BER</td>
<td>Bit Error Ratio = ( \frac{(1 + Errors)}{Bits} ).</td>
</tr>
<tr>
<td>BERT Reset</td>
<td>Resets the received bits and error counters.</td>
</tr>
<tr>
<td>RX Pattern</td>
<td>Selects which pattern the receiver is expecting.</td>
</tr>
<tr>
<td>TX Pattern</td>
<td>Selects which pattern the transmitter is sending.</td>
</tr>
<tr>
<td>TX Pre-Cursor</td>
<td>Selects the pre-cursor emphasis on the transmitter.</td>
</tr>
<tr>
<td>TX Post-Cursor</td>
<td>Selects the post-cursor emphasis on the transmitter.</td>
</tr>
<tr>
<td>TX Diff Swing</td>
<td>Selects the differential swing values for the transmitter.</td>
</tr>
<tr>
<td>DFE Enabled</td>
<td>Selects whether the Decision Feedback Equalizer is enabled on the receiver (not available for all architectures).</td>
</tr>
<tr>
<td>Inject Error</td>
<td>Injects a single bit error into the transmit path.</td>
</tr>
<tr>
<td>TX Reset</td>
<td>Resets the transmitter.</td>
</tr>
<tr>
<td>RX Reset</td>
<td>Resets the receiver and BERT counters (see BERT Reset).</td>
</tr>
<tr>
<td>Loopback Mode</td>
<td>Selects the loopback mode on the receiver GT. Warning: Changing this value might effect the link status depending on the system topology.</td>
</tr>
<tr>
<td>Termination Voltage</td>
<td>Selects the termination voltage of the receiver.</td>
</tr>
<tr>
<td>RX Common Mode</td>
<td>Selects the RX Common Mode setting of the receiver.</td>
</tr>
<tr>
<td>TXUSERCLK Freq</td>
<td>Shows the measured TXUSERCLK frequency in MHz.</td>
</tr>
<tr>
<td>TXUSERCLK2 Freq</td>
<td>Shows the measured TXUSERCLK2 frequency in MHz.</td>
</tr>
<tr>
<td>RXUSERCLK Freq</td>
<td>Shows the measured RXUSERCLK frequency in MHz.</td>
</tr>
<tr>
<td>RXUSERCLK2 Freq</td>
<td>Shows the measured RXUSERCLK2 frequency in MHz.</td>
</tr>
<tr>
<td>TX Polarity Invert</td>
<td>Inverts the polarity of the transmitted data.</td>
</tr>
<tr>
<td>RX Polarity Invert</td>
<td>Inverts the polarity of the received data.</td>
</tr>
</tbody>
</table>
It is possible to change the values of a given property for all links in a link group by changing the setting in the link group row. For instance, changing the TX Pattern to "PRBS 7-bit" in the "Link Group 0" row changes the TX Pattern of all the links to "PRBS 7-bit". If not all the links in the group have the same setting, "Multiple" appears for that column in the link group row.

Creating and Running Link Scans

To analyze the margin of a given link, it is often helpful to run a scan of the link using the specialized Eye Scan hardware of the Xilinx 7 Series FPGA transceivers. The Vivado serial I/O analyzer feature enables you to define, run, save, and recall link scans.

A scan runs on a link. To create a scan, select a link in the Link window, and either right-click and choose Create Scan, or click the Create Scan button in the Link window toolbar. This brings up the Create Scan dialog (see Figure 14-4). The Create Scan dialog shows the settings for performing a scan, as shown in Table 14-2.

![Create Scan Dialog](image)

**Figure 14-4:** Create Scan Dialog

<table>
<thead>
<tr>
<th>Table 14-2: Scan Settings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scan Setting</strong></td>
</tr>
<tr>
<td>Description</td>
</tr>
<tr>
<td>Scan Type</td>
</tr>
<tr>
<td>Horizontal Increment</td>
</tr>
<tr>
<td>Horizontal Range</td>
</tr>
</tbody>
</table>
Chapter 14: Debugging the Serial I/O Design in Hardware

By default, the scan is run after it is created. If you do not want to run the scan, and only define it, uncheck the Run Scan check box.

If a scan is created, but not run, it can be subsequently run or run by right-clicking on a scan in the Scans window and choosing Run Scan (see Figure 14-5). While a scan is running, it can be prematurely stopped by right-clicking on a scan and choosing Stop Scan, or clicking the Stop Scan button in the Scans window toolbar.

Creating and Running Link Sweeps

To analyze the margin of a given link, it can be helpful to run multiple scans of the link with different MGT settings. This helps determine which settings are the best. The Vivado serial I/O analyzer feature enables you to define, run, save, and recall link sweeps, which are a collection of link scans.

A sweep runs on a link. To create a sweep, select a link in the Link window, and either right-click and choose Create Sweep, or click the Create Sweep button in the Link window toolbar. This will bring up the Create Sweep dialog box, which looks similar to the Create Scan dialog box, except that it has additional options for defining which properties to sweep, and how.

---

Table 14-2: Scan Settings

<table>
<thead>
<tr>
<th>Scan Setting</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical Increment</td>
<td>Allows you to choose to scan the eye at a reduced resolution, but increased speed by skipping vertical codes.</td>
</tr>
<tr>
<td>Vertical Range</td>
<td>Reducing the vertical range increases the scan speed. By default, the entire eye is scanned.</td>
</tr>
<tr>
<td>Dwell BER</td>
<td>Each point in the chart is scanned for a certain amount of time. Dwell BER allows you to choose the scan depth by selecting the desired Bit Error Ratio.</td>
</tr>
<tr>
<td>Dwell Time</td>
<td>Dwell Time allows you to choose the scan depth by inputting the desired time in seconds.</td>
</tr>
</tbody>
</table>

---

Figure 14-5: Scans Window
Chapter 14: Debugging the Serial I/O Design in Hardware

Figure 14-6: Create Sweep Dialog Box

Table 14-3: Sweep Settings

<table>
<thead>
<tr>
<th>Sweep Setting</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>A user-defined name for the sweep.</td>
</tr>
<tr>
<td>Scan Type</td>
<td>The type of scan to run.</td>
</tr>
<tr>
<td>Horizontal Increment</td>
<td>Allows you to scan the eye at a reduced resolution, but at increased speed by skipping horizontal codes.</td>
</tr>
<tr>
<td>Horizontal Range</td>
<td>Reducing the horizontal range increases the scan speed. By default, the entire eye is scanned (-1/2 of a unit interval to +1/2 in reference to the center of the eye).</td>
</tr>
</tbody>
</table>
After these settings are chosen, the next step is to choose the Sweep Properties. Any writable properties of the link can be swept. To add a property, click the + button on the right side to add another row to the table. Click the Property Name to choose a property to sweep.

To change the values, click the Values to Sweep Cell, and use the chooser to select which values to sweep. If the property does not have enumerated values, type one hex value on each line of the text area provided.

- In the Semi Custom case shown in Figure 14-8, every combination of the properties chosen is defined for a single scan, and that scan is performed according to the sweep properties. The number of sweeps that are performed, and in what order can be previewed by selecting the Preview & Scans tab.

- In the Full Custom case, the first choice for each of the properties listed is used for the first scan, the second choice for each of the properties is used for the second scan, etc. If one of the properties has fewer choices than other properties, the last choice will be

<table>
<thead>
<tr>
<th>Sweep Setting</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical Increment</td>
<td>Allows the user to choose to scan the eye at a reduced resolution, but increased speed by skipping vertical codes.</td>
</tr>
<tr>
<td>Vertical Range</td>
<td>Reducing the vertical range increases the scan speed. By default, the entire eye is scanned.</td>
</tr>
<tr>
<td>Dwell BER</td>
<td>Each point in the chart is scanned for a certain amount of time. Dwell BER allows you to choose the scan depth by selecting the desired Bit Error Ratio (BER).</td>
</tr>
<tr>
<td>Dwell Time</td>
<td>Dwell Time allows you to choose the scan depth by inputting the desired time in seconds.</td>
</tr>
<tr>
<td>Sweep Mode</td>
<td>The type of sweep to run. The choices are Semi Custom, Full Custom, and Exhaustive.</td>
</tr>
</tbody>
</table>
used for all subsequent scans. With the same properties choices but Full Custom as the sweep Mode, only three scans would be performed.

- In the Exhaustive case, the **Values to Sweep** is no longer editable, as all values are chosen for a given property.

When all the properties are set, to run each of the scans sequentially, keep **Run Sweep** checked. The list of scans is elaborated in the Scan window once you click the **OK** button.

During the sweep, the progress is tracked in the **Scan** window, and the latest Scan result is displayed.

**Displaying and Navigating the Scan Plots**

After a scan is created, it automatically launches the **Scan Plots** window for that scan. For 2D Eyescan, the plot is a heat map of the BER value.
As in other charts and displays within the Vivado IDE, the mouse gestures for zooming in the eye scan plot window are as follows:

- Zoom Area: left-click drag from top-left to bottom-right
- Zoom Fit: left-click drag from bottom-right to top-left
- Zoom In: left-click drag from top-right to bottom-left
- Zoom Out: left-click drag from bottom-left to top-right

Also, when the mouse cursor is over the Plot, the current horizontal and vertical codes, along with the scanned BER value is displayed in the tooltip. You can also change the plot type by clicking the *Plot Type* button in the plot window, and choosing Show Contour (filled), Show Contour (lines), and Heat Map.

A summary view is present at the bottom of the scan plot, stating the scan settings, along with basic information like when the scan was performed. During the 2D Eyescan, the number of pixels in the scan with zero errors is calculated (taking into account the horizontal and vertical increments), and this result is displayed as Open Area. The *Scan* window contents are sorted by Open Area by default, so the scans with the largest open area appear at the top.
Writing the Scan Results to a File

When scan data exists due to a partial or full 2D Eyescan, these results can be written to a CSV file by clicking the **Write Scan** button in the **Scans** window. This saves the scan results to comma-delimited file, with the BER values in a block that replicated the scan plot.

Properties Window

Whenever a GT or a COMMON block in the hardware window, a Link in the **Links** window, or a scan in the **Scans** window is selected, the properties of that object shows in the **Properties** window. For GTs and COMMONs, these include all the attribute, port, and other settings of those objects. These settings can be changed in the **Properties** window (see **Figure 14-10**), or by writing Tcl commands to change and commit the properties. Some properties are read-only and cannot be changed.

![Properties Window](image.png)

**Figure 14-10:** Properties Window
Chapter 14: Debugging the Serial I/O Design in Hardware

Description of Serial I/O Analyzer Tcl Objects and Commands

You can use Tcl commands to interact with your hardware under test. The hardware is organized in a set of hierarchical first class Tcl objects (see Table 14-4).

<table>
<thead>
<tr>
<th>Tcl Object</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>hw_sio_ibert</td>
<td>Object referring to an IBERT core. Each IBERT object can have one or more hw_sio_gt, or hw_sio_common objects associated with it.</td>
</tr>
<tr>
<td>hw_sio_gt</td>
<td>Object referring to a single Xilinx Gigabit Transceiver (GT).</td>
</tr>
<tr>
<td>hw_sio_gtgroups</td>
<td>Object referring to a logical grouping of GTs, could be a Quad or an Octal.</td>
</tr>
<tr>
<td>hw_sio_common</td>
<td>Object referring to a COMMON block.</td>
</tr>
<tr>
<td>hw_sio_tx</td>
<td>Object referring to the transmitter side of a hw_sio_gt. Only the TX related ports, attributes, and logic properties flows to the hw_sio_tx.</td>
</tr>
<tr>
<td>hw_sio_rx</td>
<td>Object referring to the receiver side of a hw_sio_gt. Only the RX related ports, attributes, and logic properties flows to the hw_sio_rx.</td>
</tr>
<tr>
<td>hw_sio_pll</td>
<td>Object referring to a PLL in either an hw_sio_gt or an hw_sio_common object. Only the related ports, attributes, and logic properties flow to the hw_sio_pll.</td>
</tr>
<tr>
<td>hw_sio_link</td>
<td>Object referring to a link, a TX-RX pair. Note: A link can also consist of a TX only or an RX only.</td>
</tr>
<tr>
<td>hw_sio_linkgroup</td>
<td>Object referring to a group of links.</td>
</tr>
<tr>
<td>hw_sio_scan</td>
<td>Object referring to a margin analysis scan.</td>
</tr>
</tbody>
</table>

Table 14-5 contains descriptions of all Tcl commands used to interact with the IBERT core.

**IMPORTANT:** Using the get_property or set_property command does not read or write information to/from the IBERT core. You must use the refresh_hw_sio and commit_hw_sio commands to read and write information from/to the hardware, respectively.

<table>
<thead>
<tr>
<th>Tcl Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>refresh_hw_sio</td>
<td>Read the property values out of the provided object. Works for any hw_sio object that refers to hardware.</td>
</tr>
<tr>
<td>commit_hw_sio</td>
<td>Writes property changes to the hardware. Works for any hw_sio object that refers to hardware.</td>
</tr>
</tbody>
</table>
Chapter 14: Debugging the Serial I/O Design in Hardware

**Description of hw_sio_link Tcl Commands**

Table 14-6 contains descriptions of all Tcl commands used to interact with links.

<table>
<thead>
<tr>
<th>Tcl Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>create_hw_sio_link</td>
<td>Create an hw_sio_link object with the given hw_sio_rx and/or hw_sio_tx objects.</td>
</tr>
<tr>
<td>remove_hw_sio_link</td>
<td>Deletes the given link.</td>
</tr>
<tr>
<td>get_hw_sio_links</td>
<td>Get list of hw_sio_links for the given object.</td>
</tr>
</tbody>
</table>

**Description of hw_sio_linkgroup Tcl Commands**

Table 14-7 contains descriptions of all Tcl commands used to interact with linkgroups.

<table>
<thead>
<tr>
<th>Tcl Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>create_hw_sio_linkgroup</td>
<td>Create an hw_sio_linkgroup object with the hw_sio_link objects.</td>
</tr>
<tr>
<td>remove_hw_sio_linkgroup</td>
<td>Deletes the given linkgroup.</td>
</tr>
<tr>
<td>get_hw_sio_linkgroups</td>
<td>Get list of hw_sio_linkgroups for the given object.</td>
</tr>
</tbody>
</table>

**Description of hw_sio_scan Tcl Commands**

Table 14-8 contains descriptions of all Tcl commands used to interact with scans.

<table>
<thead>
<tr>
<th>Tcl Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>create_hw_sio_scan</td>
<td>Creates a scan object.</td>
</tr>
<tr>
<td>remove_hw_sio_scan</td>
<td>Deletes a scan object.</td>
</tr>
<tr>
<td>run_hw_sio_scan</td>
<td>Runs a scan.</td>
</tr>
<tr>
<td>stop_hw_sio_scan</td>
<td>Stops a scan.</td>
</tr>
<tr>
<td>wait_on_hw_sio_scan</td>
<td>Blocks the Tcl console prompt until a given run_hw_sio_scan operation is complete.</td>
</tr>
<tr>
<td>display_hw_sio_scan</td>
<td>Displays a partial or complete scan in the Scan Plot.</td>
</tr>
<tr>
<td>write_hw_sio_scan</td>
<td>Writes the scan data to a file.</td>
</tr>
<tr>
<td>read_hw_sio_scan</td>
<td>Reads scan data from a file into a scan object.</td>
</tr>
<tr>
<td>get_hw_sio_scans</td>
<td>Get a list of hw_sio_scan objects.</td>
</tr>
</tbody>
</table>


**Chapter 14:** Debugging the Serial I/O Design in Hardware

### Description of Tcl Commands to Get Objects

Table 14-9 contains descriptions of all Tcl commands used to get serial I/O objects.

