

Kintex-7 FPGA KC705 Base Targeted Reference Design

User Guide

Vivado Design Suite 2014.3

UG882 (v5.0) December 19, 2014



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Revision History

The following table shows the revision history for this document.

Date	Version	Revision
01/18/2012	1.0	Initial Xilinx release.
05/22/2012	1.1	Updated last paragraph of Hardware Test Setup Requirements . Updated Figure 3-1 . Updated table Table B-8 .
08/03/2012	1.2	Updated last paragraph of Hardware Test Setup Requirements . Added Vivado® tools to Rebuilding the Base TRD . Added step 6 to <i>Generating the MIG IP Core through the CORE Generator Tool</i> . Added Implementing the Design Using the Vivado Tools . Added Vivado tools to Configuration Requirements .
01/03/2013	2.0	The document was updated for Vivado® Design Suite 2012.4. KC705 was added to the title. The USB stick is removed from the kit and instead, design files are accessible from the Docs & Designs tab at www.xilinx.com/kc705 . Removing the stick changed sections Copy the Base TRD Files, page 17 and Shutting Down the System, page 24 . The sections “Implementing the Design Using Command Line Options” and “Implementing the Design Using the PlanAhead Design Tool” before Implementing the Design Using the Vivado Tools, page 25 were deleted. In Figure 3-1 and Figure 5-1 , at the Raw Packet Data Blocks, 64 x 156.25 MHz changed to 64 x 250 MHz. Removed references to ISE® and PlanAhead™ design tool implementation flows throughout the book. Replaced instances of CD-ROM with DVD-ROM. Changed the procedure in Configuring the PCIe Link as x4 Lane at 2.5 Gb/s, page 67 . In Appendix A, Resource Utilization , utilization numbers for the slice registers, slice LUTs, and MMCM_ADV resources changed. Figure C-1 added ip_catalog to the directory structure. Added support links to Appendix E, Additional Resources . Added Appendix F, Regulatory and Compliance Information and Appendix G, Warranty .
04/16/2013	3.0	Updated for Vivado Design Suite 2013.1. Replaced <i>ModelSim</i> references with <i>QuestaSim</i> . Replaced Figure 2-1 . Deleted reference to the LogiCORE™ system in Rebuilding the Base TRD, page 25 . Deleted the section <i>Generating the MIG IP Core through the CORE Generator Tool</i> . Updated Figure 2-19 . Updated section Simulating the Design, page 30 . Updated description of string TESTNAME=basic_test, page 32 . Updated PCIe documentation references to PG054 [Ref 3]. Updated references to Northwest Logic DMA core in Appendix E, Additional Resources . Changed the Master Answer Record link in References, page 89 .
08/21/2014	4.0	Updated for Vivado Design Suite 2014.2. Removed ISE® Lab Tools from Requirements, page 11 and changed references to ISE Design Suite to Vivado Design Suite throughout. Steps to generate the MCS file are updated in Implementing the Design Using the Vivado Tools, page 25 . Revised steps to program the BPI Linear Flash memory in Configuration Requirements, page 27 . Figure 2-16, Programming the KC05 Board Flash (Windows 7 OS) was removed. Revised the procedure in Hardware-Only Modifications, page 67 . Updated Appendix E, Additional Resources links and the Declaration of Conformity link in Appendix F .
12/19/2014	5.0	Updated for Vivado Design Suite 2014.3. The directory structure of the TRD ZIP file changed, affecting several procedures, Figure 2-7 , and Appendix C, Directory Structure . Updated sections Rebuilding the Base TRD, page 25 , Reprogramming the Base TRD, page 26 , and Simulation, page 29 . Updated utilization numbers in Table A-1 and Table A-2 .

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Introduction

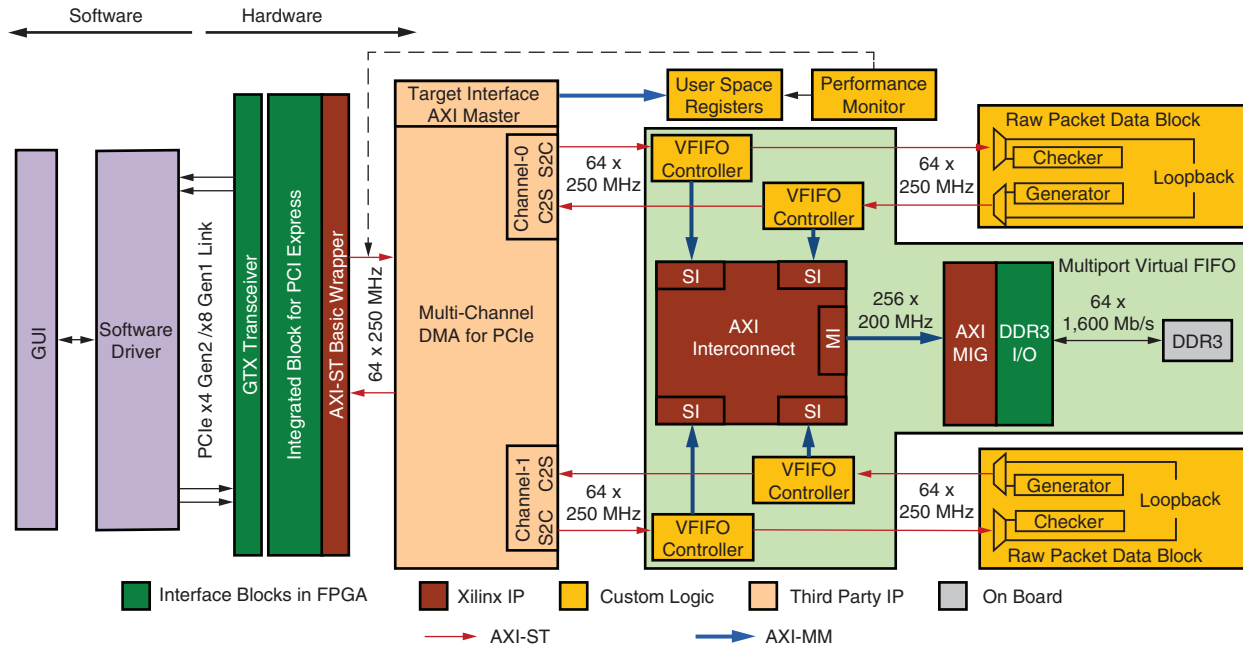
The Kintex®-7 Base Targeted Reference Design (TRD) delivers all the basic components of a targeted design platform for high performance in a single package. Targeted design platforms from Xilinx provide customers with simple, smart design platforms for the creation of FPGA-based solutions in a wide variety of industries.

This user guide details a TRD developed for high performance on a Kintex-7 FPGA. The aim is to accelerate the design cycle and enable FPGA designers to spend less time developing the infrastructure of an application and more time creating an unique value-add design. The primary components of the Kintex-7 Base TRD are the Kintex-7 FPGA integrated Endpoint block for PCI Express®, Northwest Logic Packet DMA, Memory Interface Solutions for DDR3, and AXI Interconnect IP block.

The Base Targeted Reference Design

The Kintex-7 FPGA Base TRD showcases the capabilities of Kintex-7 FPGAs and the various IP cores developed for this FPGA family. [Figure 1-1](#) shows the block level overview of the architecture of the TRD. With a few custom RTL blocks interfacing with the IP blocks, the TRD can deliver up to 10 Gb/s performance end to end.

This chapter introduces the TRD and summarizes the TRD features.



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Figure 1-1: Kintex-7 FPGA Base TRD Block Diagram

Note: The arrows in Figure 1-1 indicate AXI interface directions from master to slave. They do not indicate data flow directions.