<table>
<thead>
<tr>
<th>Tcl Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>get_hw_sio_iberts</td>
<td>Get list of IBERT objects.</td>
</tr>
<tr>
<td>get_hw_sio_gts</td>
<td>Get list of GTs.</td>
</tr>
<tr>
<td>get_hw_sio_commons</td>
<td>Get list of COMMON blocks.</td>
</tr>
<tr>
<td>get_hw_sio_txs</td>
<td>Get list of transmitters.</td>
</tr>
<tr>
<td>get_hw_sio_rxs</td>
<td>Get list of receivers.</td>
</tr>
<tr>
<td>get_hw_sio_plls</td>
<td>Get list of PLLs.</td>
</tr>
<tr>
<td>get_hw_sio_links</td>
<td>Get list of links.</td>
</tr>
<tr>
<td>get_hw_sio_linkgroups</td>
<td>Get list of linkgroups.</td>
</tr>
<tr>
<td>get_hw_sio_scans</td>
<td>Get list of scans.</td>
</tr>
</tbody>
</table>

### Using Tcl Commands to Take an IBERT Measurement

Below is an example Tcl command script that interacts with the following example system:

- One KC705 board’s Digilent JTAG-SMT1 cable (serial number 12345) accessible via a hw_server running on localhost:3121
- Single IBERT core in a design running in the XC7K325T device on the KC705 board
- IBERT core has Quad 117 and Quad 118 enabled

#### Example Tcl Command Script

```tcl
# Connect to the Digilent Cable on localhost:3121
connect_hw_server -url localhost:3121
current_hw_target [get_hw_targets */digilent_plugin/SN:12345]
open_hw_target

# Program and Refresh the XC7K325T Device
current_hw_device [lindex [get_hw_devices] 0]
refresh_hw_device -update_hw_probes false [lindex [get_hw_devices] 0]
set_property PROGRAM.FILE {C:/design.bit} [lindex [get_hw_devices] 0]
program_hw_devices [lindex [get_hw_devices] 0]
refresh_hw_device [lindex [get_hw_devices] 0]

# Set Up Link on first GT
set tx0 [lindex [get_hw_sio_txs] 0]
set rx0 [lindex [get_hw_sio_rxs] 0]
set link0 [create_hw_sio_link $tx0 $rx0]
set_property DESCRIPTION {Link 0} [get_hw_sio_links $link0]

# Set link to use PCS Loopback, and write to hardware
set_property LOOPBACK "Near-End PCS" $link0
```
commit_hw_sio $link0

# Create, run, display and save scan
set scan0 [create_hw_sio_scan 2d_full_eye [get_hw_sio_rxs -of $link0]]
run_hw_sio_scan $scan0
display_hw_sio_scan $scan0
write_hw_sio_scan "scan0.csv" $scan0
## 7 Series Bitstream Settings

The device configuration settings for 7 Series devices available for use with the `set_property <Setting> <Value> [current_design]` Vivado® tool Tcl command are shown in **Table A-1**.

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Value</th>
<th>Possible Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.CONFIG. BPI_1ST_READ_CYCLE</td>
<td>1</td>
<td>1, 2, 3, 4</td>
<td>Helps synchronize BPI configuration with the timing of page mode operations in flash devices. It allows you to set the cycle number for a valid read of the first page. The BPI_page_size must be set to 4 or 8 for this option to be available.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. BPI_PAGE_SIZE</td>
<td>1</td>
<td>1, 4, 8</td>
<td>For BPI configuration, this option lets you specify the page size which corresponds to the number of reads required per page of flash memory.</td>
</tr>
</tbody>
</table>
| BITSTREAM.CONFIG. BPI_SYNC_MODE  | Disable       | Disable, Type1, Type2 | Sets the BPI synchronous configuration mode for different types of BPI flash devices.  
  - Disable (the default) disables the synchronous configuration mode.  
  - Type1 enables the synchronous configuration mode and settings to support the Micron G18(F) family.  
  - Type2 enables the synchronous configuration mode and settings to support the Micron (Numonyx) P30 and P33 families. |
| BITSTREAM.CONFIG. CCLKPIN⁹ | Pullup        | Pullup, Pullnone | Adds an internal pull-up to the Cclk pin. The Pullnone setting disables the pullup. |
### Appendix A: Device Configuration Bitstream Settings

#### Table A-1: 7 Series Bitstream Settings

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Value</th>
<th>Possible Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.CONFIG.CONFIGFALLBACK</td>
<td>Disable</td>
<td>Disable, Enable</td>
<td>Enables or disables the loading of a default bitstream when a configuration attempt fails. If the MultiBoot solution setting BITSTREAM.CONFIG.NEXT_CONFIG_ADDR is used then the BITSTREAM.CONFIG.FALLBACK setting will be enabled. <em>Note:</em> Fallback MultiBoot is not supported in Virtex-7 HT devices.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.CONFIGRATE</td>
<td>3</td>
<td>3, 6, 9, 12, 16, 22, 26, 33, 40, 50, 66</td>
<td>Uses an internal oscillator to generate the configuration clock, Cclk, when configuring in a master mode. Use this option to select the rate for Cclk.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.DCIUPDATEMODE</td>
<td>AsRequired</td>
<td>AsRequired, Continuous, Quiet</td>
<td>Controls how often the Digitally Controlled Impedance circuit attempts to update the impedance match for DCI IOSTANDARDS.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.DONEPIN⁵</td>
<td>Pullup</td>
<td>Pullup, Pullnone</td>
<td>Adds an internal pull-up to the DONE pin. The Pullnone setting disables the pullup. Use DonePin only if you intend to connect an external pull-up resistor to this pin. The internal pull-up resistor is automatically connected if you do not use DonePin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.EXTMASTERCCLK_EN</td>
<td>Disable</td>
<td>Disable, Div-1, Div-2, Div-4, Div-8</td>
<td>Allows an external clock to be used as the configuration clock for all master modes. The external clock must be connected to the dual-purpose USERCCLK pin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.INITPIN⁵</td>
<td>Pullup</td>
<td>Pullup, Pullnone</td>
<td>Specifies whether you want to add a Pullup resistor to the INIT pin, or leave the INIT pin floating.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.INITSIGNALERROR</td>
<td>Enable</td>
<td>Enable, Disable</td>
<td>When Enabled, the INIT_B pin asserts to ‘0’ when a configuration error is detected.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.M0PIN⁵</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the M0 pin. Select Pullnone to disable both the pull-up resistor and the pull-down resistor on the M0 pin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.M1PIN⁵</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the M1 pin. Select Pullnone to disable both the pull-up resistor and the pull-down resistor on the M1 pin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.M2PIN⁵</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the M2 pin. Select Pullnone to disable both the pull-up resistor and the pull-down resistor on the M2 pin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.NEXT_CONFIG_ADDR</td>
<td>None</td>
<td>&lt;string&gt;</td>
<td>Sets the starting address for the next configuration in a MultiBoot set up, which is stored in the WBSTAR register.</td>
</tr>
</tbody>
</table>
### Appendix A: Device Configuration Bitstream Settings

#### Table A-1: 7 Series Bitstream Settings

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Value</th>
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</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.CONFIG.NEXT_CONFIG_REBOOT</td>
<td>Enable</td>
<td>Enable, Disable</td>
<td>When set to Disable the IPROG command is removed from the .bit file. This allows the Golden image to load upon power up rather than jumping to the multiboot image in a multiboot setup.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.PERSIST</td>
<td>No</td>
<td>No, Yes</td>
<td>Maintains the configuration logic access to the multi-function configuration pins after configuration. Primarily used to maintain the SelectMAP port after configuration for readback access, but can be used with any configuration mode. Persist is not needed for JTAG configuration since the JTAG port is dedicated and always available. PERSIST and ICAP cannot be used at the same time. Refer to the user guide for a description. Persist is needed for Readback and Partial Reconfiguration using the SelectMAP configuration pins, and should be used when either SelectMAP or Serial modes are used.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.REVISIONSELECT</td>
<td>00</td>
<td>00, 01, 10, 11</td>
<td>Specifies the internal value of the RS[1:0] settings in the Warm Boot Start Address (WBSTAR) register for the next warm boot.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.REVISIONSELECT_TRISTATE</td>
<td>Disable</td>
<td>Disable, Enable</td>
<td>Specifies whether the RS[1:0] 3-state is enabled by setting the option in the Warm Boot Start Address (WBSTAR).</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.SELECTMAPABORT</td>
<td>Enable</td>
<td>Enable, Disable</td>
<td>Enables or disables the SelectMAP mode Abort sequence. If disabled, an Abort sequence on the device pins is ignored.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.SPI_32BIT_ADDR</td>
<td>No</td>
<td>No, Yes</td>
<td>Enables SPI 32-bit address style, which is required for SPI devices with storage of 256 Mb and larger.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.SPI_BUSWIDTH</td>
<td>NONE</td>
<td>NONE, 1, 2, 4</td>
<td>Sets the SPI bus to Dual (x2) or Quad (x4) mode for Master SPI configuration from third party SPI flash devices.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.SPI_FALL_EDGE</td>
<td>No</td>
<td>No, Yes</td>
<td>Sets the FPGA to use a falling edge clock for SPI data capture. This improves timing margins and may allow faster clock rates for configuration.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.TCKPIN³</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds a pull-up, a pull-down, or neither to the TCK pin, the JTAG test clock. The Pullnone setting shows that there is no connection to either the pull-up or the pull-down.</td>
</tr>
</tbody>
</table>
### Appendix A: Device Configuration Bitstream Settings

#### Table A-1: 7 Series Bitstream Settings

<table>
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<tr>
<th>Setting</th>
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</tr>
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<tbody>
<tr>
<td>BITSTREAM.CONFIG. TDIPIN&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds a pull-up, a pull-down, or neither to the TDI pin, the serial data input to all JTAG instructions and JTAG registers. The Pullnone setting shows that there is no connection to either the pull-up or the pull-down.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. TDOPIN&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds a pull-up, a pull-down, or neither to the TDO pin, the serial data output for all JTAG instruction and data registers. The Pullnone setting shows that there is no connection to either the pull-up or the pull-down.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. TIMER_CFG</td>
<td>None</td>
<td>&lt;8-digit hex string&gt;</td>
<td>Sets the value of the Watchdog Timer in Configuration mode. This option cannot be used at the same time as TIMER_USR.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. TIMER_USR</td>
<td>0x00000000</td>
<td>&lt;8-digit hex string&gt;</td>
<td>Sets the value of the Watchdog Timer in User mode. This option cannot be used at the same time as TIMER_CFG.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. TMSPIN&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds a pull-up, pull-down, or neither to the TMS pin, the mode input signal to the TAP controller. The TAP controller provides the control logic for JTAG. The Pullnone setting shows that there is no connection to either the pull-up or the pull-down.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. UNUSEDPIN</td>
<td>Pulldown</td>
<td>Pulldown, Pullup, Pullnone</td>
<td>Adds a pull-up, a pull-down, or neither to unused SelectIO pins (IOBs). It has no effect on dedicated configuration pins. The list of dedicated configuration pins varies depending upon the architecture. The Pullnone setting shows that there is no connection to either the pull-up or the pull-down.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. USERID</td>
<td>0xFFFFFFFF</td>
<td>&lt;8-digit hex string&gt;</td>
<td>Used to identify implementation revisions. You can enter up to an 8-digit hexadecimal string in the User ID register.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. USR_ACCESS</td>
<td>None</td>
<td>None, &lt;8-digit hex string&gt;, TIMESTAMP</td>
<td>Writes an 8-digit hexadecimal string, or a timestamp into the AXSS configuration register. The format of the timestamp value is ddddd MMMMM yyyyhh hmmm sssss : day, month, year (year 2000 = 0000), hour, minute, seconds. The contents of this register may be directly accessed by the FPGA fabric via the USR_ACCESS primitive.</td>
</tr>
<tr>
<td>BITSTREAM.ENCRYPTION. ENCRYPT</td>
<td>No</td>
<td>No, Yes</td>
<td>Encrypts the bitstream.</td>
</tr>
</tbody>
</table>
### Table A-1: 7 Series Bitstream Settings

<table>
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<tr>
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<th>Default Value</th>
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</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.ENCRIPTION. ENCRYPTKEYSELECT</td>
<td>bbram</td>
<td>bbram, efuse</td>
<td>Determines the location of the AES encryption key to be used, either from the battery-backed RAM (BBRAM) or the eFUSE register. <strong>Note:</strong> This property is only available when the Encrypt option is set to True.</td>
</tr>
<tr>
<td>BITSTREAM.ENCRIPTION. HKEY</td>
<td>None</td>
<td>&lt;hex string&gt;</td>
<td>HKey sets the HMAC authentication key for bitstream encryption. 7 series devices have an on-chip bitstream-keyed Hash Message Authentication Code (HMAC) algorithm implemented in hardware to provide additional security beyond AES decryption alone. These devices require both AES and HMAC keys to load, modify, intercept, or clone the bitstream. To use this option, you must first set Encrypt to Yes.</td>
</tr>
<tr>
<td>BITSTREAM.ENCRIPTION. KEY0</td>
<td>None</td>
<td>&lt;hex string&gt;</td>
<td>Key0 sets the AES encryption key for bitstream encryption. To use this option, you must first set Encrypt to Yes.</td>
</tr>
<tr>
<td>BITSTREAM.ENCRIPTION. KEYFILE</td>
<td>None</td>
<td>&lt;string&gt;</td>
<td>Specifies the name of the input encryption file (with a .nky file extension). To use this option, you must first set Encrypt to Yes.</td>
</tr>
<tr>
<td>BITSTREAM.ENCRIPTION. STARTCBC</td>
<td>None</td>
<td>&lt;32-bit hex string&gt;</td>
<td>Sets the starting cipher block chaining (CBC) value.</td>
</tr>
<tr>
<td>BITSTREAM.GENERAL. COMPRESS</td>
<td>False</td>
<td>True, False</td>
<td>Uses the multiple frame write feature in the bitstream to reduce the size of the bitstream, not just the Bitstream (.bit) file. Using Compress does not guarantee that the size of the bitstream shrinks.</td>
</tr>
<tr>
<td>BITSTREAM.GENERAL. CRC</td>
<td>Enable</td>
<td>Enable, Disable</td>
<td>Controls the generation of a Cyclic Redundancy Check (CRC) value in the bitstream. When enabled, a unique CRC value is calculated based on bitstream contents. If the calculated CRC value does not match the CRC value in the bitstream, the device will fail to configure. When CRC is disabled a constant value is inserted in the bitstream in place of the CRC, and the device does not calculate a CRC.</td>
</tr>
</tbody>
</table>
### Table A-1: 7 Series Bitstream Settings

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Value</th>
<th>Possible Values</th>
<th>Description</th>
</tr>
</thead>
</table>
| BITSTREAM.GENERAL.DEBUGBITSTREAM | No            | No, Yes         | Lets you create a debug bitstream. A debug bitstream is significantly larger than a standard bitstream. DebugBitstream can be used only for master and slave serial configurations. DebugBitstream is not valid for Boundary Scan or Slave Parallel/SelectMAP. In addition to a standard bitstream, a debug bitstream offers the following features:  
  - Writes 32 0s to the LOUT register after the synchronization word.  
  - Loads each frame individually.  
  - Performs a Cyclic Redundancy Check (CRC) after each frame.  
  - Writes the frame address to the LOUT register after each frame. |
| BITSTREAM.GENERAL.DISABLE_JTAG   | No            | No, Yes         | Disables communication to the Boundary Scan (BSCAN) block via JTAG after configuration.                                                    |
| BITSTREAM.GENERAL.JTAG_XADC      | Enable        | Enable, Disable, StatusOnly | Enables or disables the JTAG connection to the XADC.                                                                                       |
| BITSTREAM.GENERAL.XADCENHANCEDLINEARITY | Off           | Off, On         | Disables some built-in digital calibration features that make INL look worse than the actual analog performance.                           |
| BITSTREAM.READBACK.ACTIVERECONFIG | No            | No, Yes         | Prevents the assertions of GHIGH and GSR during configuration. This is required for the active partial reconfiguration enhancement features. |
| BITSTREAM.READBACK.ICAP_SELECT   | Auto          | Auto, Top, Bottom | Selects between the top and bottom ICAP ports.                                                                                             |
| BITSTREAM.READBACK.READBACK      | False         | True, False     | Lets you perform the Readback function by creating the necessary readback files.                                                           |
| BITSTREAM.READBACK.SECURITY      | None          | None, Level1, Level2 | Specifies whether to disable Readback and Reconfiguration.  
  **Note:** Specifying Security Level1 disables Readback. Specifying Security Level2 disables Readback and Reconfiguration.                   |
| BITSTREAM.READBACK.XADCPARTIALRECONFIG | Disable | Disable, Enable | When Disabled XADC can work continuously during Partial Reconfiguration. When Enabled XADC works in Safe mode during partial reconfiguration. |
| BITSTREAM.STARTUP.DONEPIPE       | Yes           | Yes, No         | Tells the FPGA device to wait on the CFG_DONE (DONE) pin to go High and then wait for the first clock edge before moving to the Done state. |
## Appendix A: Device Configuration Bitstream Settings

### Table A-1: 7 Series Bitstream Settings

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Value</th>
<th>Possible Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.STARTUP.DONE_CYCLE</td>
<td>4</td>
<td>4, 1, 2, 3, 5, 6, Keep</td>
<td>Selects the Startup phase that activates the FPGA Done signal. Done is delayed when DonePipe=Yes.</td>
</tr>
<tr>
<td>BITSTREAM.STARTUP.GTS_CYCLE</td>
<td>5</td>
<td>5, 1, 2, 3, 4, 6, Done, Keep</td>
<td>Selects the Startup phase that releases the internal 3-state control to the I/O buffers.</td>
</tr>
<tr>
<td>BITSTREAM.STARTUP.GWE_CYCLE</td>
<td>6</td>
<td>6, 1, 2, 3, 4, 5, Done, Keep</td>
<td>Selects the Startup phase that asserts the internal write enable to flip-flops, LUT RAMs, and shift registers. GWE_cycle also enables the BRAMS. Before the Startup phase, both block RAMs writing and reading are disabled.</td>
</tr>
<tr>
<td>BITSTREAM.STARTUP.LCK_CYCLE</td>
<td>NoWait</td>
<td>NoWait, 0, 1, 2, 3, 4, 5, 6</td>
<td>Selects the Startup phase to wait until DLLs/DCMs/PLLs lock. If you select NoWait, the Startup sequence does not wait for DLLs/DCMs/PLLs to lock.</td>
</tr>
<tr>
<td>BITSTREAM.STARTUP.MATCH_CYCLE</td>
<td>Auto</td>
<td>Auto, NoWait, 0, 1, 2, 3, 4, 5, 6</td>
<td>Specifies a stall in the Startup cycle until digitally controlled impedance (DCI) match signals are asserted. DCI matching does not begin on the Match_cycle. The Startup sequence waits in this cycle until DCI has matched. Given that there are a number of variables in determining how long it takes DCI to match, the number of CCLK cycles required to complete the Startup sequence may vary in any given system. Ideally, the configuration solution should continue driving CCLK until DONE goes high. <strong>Note:</strong> When the Auto setting is specified, write_bitstream searches the design for any DCI I/O standards. If DCI standards exist, write_bitstream uses BITSTREAM.STARTUP.MATCH_CYCLE=2. Otherwise, write_bitstream uses BITSTREAM.STARTUP.MATCH_CYCLE=NoWait.</td>
</tr>
</tbody>
</table>
| BITSTREAM.STARTUP.STARTUPCLK    | Cclk          | Cclk, UserClk, JtagClk | The StartupClk sequence following the configuration of a device can be synchronized to either Cclk, a User Clock, or the JTAG Clock. The default is Cclk:  
  - Cclk lets you synchronize to an internal clock provided in the FPGA device.  
  - UserClk lets you synchronize to a user-defined signal connected to the CLK pin of the STARTUP symbol.  
  - JtagClk lets you synchronize to the clock provided by JTAG. This clock sequences the TAP controller which provides the control logic for JTAG. |

---

a. For the dedicated configuration pins Xilinx recommends that you use the bitstream setting default.
Appendix A: Device Configuration Bitstream Settings

Zynq-7000 Bitstream Settings

The device configuration settings for Zynq®-7000 devices available for use with the set_property <Setting> <Value> [current_design] Vivado tool Tcl command are shown in Table A-2.

Note: Bitstream settings for encryption are not valid for Zynq-7000 devices.

Table A-2: Zynq-7000 Bitstream Settings

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Value</th>
<th>Possible Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.CONFIG.BPI_1ST_READ_CYCLE</td>
<td>1</td>
<td>1, 2, 3, 4</td>
<td>Helps synchronize BPI configuration with the timing of page mode operations in flash devices. It allows you to set the cycle number for a valid read of the first page. The BPI_page_size must be set to 4 or 8 for this option to be available.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.BPI_PAGE_SIZE</td>
<td>1</td>
<td>1, 4, 8</td>
<td>For BPI configuration, this option lets you specify the page size which corresponds to the number of reads required per page of flash memory.</td>
</tr>
</tbody>
</table>
| BITSTREAM.CONFIG.BPI_SYNC_MODE | Disable       | Disable, Type1, Type2 | Sets the BPI synchronous configuration mode for different types of BPI flash devices.  
• Disable (the default) disables the synchronous configuration mode.  
• Type1 enables the synchronous configuration mode and settings to support the Micron G18(F) family.  
• Type2 enables the synchronous configuration mode and settings to support the Micron (Numonyx) P30 and P33 families. |
| BITSTREAM.CONFIG.CCLKPINa     | Pullup        | Pullup, Pullnone| Adds an internal pull-up to the Cclk pin. The Pullnone setting disables the pullup. |
| BITSTREAM.CONFIG.CONFIGFALLBACK | Enable       | Disable, Enable | Enables or disables the loading of a default bitstream when a configuration attempt fails. |
| BITSTREAM.CONFIG.CONFIGRATE   | 3             | 3, 6, 9, 12, 16, 22, 26, 33, 40, 50, 66 | Uses an internal oscillator to generate the configuration clock, Cclk, when configuring in a master mode. Use this option to select the rate for Cclk. |
| BITSTREAM.CONFIG.DCIUPDATEMODE | AsRequired    | AsRequired, Continuous, Quiet | Controls how often the Digitally Controlled Impedance circuit attempts to update the impedance match for DCI IOSTANDARDS. |
### Appendix A: Device Configuration Bitstream Settings

#### Table A-2: Zynq-7000 Bitstream Settings

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Value</th>
<th>Possible Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.CONFIG.DONEPIN(^a)</td>
<td>Pullup</td>
<td>Pullup, Pullnone</td>
<td>Adds an internal pull-up to the DONE pin. The Pullnone setting disables the pullup. Use DonePin only if you intend to connect an external pull-up resistor to this pin. The internal pull-up resistor is automatically connected if you do not use DonePin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.EXTMASTERCCLK_EN</td>
<td>Disable</td>
<td>Disable, div-48, div-24, div-12, div-8, div-6, div-4, div-3, div-2, div-1</td>
<td>Allows an external clock to be used as the configuration clock for all master modes. The external clock must be connected to the dual-purpose USERCCLK pin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.INITPIN(^a)</td>
<td>Pullup</td>
<td>Pullup, Pullnone</td>
<td>Specifies whether you want to add a Pullup resistor to the INIT pin, or leave the INIT pin floating.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.INITSIGNALERROR</td>
<td>Enable</td>
<td>Enable, Disable</td>
<td>When Enabled, the INIT_B pin asserts to '0' when a configuration error is detected.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.M0PIN(^a)</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the M0 pin. Select Pullnone to disable both the pull-up resistor and the pull-down resistor on the M0 pin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.M1PIN(^a)</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the M1 pin. Select Pullnone to disable both the pull-up resistor and the pull-down resistor on the M1 pin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.M2PIN(^a)</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the M2 pin. Select Pullnone to disable both the pull-up resistor and the pull-down resistor on the M2 pin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.NEXT_CONFIG_ADDR</td>
<td>None</td>
<td>&lt;string&gt;</td>
<td>Sets the starting address for the next configuration in a MultiBoot set up, which is stored in the WBSTAR register.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.NEXT_CONFIG_REBOOT</td>
<td>Enable</td>
<td>Enable, Disable</td>
<td>When set to Disable the IPROG command is removed from the .bit file. This allows the Golden image to load upon power up rather than jumping to the multiboot image in a multiboot setup.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.OVERTEMPPOWERDOWN</td>
<td>Disable</td>
<td>Disable, Enable</td>
<td>Enables the device to shut down when the XADC detects a temperature beyond the acceptable operational maximum. An external circuitry set up for the XADC is required to use this option.</td>
</tr>
</tbody>
</table>
### Appendix A: Device Configuration Bitstream Settings

#### Table A-2: Zynq-7000 Bitstream Settings

<table>
<thead>
<tr>
<th>Setting</th>
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<th>Possible Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.CONFIG.PERSIST</td>
<td>No</td>
<td>No, Yes</td>
<td>Maintains the configuration logic access to the multi-function configuration pins after configuration. Primarily used to maintain the SelectMAP port after configuration for readback access, but can be used with any configuration mode. Persist is not needed for JTAG configuration since the JTAG port is dedicated and always available. PERSIST and ICAP cannot be used at the same time. Refer to the user guide for a description. Persist is needed for Readback and Partial Reconfiguration using the SelectMAP configuration pins, and should be used when either SelectMAP or Serial modes are used.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.REVISIONSELECT</td>
<td>00</td>
<td>00, 01, 10, 11</td>
<td>Specifies the internal value of the RS[1:0] settings in the Warm Boot Start Address (WBSTAR) register for the next warm boot.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.REVISIONSELECT.TRISTATE</td>
<td>Disable</td>
<td>Disable, Enable</td>
<td>Specifies whether the RS[1:0] 3-state is enabled by setting the option in the Warm Boot Start Address (WBSTAR).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• RS[1:0] pins 3-state enable.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• 0: Enable RS 3-state (default)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• 1: Disable RS 3-state</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.SELECTMAPABORT</td>
<td>Enable</td>
<td>Enable, Disable</td>
<td>Enables or disables the SelectMAP mode Abort sequence. If disabled, an Abort sequence on the device pins is ignored.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.SPI_32BIT_ADDR</td>
<td>No</td>
<td>No, Yes</td>
<td>Enables SPI 32-bit address style, which is required for SPI devices with storage of 256 Mb and larger.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.SPI_BUSWIDTH</td>
<td>NONE</td>
<td>NONE, 1, 2, 4</td>
<td>Sets the SPI bus to Dual (x2) or Quad (x4) mode for Master SPI configuration from third party SPI flash devices.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.SPI_FALL_EDGE</td>
<td>No</td>
<td>No, Yes</td>
<td>Sets the FPGA to use a falling edge clock for SPI data capture. This improves timing margins and may allow faster clock rates for configuration.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.TCKPIN&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds a pull-up, a pull-down, or neither to the TCK pin, the JTAG test clock. The Pullnone setting shows that there is no connection to either the pull-up or the pull-down.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.TDIPIN&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds a pull-up, a pull-down, or neither to the TDI pin, the serial data input to all JTAG instructions and JTAG registers. The Pullnone setting shows that there is no connection to either the pull-up or the pull-down.</td>
</tr>
</tbody>
</table>
### Appendix A: Device Configuration Bitstream Settings

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Value</th>
<th>Possible Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.CONFIG. TDOPIN*</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds a pull-up, a pull-down, or neither to the TDO pin, the serial data output for all JTAG instruction and data registers. The Pullnone setting shows that there is no connection to either the pull-up or the pull-down.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. TIMER_CFG</td>
<td>None</td>
<td>&lt;8-digit hex string&gt;</td>
<td>Sets the value of the Watchdog Timer in Configuration mode. This option cannot be used at the same time as TIMER_USR.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. TIMER_USR</td>
<td>0x00000000</td>
<td>&lt;8-digit hex string&gt;</td>
<td>Sets the value of the Watchdog Timer in User mode. This option cannot be used at the same time as TIMER_CFG.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. TMSPIN*</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds a pull-up, pull-down, or neither to the TMS pin, the mode input signal to the TAP controller. The TAP controller provides the control logic for JTAG. The Pullnone setting shows that there is no connection to either the pull-up or the pull-down.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. UNUSEDPIN</td>
<td>Pulldown</td>
<td>Pulldown, Pullup, Pullnone</td>
<td>Adds a pull-up, a pull-down, or neither to unused SelectIO pins (IOBs). It has no effect on dedicated configuration pins. The list of dedicated configuration pins varies depending upon the architecture. The Pullnone setting shows that there is no connection to either the pull-up or the pull-down.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. USERID</td>
<td>0xFFFFFFFF</td>
<td>&lt;8-digit hex string&gt;</td>
<td>Used to identify implementation revisions. You can enter up to an 8-digit hexadecimal string in the User ID register.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. USR_ACCESS</td>
<td>None</td>
<td>&lt;8-digit hex string&gt;, TIMESTAMP</td>
<td>Writes an 8-digit hexadecimal string, or a timestamp into the AXSS configuration register. The format of the timestamp value is ddddd MMMM yyyy hhmmssss : day, month, year (year 2000 = 00000), hour, minute, seconds. The contents of this register may be directly accessed by the FPGA fabric via the USR_ACCESS primitive.</td>
</tr>
<tr>
<td>BITSTREAM.ENCRYPTION. ENCRYPTKEYSELECT</td>
<td>bbram</td>
<td>bbram, efuse</td>
<td>Determines the location of the AES encryption key to be used, either from the battery-backed RAM (BBRAM) or the eFUSE register. (7 Series) <strong>Note:</strong> This property is only available when the Encrypt option is set to True.</td>
</tr>
<tr>
<td>BITSTREAM.GENERAL. COMPRESS</td>
<td>False</td>
<td>True, False</td>
<td>Uses the multiple frame write feature in the bitstream to reduce the size of the bitstream, not just the Bitstream (.bit) file. Using Compress does not guarantee that the size of the bitstream shrinks.</td>
</tr>
</tbody>
</table>

### Table A-2: Zynq-7000 Bitstream Settings

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Value</th>
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</tr>
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<tbody>
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<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds a pull-up, a pull-down, or neither to the TDO pin, the serial data output for all JTAG instruction and data registers. The Pullnone setting shows that there is no connection to either the pull-up or the pull-down.</td>
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<td>BITSTREAM.CONFIG. TIMER_CFG</td>
<td>None</td>
<td>&lt;8-digit hex string&gt;</td>
<td>Sets the value of the Watchdog Timer in Configuration mode. This option cannot be used at the same time as TIMER_USR.</td>
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<td>BITSTREAM.CONFIG. TIMER_USR</td>
<td>0x00000000</td>
<td>&lt;8-digit hex string&gt;</td>
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<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
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</tr>
<tr>
<td>BITSTREAM.CONFIG. UNUSEDPIN</td>
<td>Pulldown</td>
<td>Pulldown, Pullup, Pullnone</td>
<td>Adds a pull-up, a pull-down, or neither to unused SelectIO pins (IOBs). It has no effect on dedicated configuration pins. The list of dedicated configuration pins varies depending upon the architecture. The Pullnone setting shows that there is no connection to either the pull-up or the pull-down.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. USERID</td>
<td>0xFFFFFFFF</td>
<td>&lt;8-digit hex string&gt;</td>
<td>Used to identify implementation revisions. You can enter up to an 8-digit hexadecimal string in the User ID register.</td>
</tr>
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<td>Writes an 8-digit hexadecimal string, or a timestamp into the AXSS configuration register. The format of the timestamp value is ddddd MMMM yyyy hhmmssss : day, month, year (year 2000 = 00000), hour, minute, seconds. The contents of this register may be directly accessed by the FPGA fabric via the USR_ACCESS primitive.</td>
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<td>bbram</td>
<td>bbram, efuse</td>
<td>Determines the location of the AES encryption key to be used, either from the battery-backed RAM (BBRAM) or the eFUSE register. (7 Series) <strong>Note:</strong> This property is only available when the Encrypt option is set to True.</td>
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<td>BITSTREAM.GENERAL. COMPRESS</td>
<td>False</td>
<td>True, False</td>
<td>Uses the multiple frame write feature in the bitstream to reduce the size of the bitstream, not just the Bitstream (.bit) file. Using Compress does not guarantee that the size of the bitstream shrinks.</td>
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### Table A-2: Zynq-7000 Bitstream Settings