Base TRD Features

The Kintex-7 FPGA Base TRD has these components:

- 7 Series FPGAs integrated Endpoint block for PCI Express core:
 - Configured with either 4 lanes at a 5 Gb/s data rate (Gen2) or 8 lanes at a 2.5 Gb/s data rate (Gen1) for PCI Express v2.0.
 - Provides a user interface compliant with AXI4 Stream interface protocol.
 - A performance monitor tracks the integrated block AXI-4-Stream interface for PCIe transactions.
- Bus mastering Scatter Gather Packet DMA Engine from Northwest Logic, a multichannel DMA:
 - Supports full-duplex operation with independent transmit and receive paths.
 - Provides an AXI-4 Stream interface on the backend.
 - Monitors the performance of data transfers in the receive and transmit directions.
 - Provides an AXI-4 memory mapped target interface to access user-defined registers.

Note: The Northwest Logic Packet DMA shipped with the Base TRD is an evaluation version and expires after 12 hours of run time. To get the full version, contact Northwest Logic [Ref 1].

- Multiport Virtual FIFO
 - DDR3 SDRAM (64 bits at 1,600 Mb/s, 800 MHz) is used for buffering packets. The Memory Controller is delivered through the Memory Interface Generator (MIG) tool and interfaces to the DDR3 SRAM.

- AXI Interconnect IP core with the Memory Controller supports multiple ports on the memory.
- The Packetized Virtual FIFO controller controls the addressing of the DDR3 memory for each port, allowing the DDR3 memory to be used as Virtual Packet FIFO.
- Software driver for a 32-bit Linux platform
 - Configures the hardware design parameters
 - Generates and consumes traffic
 - Provides a Graphical User Interface (GUI) to report status and performance statistics

The 7 Series FPGAs Integrated Block for PCI Express core and the Packet DMA are responsible for data transfers from the host system to the Endpoint card (S2C) and Endpoint card to host system (C2S). Data to and from the host is stored in a Virtual FIFO built around the DDR3 memory. This Multiport Virtual FIFO abstraction layer around the DDR3 memory allows the traffic to be moved efficiently without the need to manage addressing and arbitration on the memory interface. It also provides a larger depth when compared to storage implemented using block RAMs.

The Integrated Block for PCI Express core, Packet DMA, and Multiport Virtual FIFO can be considered as the base system. The base system can bridge the host system to any user application running on the other end. The Raw Data Packet module is a dummy application which generates and consumes packets. It can be replaced by any user-specific protocol like Aurora or XAUI.

The software driver runs on the host system. It generates raw data traffic for transmit operations in the S2C direction. It also consumes the data looped back or generated at the application end in the C2S direction.

The modular architecture of the Base TRD hardware and software components simplifies reuse and customization of the architecture to specific user requirements.

Getting Started

This chapter is a quick start guide enabling the user to test the Kintex®-7 FPGA Base TRD in hardware with the software driver provided and also simulate it. It provides step-by-step instructions for testing the design in hardware.

Note: The screen captures in this document are conceptual representatives of their subjects and provide general information only.

Requirements

This section lists the prerequisites for hardware testing and simulation of the Base TRD.

Hardware Test Setup Requirements

The prerequisites required to run and test the Base TRD are:

- KC705 board with the XC7K325T-2FFG900C FPGA
- Design files provided as a zipped collection under the Docs & Designs tab at www.xilinx.com/kc705 include:
 - Design source files
 - Device driver files
 - Board design files
- Vivado® Design Suite
- Micro USB cable
- PCIe® adapter cable, 4-pin to 6-pin
- Fedora 16 Live DVD for Intel-compatible PCs or pre-installed Fedora 16 Linux OS
- PC with PCIe v2.0 slot

For a list of all known issues, refer to the Kintex-7 FPGA Base Targeted Reference Design Release Notes and Known Issues Master Answer Record at www.xilinx.com/support/answers/45679.htm.

Simulation Requirements

The tools required to simulate the Base TRD are:

- Vivado Design Suite
- QuestaSim simulation software

TRD Demonstration Setup

This section provides the procedures for setting up the KC705 board and using the application GUI in preparation for demonstrating the Base TRD.

Note: When following the demonstration setup steps for the Kintex-7 FPGA Base TRD, if the behavior is not as described, refer to the known issues at www.xilinx.com/support/answers/45679.htm.

Board Configuration and Bring-Up

This section describes how to set up and install the KC705 board to demonstrate the Base TRD.

Configure KC705 Board Switches and Jumpers

1. Confirm the KC705 board jumpers and switches are configured as shown in [Table 2-1](#) and [Figure 2-1](#).

Table 2-1: Switch and Jumper Settings

Jumper	Function		Setting
J32	PCIe configuration width — 4 lane design		Jump 3-4
Switch	Function or Type		Setting
SW15	Board power slide-switch		Off
SW11	User GPIO DIP switch		
	4		Off
	3		Off
	2		Off
	1		Off
SW13	DIP switch SW13 positions 1 and 2 control the setting of address bits of the flash. DIP switch SW13 positions 3, 4, and 5 control which configuration mode.		
	5 (M0)	M2 =0 M1=1 M0=0 — Master BPI	Off
	4 (M1)	M2 =0 M1=0 M0=1 — Master SPI	On
	3 (M2)	M2 =1 M1=0 M0=1 — JTAG	Off
	2		Off
	1		Off

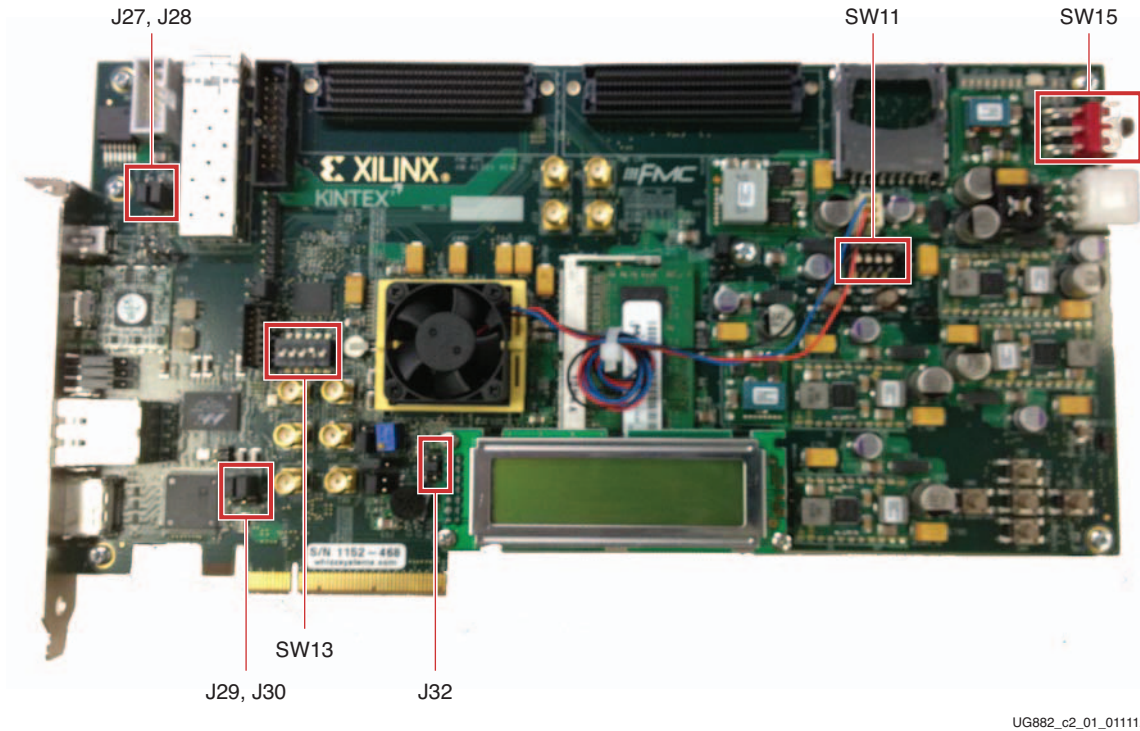
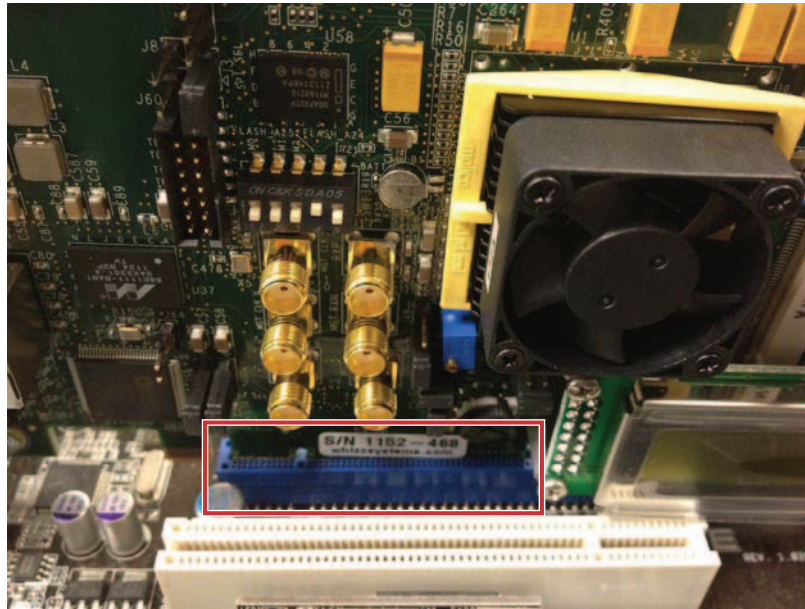


Figure 2-1: Switch and Jumper Locations

KC705 Board Installation

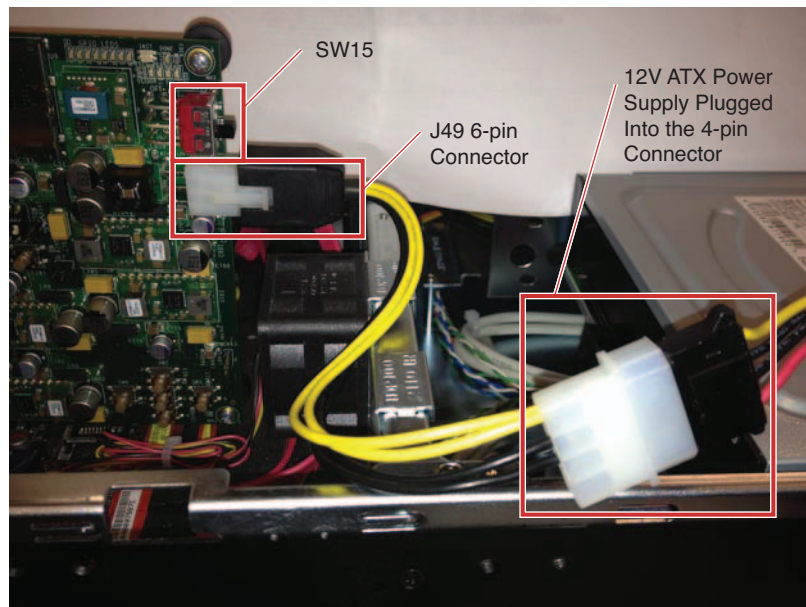
1. With the host PC switched off, insert the KC705 board in the PCIe slot through the PCI Express x8 or x16 edge connector (Figure 2-2). The Base TRD programmed on the KC705 board has a 4-lane PCIe v2.0 configuration, running at a 5 Gb/s link rate per lane. The PCI Express specification allows for a smaller lane width Endpoint to be installed into a larger lane width PCIe connector.



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Figure 2-2: KC705 Board Plugged Into a PCIe x16 Slot

2. Connect one of the spare 4-pin connectors from the PC 12V ATX power supply to J49 on the KC705 board using a 4-pin to 6-pin PCIe adapter cable. Toggle the KC705 board power switch SW15 to the ON position. [Figure 2-3](#) shows the 12V power supply connection and power switch SW15.



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Figure 2-3: Power Supply Connection

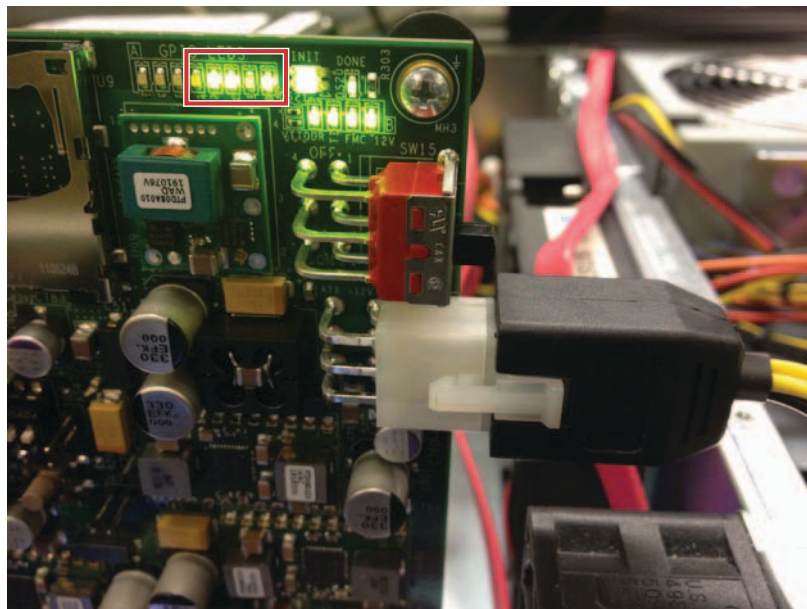
3. Confirm the connectors are latched tight and power on the PC.

Note: If the user wishes to boot Linux from the Fedora 16 Live DVD, place the DVD in the PC's DVD-ROM drive as soon as the PC system is powered on.

4. Check the status of the design on the KC705 board LEDs. The Base TRD provides status on the GPIO LEDs on the front side of the KC705 board near the upper right edge (Figure 2-4). When the PC is powered on and the Base TRD has successfully configured on the FPGA, the LED status indicators light. The LEDs are numbered from right to left. See Table 2-2 for a description of the LED status.

Table 2-2: LED Status for Base TRD Configuration

LED	LED Status	Description
0	On	The PCIe link is up.
1	Flashing	The PCIe user clock is present.
2	On	Lane width is as expected, else LED 2 flashes—expected lane width is 4 for a x4 design and 8 for an x8 design.
3	On	Memory calibration is done.
4 to 7	N/A	Not connected.



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Figure 2-4: GPIO LEDs Indicate Base TRD Status

Linux Boot Up and Driver Installation

Booting Fedora Live

If Fedora 16 Linux OS is installed on the PC's hard disk, boot as a root-privileged user and go to [step 2](#), otherwise go to [step 1](#).