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</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.GENERAL.CRC</td>
<td>Enable</td>
<td>Enable, Disable</td>
<td>Controls the generation of a Cyclic Redundancy Check (CRC) value in the bitstream. When enabled, a unique CRC value is calculated based on bitstream contents. If the calculated CRC value does not match the CRC value in the bitstream, the device will fail to configure. When CRC is disabled a constant value is inserted in the bitstream in place of the CRC, and the device does not calculate a CRC.</td>
</tr>
</tbody>
</table>
| BITSTREAM.GENERAL.DEBUGBITSTREAM     | No            | No, Yes                       | Lets you create a debug bitstream. A debug bitstream is significantly larger than a standard bitstream. DebugBitstream can be used only for master and slave serial configurations. DebugBitstream is not valid for Boundary Scan or Slave Parallel/SelectMAP. In addition to a standard bitstream, a debug bitstream offers the following features:  
  • Writes 32 0s to the LOUT register after the synchronization word.  
  • Loads each frame individually.  
  • Performs a Cyclic Redundancy Check (CRC) after each frame.  
  • Writes the frame address to the LOUT register after each frame. |
| BITSTREAM.GENERAL.DISABLE_JTAG       | No            | No, Yes                       | Disables communication to the Boundary Scan (BSCAN) block via JTAG after configuration.                                                                                                                     |
| BITSTREAM.GENERAL.JTAG_XADC          | Enable        | Enable, Disable, StatusOnly   | Enables or disables the JTAG connection to the XADC.                                                                                                                                                      |
| BITSTREAM.GENERAL.XADCENHANCEDLINEARITY | Off         | Off, On                       | Disables some built-in digital calibration features that make INL look worse than the actual analog performance.                                                                                         |
| BITSTREAM.READBACK.ACTIVERECONFIG    | No            | No, Yes                       | Prevents the assertions of GHIGH and GSR during configuration. This is required for the active partial reconfiguration enhancement features.                                                              |
| BITSTREAM.READBACK.ICAP_SELECT       | Auto          | Auto, Top, Bottom             | Selects between the top and bottom ICAP ports.                                                                                                                                                           |
| BITSTREAM.READBACK.READBACK          | False         | True, False                   | Lets you perform the Readback function by creating the necessary readback files.                                                                                                                         |
### Appendix A: Device Configuration Bitstream Settings

**Table A-2: Zynq-7000 Bitstream Settings**

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Value</th>
<th>Possible Values</th>
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</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.READBACK.SECURITY</td>
<td>None</td>
<td>None, Level1, Level2</td>
<td>Specifies whether to disable Readback and Reconfiguration. <strong>Note:</strong> Specifying Security Level1 disables Readback. Specifying Security Level2 disables Readback and Reconfiguration.</td>
</tr>
<tr>
<td>BITSTREAM.READBACK.XADC_PARTIALRECONFIG</td>
<td>Disable</td>
<td>Disable, Enable</td>
<td>When Disabled XADC can work continuously during Partial Reconfiguration. When Enabled XADC works in Safe mode during partial reconfiguration.</td>
</tr>
<tr>
<td>BITSTREAM.STARTUP.DONEPIPE</td>
<td>Yes</td>
<td>Yes, No</td>
<td>Tells the FPGA device to wait on the CFG_DONE (DONE) pin to go High and then wait for the first clock edge before moving to the Done state.</td>
</tr>
<tr>
<td>BITSTREAM.STARTUP.DONE_CYCLE</td>
<td>4</td>
<td>4, 1, 2, 3, 5, 6, Keep</td>
<td>Selects the Startup phase that activates the FPGA Done signal. Done is delayed when DonePipe=Yes.</td>
</tr>
<tr>
<td>BITSTREAM.STARTUP.GTS_CYCLE</td>
<td>5</td>
<td>5, 1, 2, 3, 4, 6, Done, Keep</td>
<td>Selects the Startup phase that releases the internal 3-state control to the I/O buffers.</td>
</tr>
<tr>
<td>BITSTREAM.STARTUP.GWE_CYCLE</td>
<td>6</td>
<td>6, 1, 2, 3, 4, 5, Done, Keep</td>
<td>Selects the Startup phase that asserts the internal write enable to flip-flops, LUT RAMs, and shift registers. GWE_cycle also enables the BRAMS. Before the Startup phase, both block RAMs writing and reading are disabled.</td>
</tr>
<tr>
<td>BITSTREAM.STARTUP.LCK_CYCLE</td>
<td>NoWait</td>
<td>NoWait, 0, 1, 2, 3, 4, 5, 6</td>
<td>Selects the Startup phase to wait until DLLs/DCMs/PLLs lock. If you select NoWait, the Startup sequence does not wait for DLLs/DCMs/PLLs to lock.</td>
</tr>
</tbody>
</table>
### Appendix A: Device Configuration Bitstream Settings

#### BITSTREAM.STARTUP.MATCH_CYCLE

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Value</th>
<th>Possible Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.STARTUP.MATCH_CYCLE</td>
<td>Auto</td>
<td>Auto, NoWait, 0, 1, 2, 3, 4, 5, 6</td>
<td>Specifies a stall in the Startup cycle until digitally controlled impedance (DCI) match signals are asserted. DCI matching does not begin on the Match_cycle. The Startup sequence waits in this cycle until DCI has matched. Given that there are a number of variables in determining how long it takes DCI to match, the number of CCLK cycles required to complete the Startup sequence may vary in any given system. Ideally, the configuration solution should continue driving CCLK until DONE goes high. <strong>Note:</strong> When the Auto setting is specified, write_bitstream searches the design for any DCI I/O standards. If DCI standards exist, write_bitstream uses BITSTREAM.STARTUP.MATCH_CYCLE=2. Otherwise, write_bitstream uses BITSTREAM.STARTUP.MATCH_CYCLE=NoWait.</td>
</tr>
</tbody>
</table>

#### BITSTREAM.STARTUP.STARTUPCLK

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Value</th>
<th>Possible Values</th>
<th>Description</th>
</tr>
</thead>
</table>
| BITSTREAM.STARTUP.STARTUPCLK | Cclk          | Cclk, UserClk, JtagClk | The StartupClk sequence following the configuration of a device can be synchronized to either Cclk, a User Clock, or the JTAG Clock. The default is Cclk.  
  • Cclk lets you synchronize to an internal clock provided in the FPGA device.  
  • UserClk lets you synchronize to a user-defined signal connected to the CLK pin of the STARTUP symbol.  
  • JtagClk lets you synchronize to the clock provided by JTAG. This clock sequences the TAP controller which provides the control logic for JTAG. |

---

Table A-2: Zynq-7000 Bitstream Settings

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Value</th>
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</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.STARTUP.MATCH_CYCLE</td>
<td>Auto</td>
<td>Auto, NoWait, 0, 1, 2, 3, 4, 5, 6</td>
<td>Specifies a stall in the Startup cycle until digitally controlled impedance (DCI) match signals are asserted. DCI matching does not begin on the Match_cycle. The Startup sequence waits in this cycle until DCI has matched. Given that there are a number of variables in determining how long it takes DCI to match, the number of CCLK cycles required to complete the Startup sequence may vary in any given system. Ideally, the configuration solution should continue driving CCLK until DONE goes high. <strong>Note:</strong> When the Auto setting is specified, write_bitstream searches the design for any DCI I/O standards. If DCI standards exist, write_bitstream uses BITSTREAM.STARTUP.MATCH_CYCLE=2. Otherwise, write_bitstream uses BITSTREAM.STARTUP.MATCH_CYCLE=NoWait.</td>
</tr>
</tbody>
</table>

---

a. For the dedicated configuration pins Xilinx recommends that you use the bitstream setting default.
## UltraScale Bitstream Settings

The device configuration settings for UltraScale™ devices available for use with the `set_property <Setting> <Value> [current_design]` Vivado® tool Tcl command are shown in Table A-3.

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Value</th>
<th>Possible Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.AUTHENTICATION.AUTHENTICATE</td>
<td>No</td>
<td>Yes, No</td>
<td>Indicates whether or not to use RSA authentication. If No then AES_GCM is used.</td>
</tr>
<tr>
<td>BITSTREAM.AUTHENTICATION.RSAPRIVATEKEYFILE</td>
<td>None</td>
<td>&lt;string&gt;</td>
<td>Specifies the OpenSSL . pem file that contains the key pairs that should be used to sign the RSA-2048 authenticated bitstream.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.BPI_1ST_READ_CYCLE</td>
<td>1</td>
<td>1, 2, 3, 4</td>
<td>Helps synchronize BPI configuration with the timing of page mode operations in flash devices. It allows you to set the cycle number for a valid read of the first page. The BPI_page_size must be set to 4 or 8 for this option to be available.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.BPI_PAGE_SIZE</td>
<td>1</td>
<td>1, 4, 8</td>
<td>For BPI configuration, this option lets you specify the page size which corresponds to the number of reads required per page of flash memory.</td>
</tr>
</tbody>
</table>
| BITSTREAM.CONFIG.BPI_SYNC_MODE | Disable | Disable, Type1, Type2 | Sets the BPI synchronous configuration mode for different types of BPI flash devices.  
  - Disable (the default) disables the synchronous configuration mode.  
  - Type1 enables the synchronous configuration mode and settings to support the Micron G18(F) family.  
  - Type2 enables the synchronous configuration mode and settings to support the Micron (Numonyx) P30 and P33 families. |
| BITSTREAM.CONFIG.CCLKPINa | Pullup | Pullup, Pullnone | Adds an internal pull-up to the Cclk pin. The Pullnone setting disables the pullup. |
| BITSTREAM.CONFIG.CONFIGFALLBACK | Enable | Disable, Enable | Enables or disables the loading of a default bitstream when a configuration attempt fails. |
| BITSTREAM.CONFIG.CONFIGRATE | 3 | 3,6,9,12,22, 33,40,50,57, 69,82,87,90, 110,115, 130,148 | Uses an internal oscillator to generate the configuration clock, Cclk, when configuring in a master mode. Use this option to select the rate for Cclk. |
| BITSTREAM.CONFIG.D00_MOSIa | Pullup | Pullup, Pulldown, Pullnone | Adds an internal pull-up, pull-down, or neither to the D00_MOSI pin. Select Pullnone to disable both the pull-up resistor and the pull-down resistor on the D00_MOSI pin. |
### Table A-3: UltraScale Bitstream Settings (Cont’d)

<table>
<thead>
<tr>
<th>Setting</th>
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<th>Possible Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.CONFIG. D01_DIN(^a)</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the D01_DIN pin. Select Pullnone to disable both the pull-up resistor and the pull-down resistor on the D01_DIN pin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. D02(^a)</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the D02 pin. Select Pullnone to disable both the pull-up resistor and the pull-down resistor on the D02 pin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. D03(^a)</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the D03 pin. Select Pullnone to disable both the pull-up resistor and the pull-down resistor on the D03 pin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. DCIUPDatemode</td>
<td>AsRequired</td>
<td>AsRequired, Continuous, Quiet</td>
<td>Controls how often the Digitally Controlled Impedance circuit attempts to update the impedance match for DCI IOSTANDARDS.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. DONEPIN(^a)</td>
<td>Pullup</td>
<td>Pullup, Pullnone</td>
<td>Adds an internal pull-up to the DONE pin. The Pullnone setting disables the pullup. Use DonePin only if you intend to connect an external pull-up resistor to this pin. The internal pull-up resistor is automatically connected if you do not use DonePin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. EXTMASTERCLK_EN</td>
<td>Disable</td>
<td>Disable, Div-1 Div-2 Div-3 Div-4 Div-6 Div-8 Div-12 Div-16 Div-24 Div-48</td>
<td>Allows an external clock to be used as the configuration clock for all master modes. The external clock must be connected to the dual-purpose USERCCLK pin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. INITPIN(^a)</td>
<td>Pullup</td>
<td>Pullup, Pullnone</td>
<td>Specifies whether you want to add a Pullup resistor to the INIT pin, or leave the INIT pin floating.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. INITSIGNALERROR</td>
<td>Enable</td>
<td>Enable, Disable</td>
<td>When Enabled, the INIT_B pin asserts to ‘0’ when a configuration error is detected.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. M0PIN(^a)</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the M0 pin. Select Pullnone to disable both the pull-up resistor and the pull-down resistor on the M0 pin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. M1PIN(^a)</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the M1 pin. Select Pullnone to disable both the pull-up resistor and the pull-down resistor on the M1 pin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. M2PIN(^a)</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the M2 pin. Select Pullnone to disable both the pull-up resistor and the pull-down resistor on the M2 pin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. NEXT_CONFIG_ADDR</td>
<td>none</td>
<td>&lt;string&gt;</td>
<td>Sets the starting address for the next configuration in a MultiBoot set up, which is stored in the WBSTAR register.</td>
</tr>
</tbody>
</table>
## Appendix A: Device Configuration Bitstream Settings

### Table A-3: UltraScale Bitstream Settings (Cont’d)

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Value</th>
<th>Possible Values</th>
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</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.CONFIG.NEXT_CONFIG_REBOOT</td>
<td>Enable</td>
<td>Enable, Disable</td>
<td>When set to Disable the IPROG command is removed from the .bit file. This allows the Golden image to load upon power up rather than jumping to the multiboot image in a multiboot setup.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.OVERTEMPSHUTDOWN</td>
<td>Disable</td>
<td>Disable, Enable</td>
<td>Enables the device to shut down when the System Monitor detects a temperature beyond the acceptable operational maximum. An external circuitry set up for the System Monitor is required to use this option.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.PERSIST</td>
<td>No</td>
<td>No, Yes</td>
<td>Maintains the configuration logic access to the multi-function configuration pins after configuration. Primarily used to maintain the SelectMAP port after configuration for readback access, but can be used with any configuration mode. Persist is not needed for JTAG configuration since the JTAG port is dedicated and always available. Persist and ICAP cannot be used at the same time. Refer to the user guide for a description. Persist is needed for Readback and Partial Reconfiguration using the SelectMAP configuration pins, and should be used when either SelectMAP or Serial modes are used.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.PROGPIN^a</td>
<td>Pullup</td>
<td>Pullup, Pullup, Pullnone</td>
<td>Adds an internal pull-up to the PROGRAM_B pin. The Pullnone setting disables the pullup. The pullup affects the pin after configuration.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.PUDC_B^a</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the PUDC_B pin. Select Pullnone to disable both the pull-up resistor and the pull-down resistor on the PUDC_B pin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.RDWR_B_FCS_B^a</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the RDWR_B_FCS_B pin. Select Pullnone to disable both the pull-up resistor and the pull-down resistor on the RDWR_B_FCS_B pin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.REVISIONSELECT</td>
<td>00</td>
<td>00, 01, 10, 11</td>
<td>Specifies the internal value of the RS[1:0] settings in the Warm Boot Start Address (WBSTAR) register for the next warm boot.</td>
</tr>
</tbody>
</table>
| BITSTREAM.CONFIG.REVISIONSELECT_TRISTATE | Disable   | Disable, Enable | Specifies whether the RS[1:0] 3-state is enabled by setting the option in the Warm Boot Start Address (WBSTAR).  
- RS[1:0] pins 3-state enable.  
- 0: Enable RS 3-state (default)  
- 1: Disable RS 3-state |
| BITSTREAM.CONFIG.SELECTMAPABORT  | Enable        | Enable, Disable | Enables or disables the SelectMAP mode Abort sequence. If disabled, an Abort sequence on the device pins is ignored. |
### Appendix A: Device Configuration Bitstream Settings