1. To boot from the Fedora 16 Live DVD provided in the kit, place the DVD in the PC's DVD-ROM drive.

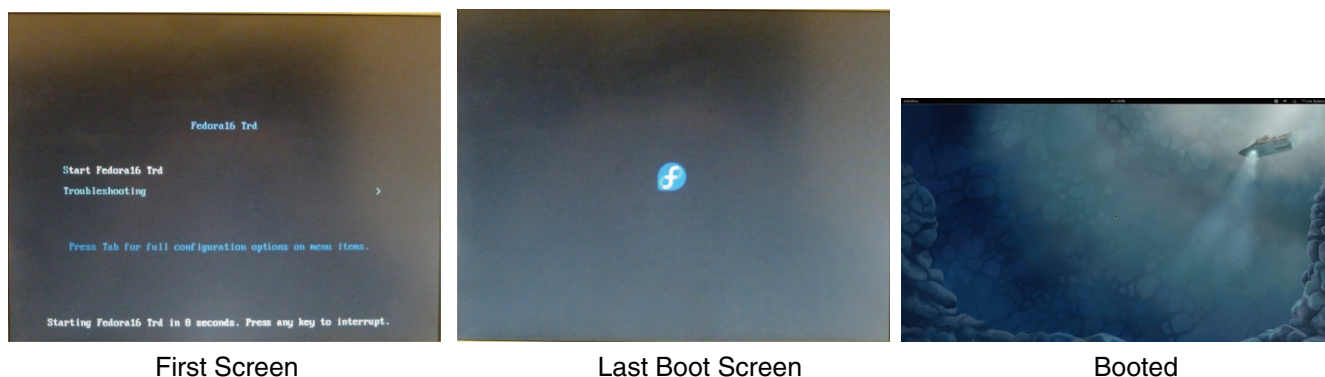
The Fedora 16 Live Media is for Intel-compatible PCs. For more details, see [Fedora Information, page 2](#). The DVD contains a complete, bootable 32-bit Fedora 16 environment with the proper packages installed for the Base TRD demonstration

environment. The PC boots from the DVD-ROM drive and logs into a liveuser account. This account has kernel development root privileges required to install and remove device driver modules.

Note: The BIOS boot order settings might have to be changed to make sure that the DVD-ROM is the first drive in the boot order. To set the boot order, enter the BIOS menu by pressing the DEL or F2 key when the system is powered on. Set the boot order and save the changes.

The DEL or F2 key is used by most PC systems to enter the BIOS setup. Some PCs might have a different way to enter the BIOS setup.

While booting from the DVD-ROM drive, the PC displays the images shown in [Figure 2-5](#).



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Figure 2-5: Fedora 16 Live DVD Boot Images

After the Fedora Core boots, log in as liveuser.

2. After Fedora Core boots, open a terminal window (click **Activities** > **Application**, scroll down, and click the **Terminal** icon).

To find out if the PCIe integrated Endpoint block is detected, at the terminal command line, type:

```
$ lspci
```

The **lspci** command displays the PCI and PCI Express buses of the PC. On the bus of the KC705 card slot is the message

```
Communication controller: Xilinx Corporation Device 7042
```

This message confirms that the design programmed into the KC705 board has been found by the BIOS and the Fedora 16 OS. The bus number varies depending on which PC motherboard and slot is used.

[Figure 2-6](#) shows an example of the output from the **lspci** command. The red highlight shows that Xilinx device 7042 has been found by the BIOS on bus number 2 (02:00.0 = bus.dev.function).


```
liveuser@localhost:~  
File Edit View Search Terminal Help  
00:14.2 PIC: Intel Corporation 5520/5500/X58 I/O Hub Control Status and RAS Registers (rev 12)  
00:14.3 PIC: Intel Corporation 5520/5500/X58 I/O Hub Throttle Registers (rev 12)  
00:19.0 Ethernet controller: Intel Corporation 82567LM-2 Gigabit Network Connection  
00:1a.0 USB Controller: Intel Corporation 82801JI (ICH10 Family) USB UHCI Controller #4  
00:1a.1 USB Controller: Intel Corporation 82801JI (ICH10 Family) USB UHCI Controller #5  
00:1a.2 USB Controller: Intel Corporation 82801JI (ICH10 Family) USB UHCI Controller #6  
00:1a.7 USB Controller: Intel Corporation 82801JI (ICH10 Family) USB2 EHCI Controller #2  
00:1b.0 Audio device: Intel Corporation 82801JI (ICH10 Family) HD Audio Controller  
00:1c.0 PCI bridge: Intel Corporation 82801JI (ICH10 Family) PCI Express Root Port 1  
00:1c.1 PCI bridge: Intel Corporation 82801JI (ICH10 Family) PCI Express Port 2  
00:1c.4 PCI bridge: Intel Corporation 82801JI (ICH10 Family) PCI Express Root Port 5  
00:1d.0 USB Controller: Intel Corporation 82801JI (ICH10 Family) USB UHCI Controller #1  
00:1d.1 USB Controller: Intel Corporation 82801JI (ICH10 Family) USB UHCI Controller #2  
00:1d.2 USB Controller: Intel Corporation 82801JI (ICH10 Family) USB UHCI Controller #3  
00:1d.7 USB Controller: Intel Corporation 82801JI (ICH10 Family) USB2 EHCI Controller #1  
00:1e.0 PCI bridge: Intel Corporation 82801 PCI Bridge (rev 90)  
00:1f.0 ISA bridge: Intel Corporation 82801JIR (ICH10R) LPC Interface Controller  
00:1f.2 IDE interface: Intel Corporation 82801JI (ICH10 Family) 4 port SATA IDE Controller #1  
00:1f.3 SMBus: Intel Corporation 82801JI (ICH10 Family) SMBus Controller  
00:1f.5 IDE interface: Intel Corporation 82801JI (ICH10 Family) 2 port SATA IDE Controller #2  
02:00.0 Communication controller: Xilinx Corporation Device 7042  
03:00.0 VGA compatible controller: nVidia Corporation GT218 [GeForce 210] (rev a2)  
03:00.1 Audio device: nVidia Corporation High Definition Audio Controller (rev a1)  
06:00.0 IDE interface: Marvell Technology Group Ltd. 88SE6121 SATA II Controller (rev b2)  
07:03.0 FireWire (IEEE 1394): Texas Instruments TSB43AB22A IEEE-1394a-2000 Controller (PHY/Link  
) [iOHCI-Lynx]
```

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Figure 2-6: PCI and PCI Express Bus Devices

Copy the Base TRD Files

Download the reference design from the [Docs & Designs](#) tab.

Unzip the downloaded ZIP file and copy the `k7_pcie_dma_ddr3_base` folder into any directory.

Driver Installation

To set up and run the TRD demonstration, the software driver should be installed on the PC system.

Installation of the software driver involves:

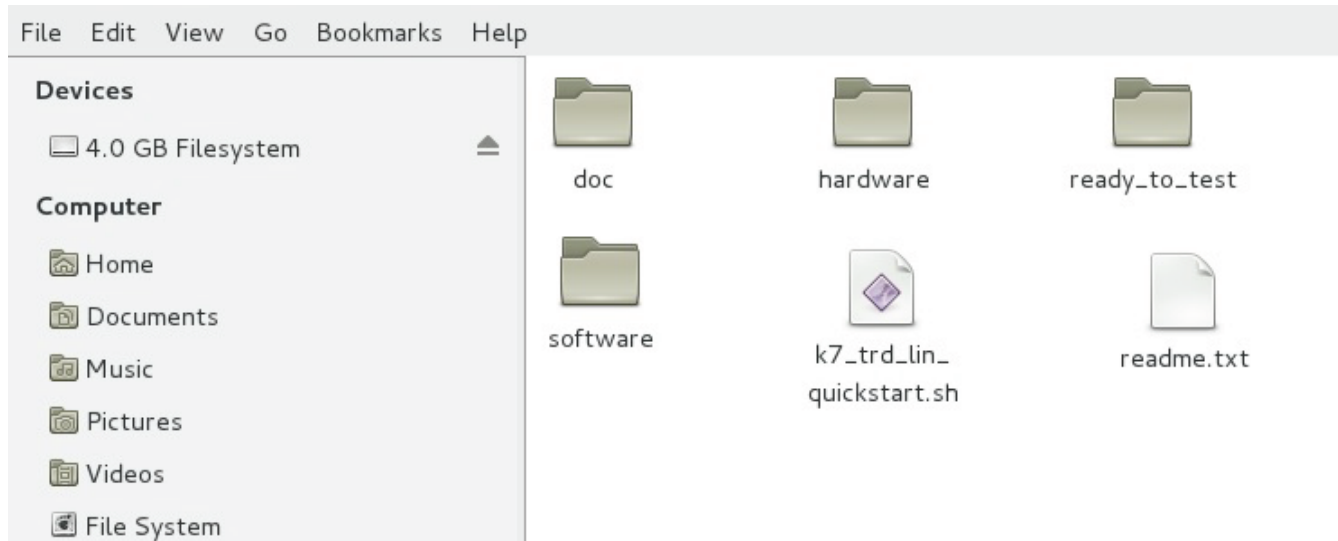
- Building the kernel objects and the GUI.
- Inserting the driver modules into the kernel.