#### Table A-3: UltraScale Bitstream Settings (Cont’d)

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Value</th>
<th>Possible Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.CONFIG.SPI_32BIT_ADDR</td>
<td>No</td>
<td>No, Yes</td>
<td>Enables SPI 32-bit address style, which is required for SPI devices with storage of 256 Mb and larger.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.SPI_BUSWIDTH</td>
<td>NONE</td>
<td>NONE, 1, 2, 4, 8</td>
<td>Sets the SPI bus to Dual (x2) or Quad (x4) mode for Master SPI configuration from third party SPI flash devices.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.SPI_FALL_EDGE</td>
<td>No</td>
<td>No, Yes</td>
<td>Sets the FPGA to use a falling edge clock for SPI data capture. This improves timing margins and may allow faster clock rates for configuration.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.TCKPIN(^a)</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds a pull-up, a pull-down, or neither to the TCK pin, the JTAG test clock. The Pullnone setting shows that there is no connection to either the pull-up or the pull-down.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.TDIPIN(^a)</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds a pull-up, a pull-down, or neither to the TDI pin, the serial data input to all JTAG instructions and JTAG registers. The Pullnone setting shows that there is no connection to either the pull-up or the pull-down.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.TDOPIN(^a)</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds a pull-up, a pull-down, or neither to the TDO pin, the serial data output for all JTAG instruction and data registers. The Pullnone setting shows that there is no connection to either the pull-up or the pull-down.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.TIMER_CFG</td>
<td>None</td>
<td>&lt;8-digit hex string&gt;</td>
<td>Sets the value of the Watchdog Timer in Configuration mode. This option cannot be used at the same time as TIMER_USR.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.TIMER_USR</td>
<td>0x00000000</td>
<td>&lt;8-digit hex string&gt;</td>
<td>Sets the value of the Watchdog Timer in User mode. This option cannot be used at the same time as TIMER_CFG.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.TMSPIN(^a)</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds a pull-up, pull-down, or neither to the TMS pin, the mode input signal to the TAP controller. The TAP controller provides the control logic for JTAG. The Pullnone setting shows that there is no connection to either the pull-up or the pull-down.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.UNUSEDPIN</td>
<td>Pulldown</td>
<td>Pulldown, Pullup, Pullnone</td>
<td>Adds a pull-up, a pull-down, or neither to unused SelectIO pins (IOBs). It has no effect on dedicated configuration pins. The list of dedicated configuration pins varies depending upon the architecture. The Pullnone setting shows that there is no connection to either the pull-up or the pull-down.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.USERID</td>
<td>0xFFFFFFFF</td>
<td>&lt;8-digit hex string&gt;</td>
<td>Used to identify implementation revisions. You can enter up to an 8-digit hexadecimal string in the User ID register.</td>
</tr>
</tbody>
</table>
### Appendix A: Device Configuration Bitstream Settings

#### Table A-3: UltraScale Bitstream Settings (Cont’d)

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Value</th>
<th>Possible Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.CONFIG. USR_ACCESS</td>
<td>None</td>
<td>&lt;8-digit hex string&gt;, TIMESTAMP</td>
<td>Writes an 8-digit hexadecimal string, or a timestamp into the AXSS configuration register. The format of the timestamp value is ddddd MMMM yyyy hhmm mmmmm ssss : day, month, year (year 2000 = 00000), hour, minute, seconds. The contents of this register may be directly accessed by the FPGA fabric via the USR_ACCESS primitive.</td>
</tr>
<tr>
<td>BITSTREAM.ENCRYPTION. ENCRYPT</td>
<td>No</td>
<td>No, Yes</td>
<td>Encrypts the bitstream.</td>
</tr>
<tr>
<td>BITSTREAM.ENCRYPTION. ENCRYPTKEYSELECT</td>
<td>bbram, efuse</td>
<td>bbram, efuse</td>
<td>Determines the location of the AES encryption key to be used, either from the battery-backed RAM (BBRAM) or the eFUSE register. Note: This property is only available when the Encrypt option is set to True.</td>
</tr>
<tr>
<td>BITSTREAM.ENCRYPTION. KEY0</td>
<td>None</td>
<td>&lt;hex string&gt;</td>
<td>Key0 sets the AES encryption key for bitstream encryption. To use this option, you must first set Encrypt to Yes.</td>
</tr>
<tr>
<td>BITSTREAM.ENCRYPTION. KEYFILE</td>
<td>None</td>
<td>&lt;string&gt;</td>
<td>Specifies the name of the input encryption file (with a .nky file extension). To use this option, you must first set Encrypt to Yes.</td>
</tr>
<tr>
<td>BITSTREAM.ENCRYPTION. KEYLIFE</td>
<td>32</td>
<td>4 up to 2147483647</td>
<td>The number of 128-bit encryption blocks over which a single key should be used for AES-GCM authenticated bitstreams.</td>
</tr>
<tr>
<td>BITSTREAM.ENCRYPTION. RSAKEYLIFEFRAMES</td>
<td>8</td>
<td>8 up to 2147483647</td>
<td>Specifies how many configuration frames should be used for any given AES-256 key when RSA Public Key Authentication is specified. A value of 8 configuration frames is equivalent to using the key for 246 encryption blocks.</td>
</tr>
<tr>
<td>BITSTREAM.ENCRYPTION. OBFUSCATEKEY</td>
<td>Disable</td>
<td>Enable, Disable</td>
<td>Creates a bitstream whereby the key used to encrypt the bitstream is obfuscated before it is written to EFUSE or Battery-backed RAM (BBR). This allows the user to provide the device programmer with an obfuscated key rather than the original customer key. The device programmer can then write the obfuscated key to the EFUSE or BBR and mark it as obfuscated using the obfuscated-key flag in the selected storage location.</td>
</tr>
<tr>
<td>BITSTREAM.ENCRYPTION. STARTIVO</td>
<td></td>
<td></td>
<td>The initialization vector used to specify the initial GCM count value in the first AES-GCM message. 32-bit hex value.</td>
</tr>
<tr>
<td>BITSTREAM.ENCRYPTION. STARTIVOBUSCATE</td>
<td></td>
<td></td>
<td>Starting obfuscate initial vector (Obfuscate IV0) value.</td>
</tr>
<tr>
<td>BITSTREAM.GENERAL. COMPRESS</td>
<td>False</td>
<td>True, False</td>
<td>Uses the multiple frame write feature in the bitstream to reduce the size of the bitstream, not just the Bitstream (.bit) file. Using Compress does not guarantee that the size of the bitstream shrinks.</td>
</tr>
</tbody>
</table>
### Appendix A: Device Configuration Bitstream Settings

#### Table A-3: UltraScale Bitstream Settings (Cont’d)

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Value</th>
<th>Possible Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.GENERAL.CRC</td>
<td>Enable</td>
<td>Enable, Disable</td>
<td>Controls the generation of a Cyclic Redundancy Check (CRC) value in the bitstream. When enabled, a unique CRC value is calculated based on bitstream contents. If the calculated CRC value does not match the CRC value in the bitstream, the device will fail to configure. When CRC is disabled a constant value is inserted in the bitstream in place of the CRC, and the device does not calculate a CRC.</td>
</tr>
</tbody>
</table>
| BITSTREAM.GENERAL.DEBUGBITSTREAM | No            | No, Yes                  | Lets you create a debug bitstream. A debug bitstream is significantly larger than a standard bitstream. DebugBitstream can be used only for master and slave serial configurations. DebugBitstream is not valid for Boundary Scan or Slave Parallel/SelectMAP. In addition to a standard bitstream, a debug bitstream offers the following features:  
- Writes 32 0s to the LOUT register after the synchronization word.  
- Loads each frame individually.  
- Performs a Cyclic Redundancy Check (CRC) after each frame.  
- Writes the frame address to the LOUT register after each frame. |
| BITSTREAM.GENERAL.DISABLE_JTAG | No            | No, Yes                  | Disables communication to the Boundary Scan (BSCAN) block via JTAG after configuration. |
| BITSTREAM.GENERAL.JTAG_SYSMON  | Enable        | Enable, Disable, StatusOnly | Enables or disables the JTAG connection to SYSMON. |
| BITSTREAM.GENERAL.SYMONPOWERDOWN | Disable       | Disable, Enable          | Enables the device to power down SYSMON to save power. Only recommended for permanently powering down SYSMON. |
| BITSTREAM.READBACK.ACTIVERECONFIG | No            | No, Yes                  | Prevents the assertions of GHIGH and GSR during configuration. This is required for the active partial reconfiguration enhancement features. |
| BITSTREAM.READBACK.ICAP_SELECT  | Auto          | Auto, Top, Bottom        | Selects between the top and bottom ICAP ports. |
| BITSTREAM.READBACK.READBACK     | False         | True, False              | Lets you perform the Readback function by creating the necessary readback files. |
| BITSTREAM.READBACK.SECURITY     | None          | None, Level1, Level2     | Specifies whether to disable Readback and Reconfiguration.  
**Note:** Specifying Security Level1 disables Readback. Specifying Security Level2 disables Readback and Reconfiguration. |
| BITSTREAM.STARTUP.DONE_CYCLE    | 4             | 4, 1, 2, 3, 5, 6, Keep   | Selects the Startup phase that activates the FPGA Done signal. Done is delayed when DonePipe=Yes. |
## Table A-3: UltraScale Bitstream Settings (Cont’d)

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Value</th>
<th>Possible Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.STARTUP. GTS_CYCLE</td>
<td>5</td>
<td>5, 1, 2, 3, 4, 6, Done, Keep</td>
<td>Selects the Startup phase that releases the internal 3-state control to the I/O buffers.</td>
</tr>
<tr>
<td>BITSTREAM.STARTUP. GWE_CYCLE</td>
<td>6</td>
<td>6, 1, 2, 3, 4, 5, Done, Keep</td>
<td>Selects the Startup phase that asserts the internal write enable to flip-flops, LUT RAMs, and shift registers. GWE_cycle also enables the BRAMS. Before the Startup phase, both block RAMs writing and reading are disabled.</td>
</tr>
<tr>
<td>BITSTREAM.STARTUP. LCK_CYCLE</td>
<td>NoWait</td>
<td>NoWait, 0, 1, 2, 3, 4, 5, 6</td>
<td>Selects the Startup phase to wait until DLLs/DCMs/PLLs lock. If you select NoWait, the Startup sequence does not wait for DLLs/DCMs/PLLs to lock.</td>
</tr>
<tr>
<td>BITSTREAM.STARTUP. MATCH_CYCLE</td>
<td>Auto</td>
<td>Auto, NoWait, 0, 1, 2, 3, 4, 5, 6</td>
<td>Specifies a stall in the Startup cycle until digitally controlled impedance (DCI) match signals are asserted. DCI matching does not begin on the Match_cycle. The Startup sequence waits in this cycle until DCI has matched. Given that there are a number of variables in determining how long it takes DCI to match, the number of CCLK cycles required to complete the Startup sequence may vary in any given system. Ideally, the configuration solution should continue driving CCLK until DONE goes high. <strong>Note:</strong> When the Auto setting is specified, write_bitstream searches the design for any DCI I/O standards. If DCI standards exist, write_bitstream uses BITSTREAM.STARTUP.MATCH_CYCLE=2. Otherwise, write_bitstream uses BITSTREAM.STARTUP.MATCH_CYCLE=NoWait.</td>
</tr>
</tbody>
</table>

a. For the dedicated configuration pins Xilinx recommends that you use the default bitstream setting.
Appendix A: Device Configuration Bitstream Settings

# Virtex and Kintex UltraScale+ Bitstream Settings

The device configuration settings for Virtex and Kintex® UltraScale+™ devices available for use with the `set_property <Setting> <Value> [current_design]` Vivado tool Tcl command are shown in Table A-4.

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Values</th>
<th>Possible Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM. AUTHENTICATION. AUTHENTICATE</td>
<td>No</td>
<td>No, Yes</td>
<td>Indicates whether or not to use RSA authentication. If No then AES_GCM is used.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Specifies the OpenSSL .pem file that contains the key pairs that should be used to sign the RSA-2048 authenticated bitstream.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. BPI_1ST_READ_CYCLE</td>
<td>1</td>
<td>1, 2, 3, 4</td>
<td>Helps synchronize BPI configuration with the timing of page mode operations in flash devices. It allows you to set the cycle number for a valid read of the first page. The BPI_page_size must be set to 4 or 8 for this option to be available.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. BPI_PAGE_SIZE</td>
<td>1</td>
<td>1, 4, 8</td>
<td>For BPI configuration, this sub-option lets you specify the page size which corresponds to the number of reads required per page of flash memory.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. BPI_SYNC_MODE</td>
<td>Disable</td>
<td>Disable, Type1, Type2</td>
<td>Sets the BPI synchronous configuration mode for different types of BPI flash devices. Disable (the default) disables the synchronous configuration mode. Type1 enables the synchronous configuration mode and settings to support the Micron G18(F) family. Type2 enables the synchronous configuration mode and settings to support the Micron (Numonyx) P30 and P33 families.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. CCLKPIN</td>
<td>Pullup</td>
<td>Pullup, Pullnone</td>
<td>Adds an internal pull-up to the Cclk pin. The Pullnone setting disables the pullup.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. PERSIST</td>
<td>No</td>
<td>No, Yes</td>
<td>Prohibit usage of the configuration pins as user I/O and persist after configuration.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. CONFIGRATE</td>
<td>3</td>
<td>2.7, 5.3, 8.0, 10.6, 21.3, 31.9, 36.4, 51.0, 56.7, 63.8, 72.9, 85.0, 102.0, 127.5, 170.0</td>
<td>Bitstream generation uses an internal oscillator to generate the configuration clock, Cclk, when configuring is in a master mode. Use this sub-option to select the rate for Cclk.</td>
</tr>
</tbody>
</table>
Table A-4:  Virtex and Kintex UltraScale+ Bitstream Settings

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Values</th>
<th>Possible Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.CONFIG.</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the D00_MOSI pin. Select Pullnone to disable both the pull-up resistor and the pull-down resistor on the D00_MOSI pin.</td>
</tr>
<tr>
<td>D00_MOSI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the D01_DIN pin. Select Pullnone to disable both the pull-up resistor and the pull-down resistor on the D01_DIN pin.</td>
</tr>
<tr>
<td>D01_DIN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the D02 pin. Select Pullnone to disable both the pull-up resistor and the pull-down resistor on the D02 pin.</td>
</tr>
<tr>
<td>D02</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the D03 pin. Select Pullnone to disable both the pull-up resistor and the pull-down resistor on the D03 pin.</td>
</tr>
<tr>
<td>D03</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.</td>
<td>AsRequired</td>
<td>AsRequired, Quiet, Safe</td>
<td>Controls how often the Digitally Controlled Impedance circuit attempts to update the impedance match for DCI IOSTANDARDS.</td>
</tr>
<tr>
<td>DCUPDATEMODE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.</td>
<td>Pullup</td>
<td>Pullup, Pullnone</td>
<td>Adds an internal pull-up to the DONE pin. The Pullnone setting disables the pullup. Use DonePin only if you intend to connect an external pull-up resistor to this pin. The internal pull-up resistor is automatically connected if you do not use DonePin.</td>
</tr>
<tr>
<td>DONEPIN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.</td>
<td>Disable</td>
<td>Disable Div-1 Div-2 Div-3 Div-4 Div-6 Div-8 Div-12 Div-16 Div-24 Div-48</td>
<td>Allows an external clock to be used as the configuration clock for all master modes. The external clock must be connected to the dual-purpose USERCCLK pin.</td>
</tr>
<tr>
<td>EXTMASTERCCLK_EN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.</td>
<td>Pullup</td>
<td>Pullup, Pullnone</td>
<td>Specifies whether you want to add a Pullup resistor to the INIT pin, or leave the INIT pin floating.</td>
</tr>
<tr>
<td>INITPIN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the M0 pin. Select Pullnone to disable both the pull-up resistor and the pull–down resistor on the M0 pin.</td>
</tr>
<tr>
<td>M0PIN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the M1 pin. Select Pullnone to disable both the pull-up resistor and the pull–down resistor on the M1 pin.</td>
</tr>
<tr>
<td>M1PIN</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table A-4: Virtex and Kintex UltraScale+ Bitstream Settings