After the driver modules are loaded, the application GUI can be invoked. The user can set parameters through the GUI and run the TRD.

When the user is done running the TRD, the application GUI can be closed and the drivers can be removed.

A script is provided to execute these actions. To run this script:

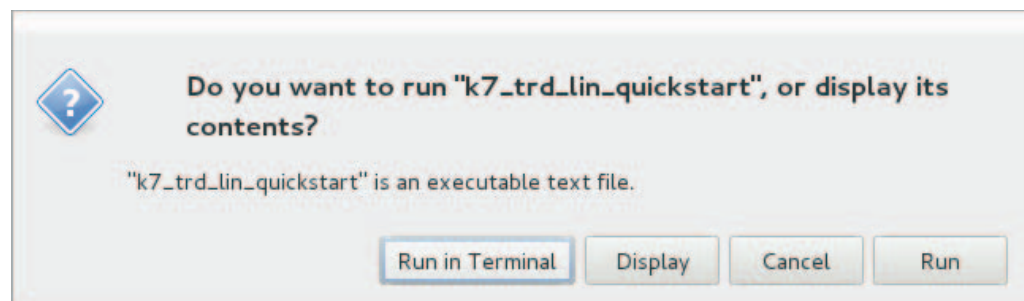
1. Double-click `k7_trd_lin_quickstart` in the `k7_pcie_dma_ddr3` folder ([Figure 2-7](#)).



UG882_c2_07_110314

Figure 2-7: k7_pcie_dma_ddr3 Folder

- When the window prompt shown in [Figure 2-8](#) appears. Click **Run in Terminal**.



UG882_c2_08_010612

Figure 2-8: Run in Terminal

The application GUI is invoked. Proceed to [Using the Application GUI](#) to set design parameters and run the Base TRD.

In case issues are encountered or if the user wants to understand driver details, the user can run the individual steps detailed in [Appendix D, Compiling Linux Drivers](#).

Using the Application GUI

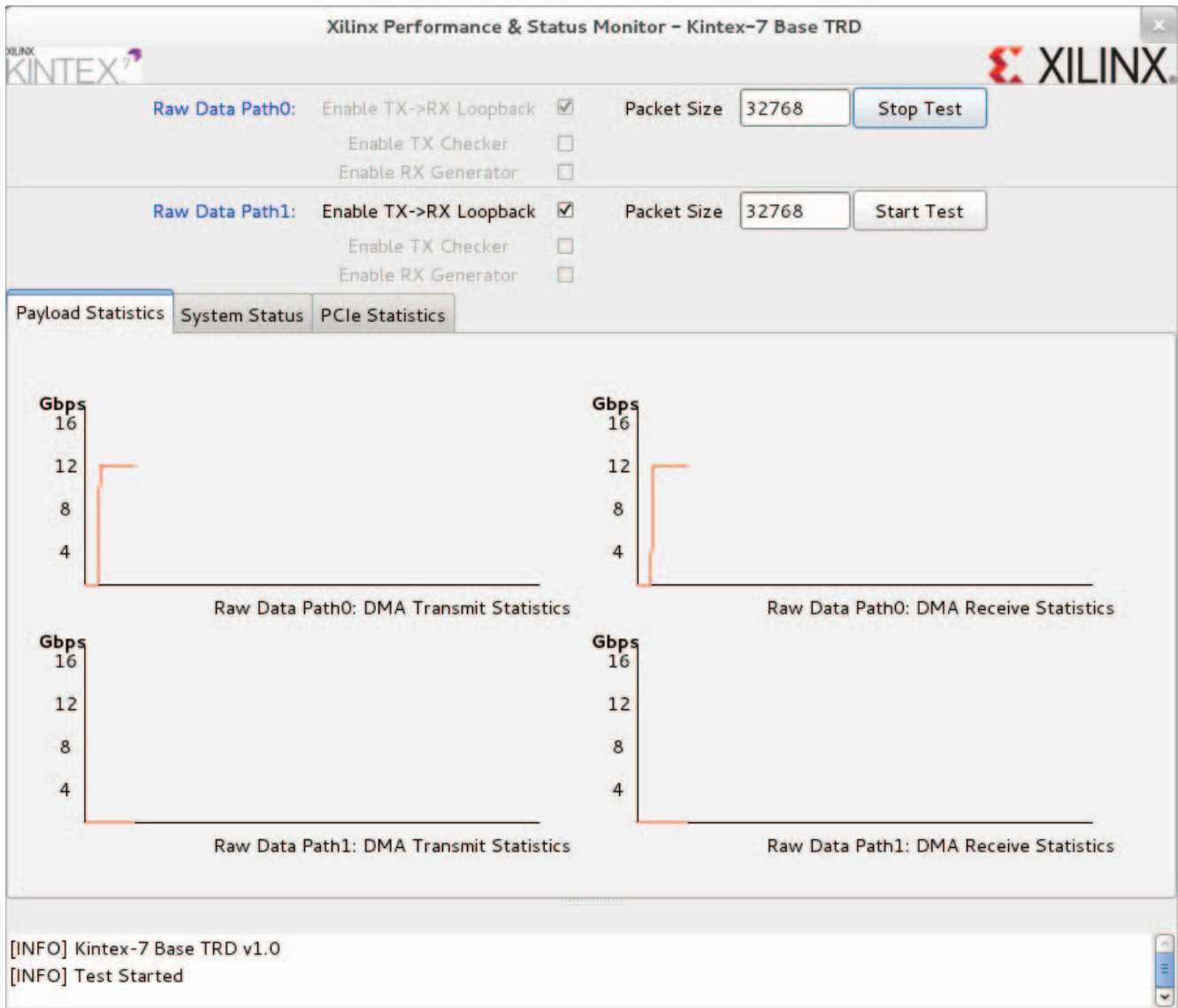
After the drivers are loaded and the GUI is invoked, the application can be configured for sending and receiving data. The GUI shows the Base TRD status and performance statistics collected over time.

This section provides a screen-by-screen description of the GUI.

Test Setup and Payload Statistics

This screen shows up as soon as the GUI is invoked. It defines the various test options provided for the raw datapaths.

For each raw datapath the user can input a fixed packet size in bytes. While executing the test, the software driver builds packets of fixed length. The packet size can range from 64 bytes to 32,768 bytes. Select **Enable Loopback** to loopback the transmit data and send it in the receive direction. This loopback is done at the application end (Raw Packet Data block). Click **Start Test** to begin packet generation. As packets are generated, the GUI plots the number of bytes transmitted and received by the Packet DMA for each raw datapath. Click **Stop Test** to stop packet generation. The screen in [Figure 2-9](#) shows the data throughput obtained from the C2S and S2C DMA engines for the raw data Path0 with **Enable TX→RX Loopback** selected.

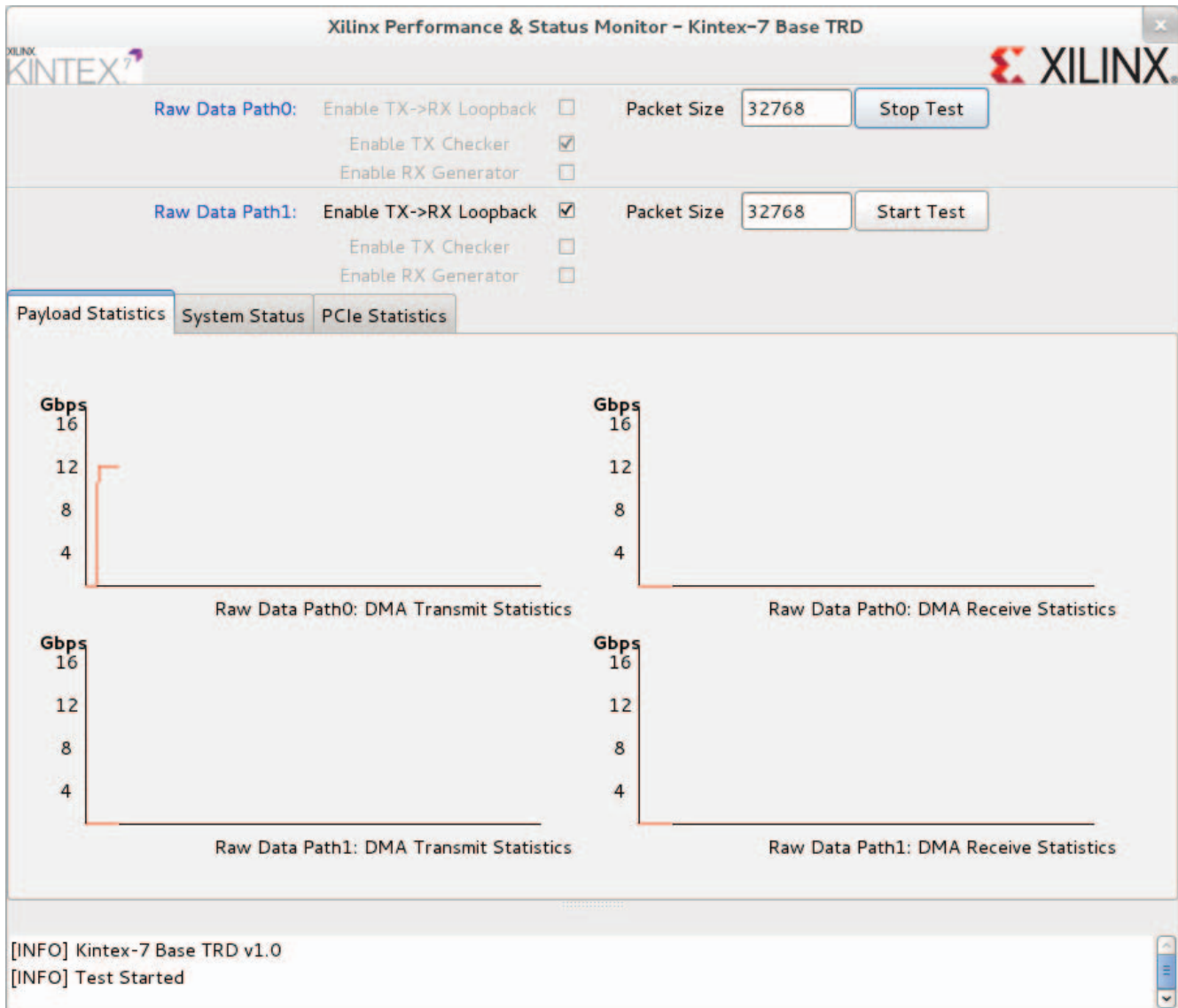


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Figure 2-9: Test Setup and Payload Statistics Screen – Raw Data TX>RX Loopback

Unselect **Enable Loopback** to select **Enable TX Checker** or **Enable RX Generator** or both. Select **Enable TX Checker** and click **Start Test** to enable the data checker implemented in hardware. The packets generated by the driver are transferred via the Packet DMA and are verified at the application end (Raw Packet Data block) by the

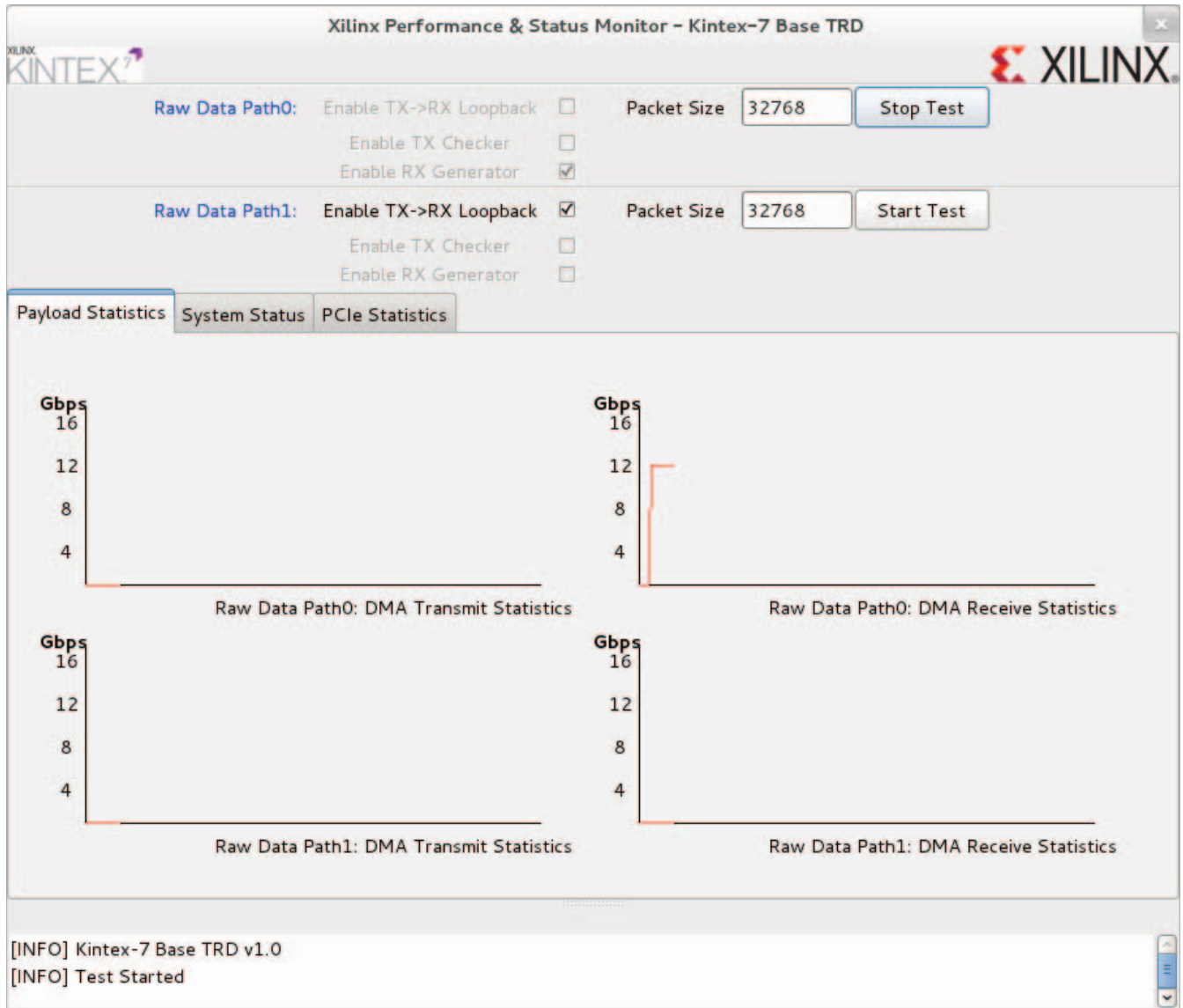
checker. The GUI plots the number of bytes transmitted by the Packet DMA. Click **Stop Test** to stop packet generation in the transmit path. The screen in Figure 2-10 shows the data throughput obtained from the S2C DMA engine for the raw data Path0 with **Enable TX Checker** selected.