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<thead>
<tr>
<th>Setting</th>
<th>Default Values</th>
<th>Possible Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.CONFIG.M2PIN</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the M2 pin. Select Pullnone to disable both the pull-up resistor and the pull-down resistor on the M2 pin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.NEXT_CONFIG_ADDR</td>
<td>None</td>
<td>&lt;string&gt;</td>
<td>Sets the starting address for the next configuration in a MultiBoot set up, which is stored in the WBSTAR register.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.NEXT_CONFIG_REBOOT</td>
<td>Enable</td>
<td>Enable, Disable</td>
<td>When set to Disable the IPROG command is removed from the .bit file.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.SELECTMAPABORT</td>
<td>Enable</td>
<td>Enable, Disable</td>
<td>Enables or disables the SelectMAP mode Abort sequence. If disabled, an Abort sequence on the device pins is ignored.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.CONFIGFALLBACK</td>
<td>Enable</td>
<td>Enable, Disable</td>
<td>Enables or disables the loading of a default bitstream when a configuration attempt fails.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.PROGPIN</td>
<td>Pullup</td>
<td>Pullup, Pullnone</td>
<td>Adds an internal pull-up to the PROGRAM_B pin. The Pullnone setting disables the pullup. The pullup affects the pin after configuration.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.PUDC_B</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the PUDC_B pin. Select Pullnone to disable both the pull-up resistor and the pull-down resistor on the PUDC_B pin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.RDWR_B_FCS_B</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the RDWR_B_FCS_B pin. Select Pullnone to disable both the pull-up resistor and the pull-down resistor on the RDWR_B_FCS_B pin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.REVISIONSELECT</td>
<td>00</td>
<td>00, 01, 10, 11</td>
<td>Specifies the internal value of the RS[1:0] settings in the Warm Boot Start Address (WBSTAR) register for the next warm boot.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.REVISIONSELECT_TRISTATE</td>
<td>Disable</td>
<td>Disable, Enable</td>
<td>Specifies whether the RS[1:0] 3-state is enabled by setting the option in the Warm Boot Start Address (WBSTAR). RS[1:0] pins 3-state enable. 0: Enable RS 3-state (default) 1: Disable RS 3-state</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.OVERTEMPSHUTDOWN</td>
<td>Disable</td>
<td>Disable, Enable</td>
<td>Enables the device to shut down when the System Monitor detects a temperature beyond the acceptable operational maximum. An external circuitry set up for the System Monitor is required to use this option.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.SPI_32BIT_ADDR</td>
<td>No</td>
<td>No, Yes</td>
<td>Enables SPI 32-bit address style, which is required for SPI devices with storage of 256 Mb and larger.</td>
</tr>
</tbody>
</table>
### Appendix A: Device Configuration Bitstream Settings

**Table A-4: Virtex and Kintex UltraScale+ Bitstream Settings**

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Values</th>
<th>Possible Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.CONFIG.SPI_BUSWIDTH</td>
<td>NONE</td>
<td>NONE, 1, 2, 4, 8</td>
<td>Sets the SPI bus to Dual (x2) or Quad (x4) mode for Master SPI configuration from third party SPI flash devices.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.SPI_FALL_EDGE</td>
<td>No</td>
<td>No, Yes</td>
<td>Sets the FPGA to use a falling edge clock for SPI data capture. This improves timing margins and may allow faster clock rates for configuration.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.TCKPIN</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds a pull-up, a pull-down, or neither to the TCK pin, the JTAG test clock. The Pullnone setting shows that there is no connection to either the pull-up or the pull-down.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.TDIPIN</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds a pull-up, a pull-down, or neither to the TDI pin, the serial data input to all JTAG instructions and JTAG registers. The Pullnone setting shows that there is no connection to either the pull-up or the pull-down.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.TDOPIN</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds a pull-up, a pull-down, or neither to the TDO pin, the serial data output for all JTAG instruction and data registers. The Pullnone setting shows that there is no connection to either the pull-up or the pull-down.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.TMSPIN</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds a pull-up, pull-down, or neither to the TMS pin, the mode input signal to the TAP controller. The TAP controller provides the control logic for JTAG. The Pullnone setting shows that there is no connection to either the pull-up or the pull-down.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.UNUSEDPIN</td>
<td>Pulldown</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds a pull-up, a pull-down, or neither to unused SelectIO pins (IOBs). It has no effect on dedicated configuration pins. The list of dedicated configuration pins varies depending upon the architecture. The Pullnone setting shows that there is no connection to either the pull-up or the pull-down.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.USERID</td>
<td>0xFFFFFFFF</td>
<td>0xFFFFFFFF</td>
<td>Used to identify implementation revisions. You can enter up to an 8-digit hexadecimal string in the User ID register.</td>
</tr>
</tbody>
</table>
## Appendix A: Device Configuration Bitstream Settings

### Table A-4: Virtex and Kintex UltraScale+ Bitstream Settings

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Values</th>
<th>Possible Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.CONFIG. USR_ACCESS</td>
<td>None</td>
<td>None, &lt;8-digit hex string&gt;, TIMESTAMP</td>
<td>Writes an 8-digit hexadecimal string, or a timestamp into the AXSS configuration register. The format of the timestamp value is ddddd MMMM yyyy hhhhh mmmmmm sssss : day, month, year (year 2000 = 00000), hour, minute, seconds. The contents of this register may be directly accessed by the FPGA fabric via the USR_ACCESS primitive.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG. INITERROR</td>
<td>Enable</td>
<td>Enable, Disable</td>
<td>When Enabled, the INIT_B pin asserts to '0' when a configuration error is detected.</td>
</tr>
<tr>
<td>BITSTREAM. ENCRYPTION. ENCRYPT</td>
<td>No</td>
<td>No, Yes</td>
<td>Encrypts the bitstream</td>
</tr>
<tr>
<td>BITSTREAM. ENCRYPTION. ENCRYPTKEYSELECT</td>
<td>bbram</td>
<td>bbram, efuse</td>
<td>Determines the location of the AES encryption key to be used, either from the battery-backed RAM (BBRAM) or the eFUSE register. This property is only available when the Encrypt option is set to True.</td>
</tr>
<tr>
<td>BITSTREAM. ENCRYPTION. OBFSKEY</td>
<td>Disable</td>
<td>Disable, Enable</td>
<td>When the AES key is not read-secured, a read of the key returns the CRC hash of the key instead of the actual key value.</td>
</tr>
<tr>
<td>BITSTREAM. ENCRYPTION. KEY0</td>
<td></td>
<td></td>
<td>Key0 sets the 64-bit AES encryption key for bitstream encryption. To get the pick setting, leave this blank generator to select a random number for the value. To use this option, you must first set Encrypt to Yes.</td>
</tr>
<tr>
<td>BITSTREAM. ENCRYPTION. STARTIV0</td>
<td></td>
<td></td>
<td>Sets the 32-bit starting AES initial vector value. To use this option, you must first set Encrypt to Yes.</td>
</tr>
<tr>
<td>BITSTREAM. ENCRYPTION. STARTIVOBFS</td>
<td></td>
<td></td>
<td>Sets the 32-bit starting obfuscate initial vector value. To use this option, you must first set Encrypt to Yes.</td>
</tr>
<tr>
<td>BITSTREAM. ENCRYPTION. KEYFILE</td>
<td></td>
<td></td>
<td>Specifies the name of the input encryption file (with a .nky file extension). To use this option, you must first set Encrypt to Yes.</td>
</tr>
<tr>
<td>BITSTREAM. ENCRYPTION. KEYLIFE</td>
<td>32</td>
<td>4 up to 2147483647</td>
<td>The number of 128-bit encryption blocks over which a single key should be used for AES-GCM authenticated bitstreams.</td>
</tr>
<tr>
<td>BITSTREAM. ENCRYPTION. RSAKEYLIFEFRAMES</td>
<td>8</td>
<td>8 up to 2147483647</td>
<td>Specifies how many configuration frames should be used for any given AES-256 key when RSA Public Key Authentication is specified. A value of 8 configuration frames is equivalent to using the key for 246 encryption blocks.</td>
</tr>
</tbody>
</table>
### Appendix A: Device Configuration Bitstream Settings

#### Table A-4: Virtex and Kintex UltraScale+ Bitstream Settings

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Values</th>
<th>Possible Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.GENERAL.COMPRESS</td>
<td>False</td>
<td>True, False</td>
<td>Uses the multiple frame write feature in the bitstream to reduce the size of the bitstream, not just the bit file. Using compress does not guarantee that the size of the bitstream will shrink.</td>
</tr>
<tr>
<td>BITSTREAM.GENERAL.CRC</td>
<td>Enable</td>
<td>Enable, Disable</td>
<td>Controls the generation of a Cyclic Redundancy Check (CRC) value in the bitstream. When enabled, a unique CRC value is calculated based on bitstream contents. If the calculated CRC value does not match the CRC value in the bitstream, the device will fail to configure. When CRC is disabled a constant value is inserted in the bitstream in place of the CRC, and the device does not calculate a CRC.</td>
</tr>
<tr>
<td>BITSTREAM.GENERAL.DEBUGBITSTREAM</td>
<td>No</td>
<td>No, Yes</td>
<td>Lets you create a debug bitstream. A debug bitstream is significantly larger than a standard bitstream. DebugBitstream can be used only for master and slave serial configurations. DebugBitstream is not valid for Boundary Scan or Slave Parallel/SelectMAP. In addition to a standard bitstream, a debug bitstream offers the following features: Writes 32 0s to the LOUT register after the synchronization word. Loads each frame individually. Performs a Cyclic Redundancy Check (CRC) after each frame. Writes the frame address to the LOUT register after each frame.</td>
</tr>
<tr>
<td>BITSTREAM.GENERAL.SYSMONPOWERDOWN</td>
<td>Disable</td>
<td>Disable, Enable</td>
<td>Enables the device to power down SYSMON to save power. Only recommended for permanently powering down SYSMON.</td>
</tr>
<tr>
<td>BITSTREAM.GENERAL.DISABLE_JTAG</td>
<td>No</td>
<td>No, Yes</td>
<td>Disables communication to the Boundary Scan (BSCAN) block via JTAG after configuration.</td>
</tr>
<tr>
<td>BITSTREAM.GENERAL.JTAG_SYSMON</td>
<td>Enable</td>
<td>Enable, Disable, StatusOnly</td>
<td>Enables or disables the JTAG connection to SYSMON</td>
</tr>
<tr>
<td>BITSTREAM.READBACK.ICAP_SELECT</td>
<td>Auto</td>
<td>Auto, Top, Bottom</td>
<td>Selects between the top and bottom ICAP ports.</td>
</tr>
<tr>
<td>BITSTREAM.READBACK.ACTIVERECONFIG</td>
<td>No</td>
<td>No, Yes</td>
<td>Prevents the assertions of GHIGH and GSR during configuration. This is required for the active partial reconfiguration enhancement features.</td>
</tr>
</tbody>
</table>
### Table A-4: Virtex and Kintex UltraScale+ Bitstream Settings

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Values</th>
<th>Possible Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.</td>
<td>None</td>
<td>None, Level1, Level2</td>
<td>Specifies whether to disable Readback and Reconfiguration. Note: Specifying Security Level1 disables Readback. Specifying Security</td>
</tr>
<tr>
<td>READBACK.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SECURITY</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BITSTREAM.STARTUP.</td>
<td>4</td>
<td>4, 1, 2, 3, 5, 6</td>
<td>Selects the Startup phase that activates the FPGA Done signal. Done is delayed when DonePipe=Yes</td>
</tr>
<tr>
<td>DONE_CYCLE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BITSTREAM.STARTUP.</td>
<td>5</td>
<td>5, 1, 2, 3, 4, 6, Done, Keep</td>
<td>Selects the Startup phase that releases the internal 3-state control to the I/O buffers</td>
</tr>
<tr>
<td>GTS_CYCLE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BITSTREAM.STARTUP.</td>
<td>6</td>
<td>6, 1, 2, 3, 4, 5, Done, Keep</td>
<td>Selects the Startup phase that asserts the internal write enable to flip-flops, LUT RAMs, and shift registers. GWE_cycle also enables the BRAMS. Before the Startup phase, both block RAMs writing and reading are disabled.</td>
</tr>
<tr>
<td>GWE_CYCLE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BITSTREAM.STARTUP.</td>
<td>NoWait</td>
<td>NoWait, 0, 1, 2, 3, 4, 5, 6</td>
<td>Selects the Startup phase to wait until MMCM/PLLs lock. If you select NoWait, the Startup sequence does not wait for MMCM/PLLs to lock.</td>
</tr>
<tr>
<td>LCK_CYCLE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BITSTREAM.STARTUP.</td>
<td>Auto</td>
<td>Auto, NoWait, 0, 1, 2, 3, 4, 5, 6</td>
<td>Specifies a stall in the Startup cycle until digitally controlled impedance (DCI) match signals are asserted. DCI matching does not begin on the Match_cycle. The Startup sequence waits in this cycle until DCI has matched. Given that there are a number of variables in determining how long it takes DCI to match, the number of CCLK cycles required to complete the Startup sequence may vary in any given system. Ideally, the configuration solution should continue driving CCLK until DONE goes high. Note: When the Auto setting is specified, write_bitstream searches the design for any DCI I/O standards. If DCI standards exist, write_bitstream uses BITSTREAM.STARTUP.MATCH_CYCLE=2. Otherwise, write_bitstream uses BITSTREAM.STARTUP.MATCH_CYCLE=NoWait.</td>
</tr>
<tr>
<td>MATCH_CYCLE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>POST_CRC</td>
<td>Disable</td>
<td>Enable, Disable, Oneshot</td>
<td>NA</td>
</tr>
</tbody>
</table>
### Table A-4:  Virtex and Kintex UltraScale+ Bitstream Settings

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Values</th>
<th>Possible Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>POST_CRC_ACTION</td>
<td>Continue</td>
<td>Halt, Continue, Correct_and_continue, Correct_and_halt</td>
<td>NA</td>
</tr>
<tr>
<td>POST_CRC_FREQ</td>
<td>1</td>
<td>50, 25, 13, 6, 3, 2, 1</td>
<td>NA</td>
</tr>
</tbody>
</table>
Zynq UltraScale+ MPSoC Bitstream Settings

The device configuration settings for Zynq® UltraScale+™ MPSoC devices available for use with the `set_property <Setting> <Value> [current_design]` Vivado tool Tcl command are shown in Table A-5.

Table A-5: Zynq® UltraScale+™ MPSoC Bitstream Settings

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Values</th>
<th>Possible Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.CONFIG.DCIUPDATEMODE</td>
<td>AsRequired</td>
<td>AsRequired, Quiet, Safe</td>
<td>Controls how often the Digitally Controlled Impedance circuit attempts to update the impedance match for DCI IOSTANDARDS.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.PUDC_B</td>
<td>Pullup</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds an internal pull-up, pull-down, or neither to the PUDC_B pin. Select Pullnone to disable both the pull-up resistor and the pull-down resistor on the PUDC_B pin.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.OVERTEMPSHUTDOWN</td>
<td>Disable</td>
<td>Disable, Enable</td>
<td>Enables the device to shut down when the System Monitor detects a temperature beyond the acceptable operational maximum. An external circuitry set up for the System Monitor is required to use this option.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.UNUSEDPIN</td>
<td>Pulldown</td>
<td>Pullup, Pulldown, Pullnone</td>
<td>Adds a pull-up, a pull-down, or neither to unused SelectIO pins (IOBs). The list of dedicated configuration pins varies depending upon the architecture. The Pullnone setting shows that there is no connection to either the pull-up or the pull-down.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.USERID</td>
<td>0xFFFFFFFF</td>
<td>0xFFFFFFFF</td>
<td>Used to identify implementation revisions. You can enter up to an 8-digit hexadecimal string in the User ID register.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.USR_ACCESS</td>
<td>None</td>
<td>None, &lt;8-digit hex string&gt;, TIMESTAMP</td>
<td>Writes an 8-digit hexadecimal string, or a timestamp into the AXSS configuration register. The format of the timestamp value is ddddd MMMM yyyy yyyyy hhhhh mmmmmm sssss : day, month, year (year 2000 = 00000), hour, minute, seconds. The contents of this register may be directly accessed by the FPGA fabric via the USR_ACCESS primitive.</td>
</tr>
<tr>
<td>BITSTREAM.CONFIG.INITSIGNALSERROR</td>
<td>Enable</td>
<td>Enable, Disable</td>
<td>When Enabled, the INIT_B pin asserts to '0' when a configuration error is detected.</td>
</tr>
<tr>
<td>BITSTREAM.GENERAL.COMPRESS</td>
<td>False</td>
<td>True, False</td>
<td>Uses the multiple frame write feature in the bitstream to reduce the size of the bitstream, not just the bit file. Using compress does not guarantee that the size of the bitstream will shrink.</td>
</tr>
</tbody>
</table>
## Appendix A: Device Configuration Bitstream Settings

### Table A-5: Zynq® UltraScale+™ MPSoC Bitstream Settings

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Values</th>
<th>Possible Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.GENERAL.CRC</td>
<td>Enable</td>
<td>Enable, Disable</td>
<td>Controls the generation of a Cyclic Redundancy Check (CRC) value in the bitstream. When enabled, a unique CRC value is calculated based on bitstream contents. If the calculated CRC value does not match the CRC value in the bitstream, the device will fail to configure. When CRC is disabled a constant value is inserted in the bitstream in place of the CRC, and the device does not calculate a CRC.</td>
</tr>
<tr>
<td>BITSTREAM.GENERAL.SYSDMONPOWERDOWN</td>
<td>Disable</td>
<td>Disable, Enable</td>
<td>Enables the device to power down SYSDMON to save power. Only recommended for permanently powering down SYSDMON.</td>
</tr>
<tr>
<td>BITSTREAM.GENERAL.DISABLE_JTAG</td>
<td>No</td>
<td>No, Yes</td>
<td>Disables communication to the Boundary Scan (BSCAN) block via JTAG after configuration.</td>
</tr>
<tr>
<td>BITSTREAM.GENERAL.JTAG_SYSDMON</td>
<td>Enable</td>
<td>Enable, Disable, StatusOnly</td>
<td>Enables or disables the JTAG connection to SYSDMON.</td>
</tr>
<tr>
<td>BITSTREAM.READBACK.ICAP_SELECT</td>
<td>Auto</td>
<td>Auto, Top, Bottom</td>
<td>Selects between the top and bottom ICAP ports.</td>
</tr>
<tr>
<td>BITSTREAM.READBACK.ACTIVERECONFIG</td>
<td>No</td>
<td>No, Yes</td>
<td>Prevents the assertions of GHIGH and GSR during configuration. This is required for the active partial reconfiguration enhancement features.</td>
</tr>
<tr>
<td>BITSTREAM.READBACK.SECURITY</td>
<td>None</td>
<td>None, Level1, Level2</td>
<td>Specifies whether to disable Readback and Reconfiguration. Note: Specifying Security Level1 disables Readback. Specifying Security</td>
</tr>
<tr>
<td>BITSTREAM.STARTUP.DONE_CYCLE</td>
<td>4</td>
<td>4, 1, 2, 3, 5, 6, Keep</td>
<td>Selects the Startup phase that activates the FPGA Done signal. Done is delayed when DonePipe=Yes</td>
</tr>
<tr>
<td>BITSTREAM.STARTUP.GTS_CYCLE</td>
<td>5</td>
<td>5, 1, 2, 3, 4, 6, Done, Keep</td>
<td>Selects the Startup phase that releases the internal 3-state control to the I/O buffers</td>
</tr>
<tr>
<td>BITSTREAM.STARTUP.GWE_CYCLE</td>
<td>6</td>
<td>6, 1, 2, 3, 4, 5, Done, Keep</td>
<td>Selects the Startup phase that asserts the internal write enable to flip-flops, LUT RAMs, and shift registers. GWE_cycle also enables the BRAMS. Before the Startup phase, both block RAMs writing and reading are disabled.</td>
</tr>
<tr>
<td>BITSTREAM.STARTUP.LCK_CYCLE</td>
<td>NoWait</td>
<td>NoWait, 0, 1, 2, 3, 4, 5, 6</td>
<td>Selects the Startup phase to wait until MMCM/PLLs lock. If you select NoWait, the Startup sequence does not wait for MMCM/PLLs to lock.</td>
</tr>
</tbody>
</table>
### Table A-5: Zynq® UltraScale+™ MPSoC Bitstream Settings

<table>
<thead>
<tr>
<th>Setting</th>
<th>Default Values</th>
<th>Possible Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BITSTREAM.STARTUP.MATCH_CYCLE</td>
<td>Auto</td>
<td>Auto, NoWait, 0, 1, 2, 3, 4, 5, 6</td>
<td>Specifies a stall in the Startup cycle until digitally controlled impedance (DCI) match signals are asserted. DCI matching does not begin on the Match_cycle. The Startup sequence waits in this cycle until DCI has matched. Given that there are a number of variables in determining how long it takes DCI to match, the number of CCLK cycles required to complete the Startup sequence may vary in any given system. Ideally, the configuration solution should continue driving CCLK until DONE goes high. Note: When the Auto setting is specified, write_bitstream searches the design for any DCI I/O standards. If DCI standards exist, write_bitstream uses BITSTREAM.STARTUP.MATCH_CYCLE=2. Otherwise, write_bitstream uses BITSTREAM.STARTUP.MATCH_CYCLE=NoWait.</td>
</tr>
<tr>
<td>POST_CRC</td>
<td>DISABLE</td>
<td>ENABLE, DISABLE, ONESHOT</td>
<td>NA</td>
</tr>
<tr>
<td>POST_CRC_ACTION</td>
<td>CONTINUE</td>
<td>HALT, CONTINUE, CORRECT_AND_CONTINUE, CORRECT_AND_HALT</td>
<td>NA</td>
</tr>
<tr>
<td>POST_CRC_FREQ</td>
<td>1</td>
<td>50, 25, 13, 6, 3, 2, 1</td>
<td>NA</td>
</tr>
<tr>
<td>POST_CRC_INIT_FLAG</td>
<td>ENABLE</td>
<td>ENABLE, DISABLE</td>
<td>NA</td>
</tr>
<tr>
<td>POST_CRC_SOURCE</td>
<td>FIRST_READ BACK</td>
<td>PRE_COMPUTED FIRST_READ BACK</td>
<td>NA</td>
</tr>
</tbody>
</table>
Trigger State Machine Language Description

The trigger state machine language is used to describe complex trigger conditions that map to the advanced trigger logic of the ILA debug core. The trigger state machine has the following features:

- Up to 16 states.
- One-, two-, and three-way conditional branching used for complex state transitions.
- Four built-in 16-bit counters used to count events, implement timers, etc.
- Four built-in flags used for monitoring trigger state machine execution status.
- Trigger action.

States

Each state machine program can have up to 16 states declared. Each state is composed of a state declaration and a body:

```
state <state_name>:
    <state_body>
```

Goto Action

The `goto` action is used to transition between states. Here is an example of using the `goto` action to transition from one state to another before triggering:

```
state my_state_0:
    goto my_state_1;

state my_state_1:
    trigger;
```
Conditional Branching

The trigger state machine language supports one-, two-, and three-way conditional branching per state.

- **One-way branching** involves using `goto` actions without any `if/elseif/else/endif` constructs:
  ```
  state my_state_0:
  goto my_state_1;
  ```

- **Two-way conditional branching** uses `goto` actions with `if/else/endif` constructs:
  ```
  state my_state_0:
  if (<condition1>) then
  goto my_state_1;
  else
  goto my_state_0;
  endif
  ```

- **Three-way conditional branching** uses `goto` actions with `if/else/elseif/endif` constructs:
  ```
  state my_state_0:
  if (<condition1>) then
  goto my_state_1;
  elseif (<condition2>) then
  goto my_state_2;
  else
  goto my_state_0;
  endif
  ```

For more information on how to construct conditional statements represented above with `<condition1>` and `<condition2>`, refer to the section called Conditional Statements.

Counters

The four built-in 16-bit counters have fixed names and are called `$counter0`, `$counter1`, `$counter2`, `$counter3`. The counters can be reset, incremented, and used in conditional statements.

- **To reset a counter**, use the `reset_counter` action:
  ```
  state my_state_0:
  reset_counter $counter0;
  goto my_state_1;
  ```
• To increment a counter, use the increment_counter action:

    state my_state_0:
    increment_counter $counter3;
    goto my_state_1;

For more information on how to use counters in conditional statements, refer to Conditional Statements.

---

**Flags**

Flags can be used to monitor progress of the trigger state machine program as it executes. The four built-in flags have fixed names and are called $flag0, $flag1, $flag2, and $flag3. The flags can be set and cleared.

• To set a flag, use the set_flag action:

    state my_state_0:
    set_flag $flag0;
    goto my_state_1;

• To clear a flag, use the clear_flag action:

    state my_state_0:
    clear_flag $flag2;
    goto my_state_1;

---

**Conditional Statements**

**Debug Probe Conditions**

Debug probe conditions can be used in two-way and three-way branching conditional statements. Each debug probe condition consumes one trigger comparator on the PROBE port of the ILA to which the debug probe is attached.

**IMPORTANT:** Each PROBE port can have from 1 to 16 trigger comparators as configured at compile time. This means that you can only use a particular debug probe in a debug probe condition up from 1 to 16 times in the entire trigger state machine program, depending on the number of comparators configured on the PROBE port.
The debug probe conditions consist of a comparison operator and a value. The valid debug probe condition comparison operators are:

- `==` (equals)
- `!=` (not equals)
- `>` (greater than)
- `<` (less than)
- `>=` (greater than or equal to)
- `<=` (less than or equal to)

Valid values are of the form:

```
<bit_width>'<radix><value>
```

Where:

- `<bit width>` is the width of the probe (in bits)
- `<radix>` is one of
  - `b` (binary)
  - `h` (hexadecimal)
  - `u` (unsigned decimal)
- `<value>` is one of
  - `0` (Logical zero)
  - `1` (Logical one)
  - `X` (don't care)
  - `R` (0-to-1 transition) - Valid only for 1 bit probes
  - `F` (1-to-0 transition) - Valid only for 1 bit probes
  - `B` (both transitions) - Valid only for 1 bit probes
  - `N` (No transitions) - Valid only for 1 bit probes

Examples of valid debug probe condition values are:

- 1-bit binary value of 0
  
  `1'b0`

- 12-bit hex value of 7A
  
  `12'h07A`
• 9-bit integer value of 123
  
  `9u123`

Examples of debug probe condition statements are:

• A single-bit debug probe called `abc` equals 0
  
  ```
  if (abc == 1'b0) then
  ```

• A 23-bit debug probe `xyz` equals 456
  
  ```
  if (xyz >= 23'u456) then
  ```

• A 23-bit debug probe `klm` does not equal hex A5
  
  ```
  if (klm != 23'h0000A5) then
  ```

Examples of multiple debug probe condition statements are:

• Two debug probe comparisons combined with an "OR" function:
  
  ```
  if ((xyz >= 23'u456) || (abc == 1'b0)) then
  ```

• Two debug probe comparisons combined with an "AND" function:
  
  ```
  if ((xyz >= 23'u456) && (abc == 1'b0)) then
  ```

• Three debug probe comparisons combined with an "OR" function:
  
  ```
  if ((xyz >= 23'u456) || (abc == 1'b0) || (klm != 23'h0000A5)) then
  ```

• Three debug probe comparisons combined with an "AND" function:
  
  ```
  if ((xyz >= 23'u456) && (abc == 1'b0) && (klm != 23'h0000A5)) then
  ```

## Counter Conditions

Counter conditions can be used in two-way and three-way branching conditional statements. Each counter condition consumes one counter comparator.

**IMPORTANT:** Each counter has only one counter comparator. This means that you can only use a particular counter in a counter condition once in the entire trigger state machine program.

The probe port conditions consist of a comparison operator and a value. The valid probe condition comparison operators are:

- `==` (equals)
- `!=` (not equals)

**IMPORTANT:** Each counter is always 16 bits wide.
Examples of valid counter condition values are:

- 16-bit binary value of 0
  
  `16'b0000_0000_0000_0000
  `16'b0000000000000000

- 16-bit hex value of 7A
  
  `16'h007A

- 16-bit integer value of 123
  
  `16'u123

Examples of counter condition statements:

- Counter $counter0 equals binary 0
  
  `($counter0 == 16'b0000000000000000)

- Counter $counter2 does not equal decimal 23
  
  `($counter2 != 16'u23)

### Combined Debug Probe and Counter Conditions

Debug probe conditions and counter conditions can be combined together to form a single condition using the following rules:

- All debug probe comparisons must be combined together using the same "||" (OR) or "&&" (AND) operators.

- The combined debug probe condition can be combined with the counter condition using either the "||" (OR) or "&&" (AND) operators, regardless of the operator used to combine the debug probe comparisons together.

Examples of multiple debug probe and counter condition statements are:

- Two debug probe comparisons combined with an "OR" function, then combined with counter conditional using "AND" function:
  
  ```
  if (((xyz >= 23'u456) || (abc == 1'b0)) && ($counter0 == 16'u0023)) then
  ```

- Two debug probe comparisons combined with an "AND" function, then combined with counter conditional using "OR" function:
  
  ```
  if (((xyz >= 23'u456) && (abc == 1'b0)) || ($counter0 == 16'u0023)) then
  ```

- Three debug probe comparisons combined with an "OR" function, then combined with counter conditional using "AND" function:
  
  ```
  if (((xyz >= 23'u456) || (abc == 1'b0) || (klm != 23'h0000A5)) && ($counter0 == 16'u0023)) then
  ```
Appendix B: Trigger State Machine Language Description

- Three debug probe comparisons combined with an "AND" function, then combined with counter conditional using "OR" function:

\[
\text{if (}((xyz \geq 23\text{'}u456) \&\& (abc == 1\text{'}b0) \&\& (klm != 23\text{'}h0000A5)) \| (\$counter0 == 16\text{'}u0023)) \text{ then}
\]

**Trigger State Machine Language Grammar**

**NOTES:**
- The language is case insensitive
- Comment character is hash '#' character. Anything including and after a # character is ignored.
- 'THING' = THING is a terminal
- '{<thing>}' = 0 or more thing
- '[<thing>]' = 0 or 1 thing

<program> ::= <state_list>

<state_list> ::= <state_list> <state> | <state>

<state> ::= 'STATE' <state_label> ':' <if_condition> | <action_block>

<action_block> ::= <action_list> 'GOTO' <state_label> ';'
| <action_list> 'TRIGGER' ';'
| 'GOTO' <state_label> ';'
| 'TRIGGER';'

<action_list> ::= <action_statement> | <action_list> <action_statement>

<action_statement> ::= 'SET_FLAG' <flag_name> ';
| 'CLEAR_FLAG' <flag_name> ';
| 'INCREMENT_COUNTER' <counter_name> ';
| 'RESET_COUNTER' <counter_name> ';

<if_condition> ::= 'IF' '(' <condition> ')' 'THEN' <actionblock>
| ['ELSEIF' '(' <condition> ')' 'THEN' <actionblock>]
| 'ELSE' <actionblock>
| 'ENDIF'

<condition> ::= <probe_match_list>
| <counter_match>
| <probe_counter_match>

<probe_counter_match> ::= '(' <probe_counter_match> ')'
| <probe_match_list> <boolean_logic_op> <counter_match>
| <counter_match> <boolean_logic_op> <probe_match_list>

<probe_match_list> ::= '(' <probe_match> ')
| <probe_match>
Appendix B: Trigger State Machine Language Description

\[
\text{<probe_match>} ::= \text{<probe_match_list>} \ \text{<boolean_logic_op>} \ \text{<probe_match_list>}
| \ \text{<probe_name>} \ \text{<compare_op>} \ \text{<constant>}
| \ \text{<constant>} \ \text{<compare_op>} \ \text{<probe_name>}
\]

\[
\text{<counter_match>} ::= '(' \text{<counter_match>} ')'
| \ \text{<counter_name>} \ \text{<compare_op>} \ \text{<constant>}
| \ \text{<constant>} \ \text{<compare_op>} \ \text{<counter_name>}
\]

\[
\text{<constant>} ::= \text{<integer_constant>}
| \ \text{<hex_constant>}
| \ \text{<binary_constant>}
\]

\[
\text{<compare_op>} ::= '==' | '!=' | '>' | '>=' | '<' | '<='
\]

\[
\text{<boolean_logic_op>} ::= '&&' | '||'
\]

--- The following are in regular expression format to simplify expressions:
--- [AB]+ means match [AB] one or more times like A, AB, ABAB, AAA, etc
--- [AB]* means match [AB] zero or more times
\[
\text{<probe_name>} ::= [A-Z_].\{0,9\}[<>/.]/[A-Z_0-9].\{0,9\}<[/>/.]+
\text{<state_label>} ::= [A-Z_].\{0,9\}+
\text{<flag_name>} ::= \$FLAG[0-3]
\text{<counter_name>} ::= \$COUNTER[0-3]
\text{<hex_constant>} ::= \text{<integer>}'*h<hex_digit>+
\text{<binary_constant>} ::= \text{<integer>}'*b<binary_digit>+
\text{<integer_constant>} ::= \text{<integer>}'*u<integer_digit>+
\text{<integer>} ::= \text{<digit>}+
\text{<hex_digit>} ::= [0-9ABCDEFBN_]
\text{<binary_digit>} ::= [01XRFBN_]
\text{<digit>} ::= [0-9]
Appendix C

Configuration Memory Support

This section covers the various Flash device memories that are supported by Vivado® software. Use this section as a guide to select the appropriate configuration memory device for your application by Xilinx device, interface, manufacturer, Flash device, density, and data width.