UG882_c2_10_010612

Figure 2-10: Test Setup and Payload Statistics Screen – Raw Data TX Only

Uncheck **Enable TX Checker**, select **Enable RX Generator**, and click **Start Test** to enable the data generator implemented in hardware. The packets generated are transferred via the Packet DMA to the host system and are spot checked by the driver. The GUI plots the number of bytes received by the Packet DMA. Click **Stop Test** to stop packet generation in the receive path. The screen in Figure 2-11 shows the data throughput obtained from the S2C DMA engine for the raw data Path0 with **Enable RX Generator** selected.



UG882_c2_11_010612

Figure 2-11: Test Setup and Payload Statistics Screen – Raw Data RX Only

Select **Enable TX Checker** and **Enable RX Generator** and click **Start Test** to enable both the data checker and the data generator. Packets are generated and checked in both directions. The GUI plots the number of bytes transmitted and received by the Packet DMA. Click **Stop Test** to stop packet generation. The screen in Figure 2-12 shows the data throughput obtained from the S2C and C2S DMA engines for the raw data Path0 with **Enable TX Checker** and **Enable RX Generator** selected.

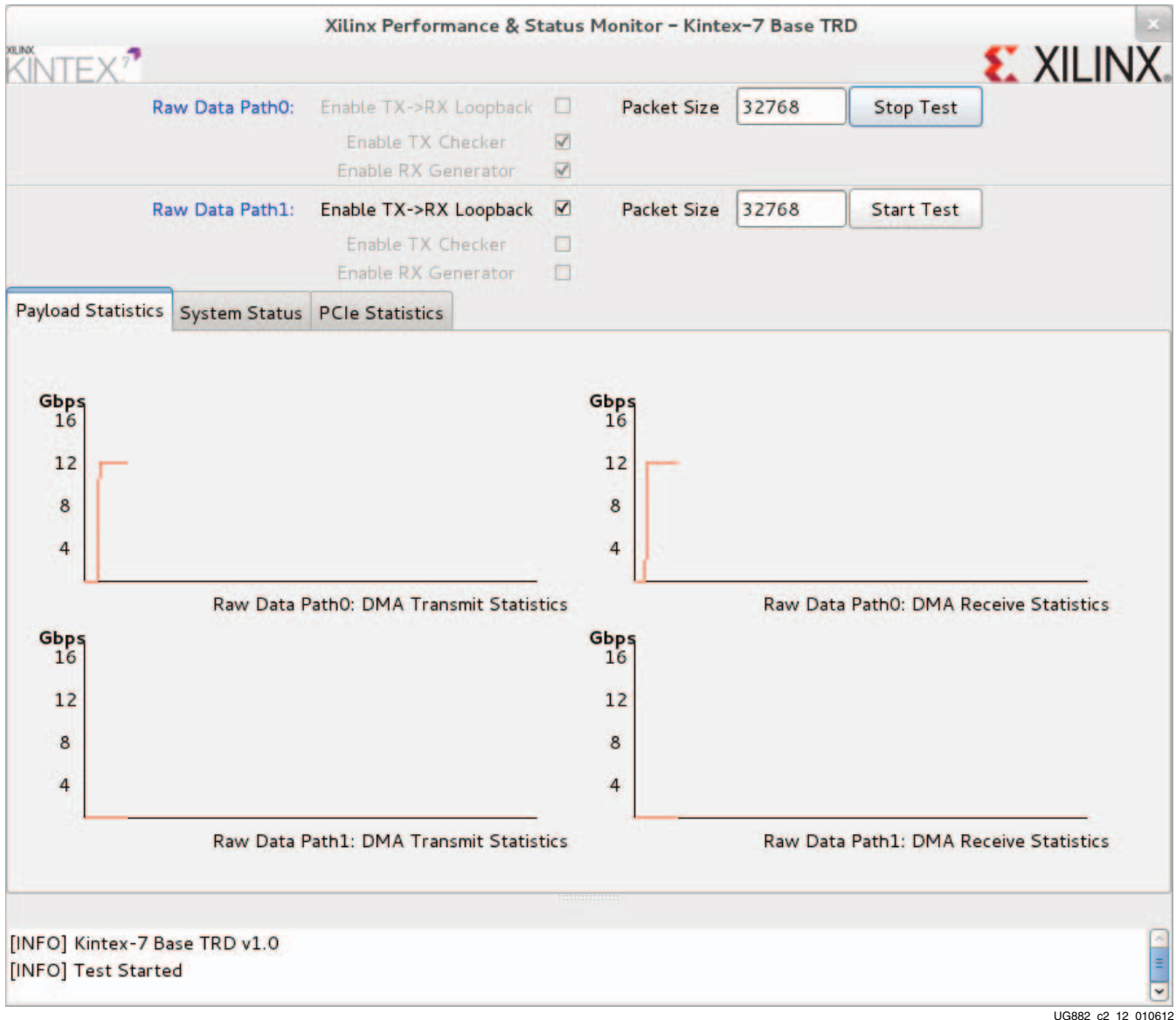
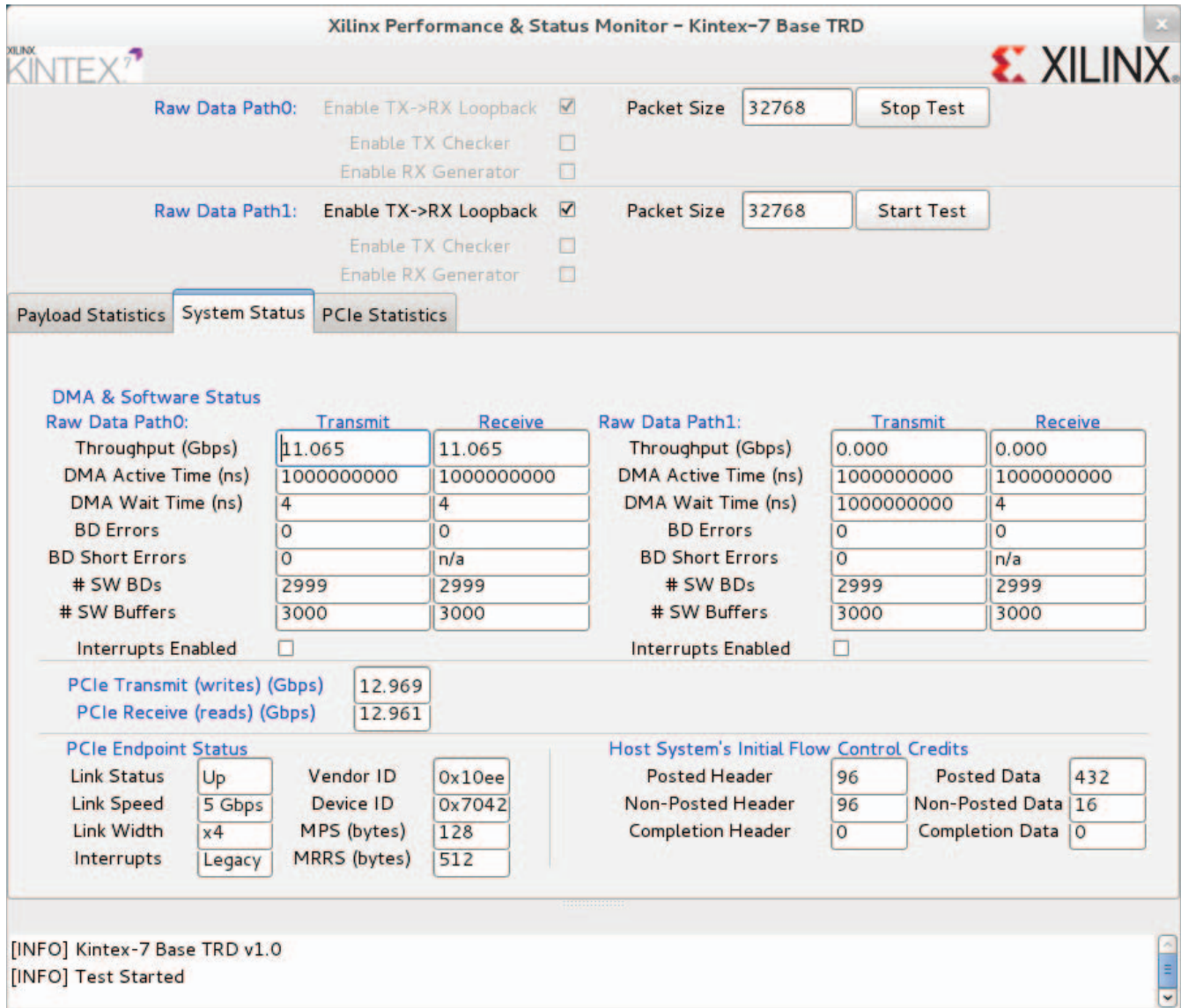