Artix-7 Configuration Memory Devices

The Flash devices supported for configuration of Artix-7® devices that can be erased, blank checked, programmed, and verified by Vivado software are shown in Table C-1.

<table>
<thead>
<tr>
<th>Interface</th>
<th>Manufacturer</th>
<th>Manufacturer Family</th>
<th>Device (Alias)</th>
<th>Density (Mbits)</th>
<th>Data Widths (bits)</th>
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<tbody>
<tr>
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<td>28f128g18f</td>
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<td>x16</td>
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<td>256</td>
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### Table C-1: Supported Flash Memory Devices for Artix-7 Device Configuration

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<th>Interface</th>
<th>Manufacturer</th>
<th>Manufacturer Family</th>
<th>Device (Alias)</th>
<th>Density (Mbits)</th>
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## Table C-1: Supported Flash Memory Devices for Artix-7 Device Configuration

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<th>Device (Alias)</th>
<th>Density (Mbits)</th>
<th>Data Widths (bits)</th>
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Kintex-7 Configuration Memory Devices

The Flash devices supported for configuration of Kintex®-7 devices that can be erased, blank checked, programmed, and verified by Vivado software are shown in Table C-2.

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### Table C-2: Supported Flash Memory Devices for Kintex-7 Device Configuration

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### Appendix C: Configuration Memory Support

### Table C-2: Supported Flash Memory Devices for Kintex-7 Device Configuration

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<th>Density (Mbits)</th>
<th>Data Widths (bits)</th>
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## Virtex-7 Configuration Memory Devices

The Flash devices supported for configuration of Virtex®-7 devices that can be erased, blank checked, programmed, and verified by Vivado software are shown in Table C-3.

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### Table C-3: Supported Flash Memory Devices for Virtex-7 Device Configuration

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**Kintex UltraScale Configuration Memory Devices**

The Flash devices supported for configuration of Kintex® UltraScale™ devices that can be erased, blank checked, programmed, and verified by Vivado software are shown in Table C-4.

**Table C-4: Supported Flash Memory Devices for Kintex UltraScale Device Configuration**

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<th>Interface</th>
<th>Manufacturer</th>
<th>Manufacturer Family</th>
<th>Device (Alias)</th>
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### Table C-4:  Supported Flash Memory Devices for Kintex UltraScale Device Configuration

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<th>Data Widths (bits)</th>
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## Configuration Memory Support

### Table C-4: Supported Flash Memory Devices for Kintex UltraScale Device Configuration

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### Kintex UltraScale+ Configuration Memory Devices

The Flash devices supported for configuration of Kintex® UltraScale+™ devices that can be erased, blank checked, programmed, and verified by Vivado software are shown in Table C-5.

**Table C-5: Supported Flash Memory Devices for Kintex UltraScale+ Device Configuration**

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<th>Interface</th>
<th>Manufacturer</th>
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<th>Device (Alias)</th>
<th>Density (Mbits)</th>
<th>Data Widths (bits)</th>
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### Appendix C: Configuration Memory Support

**Table C-5: Supported Flash Memory Devices for Kintex UltraScale+ Device Configuration**

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<tr>
<th>Interface</th>
<th>Manufacturer</th>
<th>Manufacturer Family</th>
<th>Device (Alias)</th>
<th>Density (Mbits)</th>
<th>Data Widths (bits)</th>
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## Appendix C: Configuration Memory Support

### Virtex UltraScale Configuration Memory Devices

The Flash devices supported for configuration of Virtex® UltraScale™ devices that can be erased, blank checked, programmed, and verified by Vivado software are shown in Table C-6.

<table>
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<th>Interface</th>
<th>Manufacturer</th>
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<th>Device (Alias)</th>
<th>Density (Mbits)</th>
<th>Data Widths (bits)</th>
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### Table C-6: Supported Flash Memory Devices for Virtex UltraScale Device Configuration

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Table C-6: Supported Flash Memory Devices for Virtex UltraScale Device Configuration

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# Appendix C: Configuration Memory Support

## Virtex UltraScale+ Configuration Memory Devices

The Flash devices supported for configuration of Virtex® UltraScale+™ devices that can be erased, blank checked, programmed, and verified by Vivado software are shown in Table C-7.

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### Supported Flash Memory Devices for Virtex UltraScale+ Device Configuration

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<tr>
<td>SPI</td>
<td>Spansion</td>
<td>s25f1xxx</td>
<td>s25f256sxxxxxx0</td>
<td>256</td>
<td>x1, x2, x4, x8</td>
</tr>
<tr>
<td>SPI</td>
<td>Spansion</td>
<td>s25f1xxx</td>
<td>s25f256sxxxxxx1</td>
<td>256</td>
<td>x1, x2, x4, x8</td>
</tr>
<tr>
<td>SPI</td>
<td>Spansion</td>
<td>s25f1xxx</td>
<td>s25fl512s</td>
<td>512</td>
<td>x1, x2, x4, x8</td>
</tr>
</tbody>
</table>
Zynq-7000 Configuration Memory Devices

The Flash devices supported for configuration of Zynq®-7000 devices that can be erased, blank checked, programmed, and verified by Vivado software are shown in Table C-8.

*Note:* The U-Boot tags used to build the Configuration Memory Device Programmer are as follows:

<table>
<thead>
<tr>
<th>Interface</th>
<th>UBoot Tags</th>
</tr>
</thead>
<tbody>
<tr>
<td>qspi</td>
<td>xilinx-v2015.2.01</td>
</tr>
<tr>
<td>nor</td>
<td>xilinx-14.3-build1</td>
</tr>
<tr>
<td>nand</td>
<td>xilinx-v2015.2.01</td>
</tr>
</tbody>
</table>

Table C-8: Supported Flash Memory Devices for Zynq-7000 Device Configuration

<table>
<thead>
<tr>
<th>Interface</th>
<th>Manufacturer</th>
<th>Manufacturer Family</th>
<th>Device</th>
<th>Density (Mbits)</th>
<th>Data Widths (bits)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAND</td>
<td>Micron</td>
<td>m29ew</td>
<td>mt29f2g08ab</td>
<td>2,048</td>
<td>x8</td>
</tr>
<tr>
<td>NAND</td>
<td>Micron</td>
<td>m29ew</td>
<td>mt29f2g16ab</td>
<td>2,048</td>
<td>x16</td>
</tr>
<tr>
<td>NAND</td>
<td>Spansion</td>
<td>s34ml</td>
<td>s34ml01g1</td>
<td>1,024</td>
<td>x16, x8</td>
</tr>
<tr>
<td>NAND</td>
<td>Spansion</td>
<td>s34ml</td>
<td>s34ml02g1</td>
<td>2,048</td>
<td>x16, x8</td>
</tr>
<tr>
<td>NOR</td>
<td>Micron</td>
<td>m29ew</td>
<td>28f032m29ewt</td>
<td>32</td>
<td>x8</td>
</tr>
<tr>
<td>NOR</td>
<td>Micron</td>
<td>m29ew</td>
<td>28f064m29ewt</td>
<td>64</td>
<td>x8</td>
</tr>
<tr>
<td>NOR</td>
<td>Micron</td>
<td>m29ew</td>
<td>28f128m29ewh</td>
<td>128</td>
<td>x8</td>
</tr>
<tr>
<td>NOR</td>
<td>Micron</td>
<td>m29ew</td>
<td>28f256m29ewh</td>
<td>256</td>
<td>x8</td>
</tr>
<tr>
<td>NOR</td>
<td>Micron</td>
<td>m29ew</td>
<td>28f512m29ewh</td>
<td>512</td>
<td>x8</td>
</tr>
<tr>
<td>QSPI</td>
<td>Macronix</td>
<td>mx25l</td>
<td>mx25l25635f</td>
<td>256</td>
<td>x4-dual_shared, x4-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Macronix</td>
<td>mx66l</td>
<td>mx66l51235f</td>
<td>512</td>
<td>x4-dual_shared, x4-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Micron</td>
<td>mt25q</td>
<td>mt25q512</td>
<td>512</td>
<td>x4-dual_shared, x4-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Micron</td>
<td>n25q</td>
<td>n25q64</td>
<td>64</td>
<td>x4-dual_shared, x4-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Micron</td>
<td>n25q</td>
<td>n25q128</td>
<td>128</td>
<td>x4-dual_shared, x4-dual_parallel</td>
</tr>
</tbody>
</table>
## Appendix C: Configuration Memory Support

### Table C-8: Supported Flash Memory Devices for Zynq-7000 Device Configuration

<table>
<thead>
<tr>
<th>Interface</th>
<th>Manufacturer</th>
<th>Manufacturer Family</th>
<th>Device</th>
<th>Density (Mbits)</th>
<th>Data Widths (bits)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QSPI</td>
<td>Micron</td>
<td>n25q</td>
<td>n25q256</td>
<td>256</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Micron</td>
<td>n25q</td>
<td>n25q512</td>
<td>512</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Micron</td>
<td>n25q</td>
<td>n25q00a</td>
<td>1,024</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Spansion</td>
<td>s25flxxxp</td>
<td>s25fl129p</td>
<td>128</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Spansion</td>
<td>s25flxxxxs</td>
<td>s25fl128s-1.8v [s25fl127s]</td>
<td>128</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Spansion</td>
<td>s25flxxxxs</td>
<td>s25fl128s-3.3v [s25fl127s]</td>
<td>128</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Spansion</td>
<td>s25flxxxxs</td>
<td>s25fl256s-1.8v</td>
<td>256</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Spansion</td>
<td>s25flxxxxs</td>
<td>s25fl256s-3.3v</td>
<td>256</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Spansion</td>
<td>s25flxxxxs</td>
<td>s25fl512s</td>
<td>512</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Spansion</td>
<td>s70flxxxxp</td>
<td>s70fl01gs_00</td>
<td>1,024</td>
<td>x4-dual_stacked</td>
</tr>
<tr>
<td>QSPI</td>
<td>Winbond</td>
<td>w25q</td>
<td>w25q128</td>
<td>128</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
</tbody>
</table>
Zynq UltraScale+ MPSoC Configuration Memory Devices

The Flash devices supported for configuration of Zynq® UltraScale+™ MPSoC devices that can be erased, blank checked, programmed, and verified by Vivado software are shown in Table C-9.

Table C-9: Supported Flash Memory Devices for Zynq® UltraScale+ MPSoC Device Configuration

<table>
<thead>
<tr>
<th>Interface</th>
<th>Manufacturer</th>
<th>Manufacturer Family</th>
<th>Device</th>
<th>Density (Mbits)</th>
<th>Data Widths (bits)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAND</td>
<td>Micron</td>
<td>m29ew</td>
<td>mt29f2g08ab</td>
<td>2,048</td>
<td>x8</td>
</tr>
<tr>
<td>NAND</td>
<td>Spansion</td>
<td>s34ml</td>
<td>s34ml01g1</td>
<td>1,024</td>
<td>x8</td>
</tr>
<tr>
<td>NAND</td>
<td>Spansion</td>
<td>s34ml</td>
<td>s34ml02g1</td>
<td>2,048</td>
<td>x8</td>
</tr>
<tr>
<td>QSPI</td>
<td>Macronix</td>
<td>mx25l</td>
<td>mx25l25635f</td>
<td>256</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Micron</td>
<td>mt25ql</td>
<td>mt25ql512</td>
<td>512</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Micron</td>
<td>mt25ql</td>
<td>mt25ql01g</td>
<td>1,024</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Micron</td>
<td>mt25ql</td>
<td>mt25ql02g</td>
<td>2,048</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Micron</td>
<td>mt25qu</td>
<td>mt25qu512</td>
<td>512</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Micron</td>
<td>n25q</td>
<td>n25q64</td>
<td>64</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Micron</td>
<td>n25q</td>
<td>n25q128</td>
<td>128</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Micron</td>
<td>n25q</td>
<td>n25q256</td>
<td>256</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Micron</td>
<td>n25q</td>
<td>n25q512</td>
<td>512</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Micron</td>
<td>n25q</td>
<td>n25q00a</td>
<td>1,024</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
</tbody>
</table>
## Configuration Memory Support

### Table C-9: Supported Flash Memory Devices for Zynq® UltraScale+ MPSoC Device Configuration

<table>
<thead>
<tr>
<th>Interface</th>
<th>Manufacturer</th>
<th>Manufacturer Family</th>
<th>Device</th>
<th>Density (Mbits)</th>
<th>Data Widths (bits)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QSPI</td>
<td>Spansion</td>
<td>s25flxxxp</td>
<td>s25fl129p</td>
<td>128</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Spansion</td>
<td>s25flxxxxs</td>
<td>s25fl128s-1.8v [s25fl127s]</td>
<td>128</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Spansion</td>
<td>s25flxxxxs</td>
<td>s25fl128s-3.3v [s25fl127s]</td>
<td>128</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Spansion</td>
<td>s25flxxxxs</td>
<td>s25fl256s-1.8v</td>
<td>256</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Spansion</td>
<td>s25flxxxxs</td>
<td>s25fl256s-3.3v</td>
<td>256</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Spansion</td>
<td>s25flxxxxs</td>
<td>s25fl512s</td>
<td>512</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
<tr>
<td>QSPI</td>
<td>Spansion</td>
<td>s70flxxxp</td>
<td>s70fl01gs_00</td>
<td>1,024</td>
<td>x4-dual_stacked, x4-single, x8-dual_parallel</td>
</tr>
</tbody>
</table>
Appendix D

Additional Resources and Legal Notices

Xilinx Resources

For support resources such as Answers, Documentation, Downloads, and Forums, see Xilinx Support.

Solution Centers

See the Xilinx Solution Centers for support on devices, software tools, and intellectual property at all stages of the design cycle. Topics include design assistance, advisories, and troubleshooting tips.

References

These documents provide supplemental material useful with this guide:

Vivado® Design Suite Documentation

9. 7 Series FPGAs Configuration User Guide (UG470)
10. 7 Series FPGAs and Zynq-7000 All Programmable SoC XADC Dual 12-Bit 1 MSPS Analog-to-Digital Converter User Guide (UG480)

11. UltraScale Architecture Configuration User Guide (UG570)


13. Xilinx Virtual Cable Running on Zynq-7000 Using the PetaLinux Tools (XAPP1251)


15. Xilinx In-System Programming Using an Embedded Microcontroller (XAPP058)

Xilinx IP Documentation

16. LogiCORE IP Virtual Input/Output (VIO) v3.0 Product Guide (PG159)

17. LogiCORE IP IBERT for 7 Series GTX Transceivers (PG132)

18. LogiCORE IP IBERT for 7 Series GTP Transceivers (PG133)

19. LogiCORE IP IBERT for 7 Series GTH Transceivers (PG152)


21. LogiCORE IP JTAG to AXI Master v1.0 Product Guide (PG174)

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**Training Courses**

Xilinx provides a variety of training courses and QuickTake videos to help you learn more about the concepts presented in this document. Use these links to explore related training resources:

1. Vivado Design Suite Hands-on Introductory Workshop Training Course
2. Vivado Design Suite Tool Flow Training Course
3. Essentials of FPGA Design Training Course
4. Vivado Design Suite QuickTake Video: Designing with Vivado IP Integrator
5. Vivado Design Suite QuickTake Video: Targeting Zynq Devices Using Vivado IP Integrator
7. Vivado Design Suite QuickTake Video: Using Vivado Design Suite with Revision Control
8. Debugging Techniques Using the Vivado Logic Analyzer
9. Vivado Design Suite QuickTake Video Tutorials
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