Figure 2-12: Test Setup and Payload Statistics Screen – Raw Data TX and RX

Note: If **Enable Loopback** is selected, then **Enable TX Checker** and **Enable RX Generator** options are not available to the user. If **Enable TX Checker** is selected, then the **Enable Loopback** option is not available to the user. If **Enable RX Generator** is selected, then the **Enable Loopback** option is not available to the user. The **Enable TX Checker** and **Enable RX Generator** options can be selected simultaneously. For both raw datapaths, all configuration options should be selected before clicking **Start Test**. Configuration options that a user changes while a test is running are not taken into account.

System Status

Click the **System Status** tab to view the system status screen (see Figure 2-13). This screen shows the throughput numbers reported by the DMA engines for raw data Path0 and the performance monitor on the transaction layer of the Kintex-7 FPGA. For more details on the System Status window, refer to Figure 3-10.

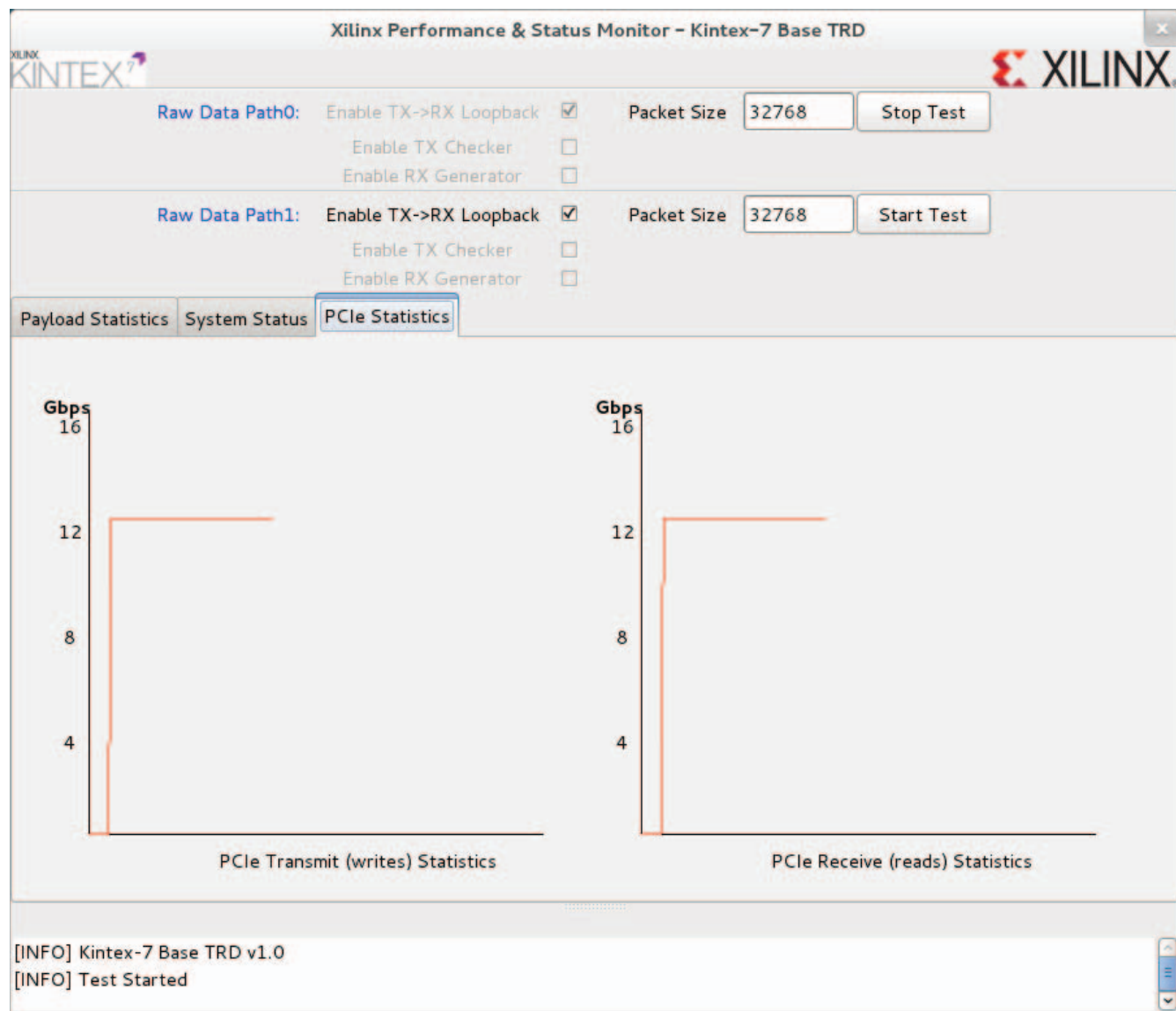


UG882_c2_13_010612

Figure 2-13: System Status

Transaction Statistics

Click the **PCIe Statistics** tab (Figure 2-14) to view the PCIe transaction statistics screen. This screen plots the data bus utilization statistics on the AXI4-Stream interface. After the Base TRD has run successfully, close the application GUI. Wait for the drivers to be removed, and then proceed to [Shutting Down the System, page 24](#).



UG882_c2_14_010612

Figure 2-14: Transaction Statistics

Shutting Down the System

Before the PC running Linux OS is shut down, hold down the ALT key and select the **Live System User > Power off** option to shut down the system. If the ALT key is not held down, only the Suspend option is available. The system slowly shuts down all processes.

Note: Any files copied or icons created will not be present after the next Fedora 16 Live DVD boot.

Rebuilding the Base TRD

The `ready_to_test` folder provides the BIT and MCS files for the Base TRD with the PCIe link configured as x4 at a 5 Gb/s link rate (Gen2) and x8 at a 2.5 Gb/s link rate (Gen1). They can be used to reprogram the KC705 board. Programming the KC705 board with the design, where the PCIe link is configured as x8 at a 2.5 Gb/s link rate requires driver changes for the Base TRD to run successfully. Refer to [Hardware and Software Modifications](#), page 68 for details.

The designs can also be re-implemented using the Vivado Design Suite. Refer to *Vivado Design Suite User Guide: Release Notes, Installation, and Licensing* (UG973) [Ref 2]. Before running any command line scripts, refer to the “Platform-Specific Installation Instructions” section of this book to learn how to set the appropriate environment variables for the operating system. All scripts mentioned in this user guide assume the XILINX environment variables have been set.

Note: The development machine does not have to be the hardware test machine with the PCIe slots used to run the Base TRD.

Copy the `k7_pcie_dma_ddr3_base` files to the PC with the Vivado tools installed.

To implement the design, the IP Catalog project files are in the `k7_pcie_dma_ddr3_base/hardware/sources/ip_catalog` directory, and the IP cores will be generated automatically when the synthesis step is initiated.

Implementing the Design Using the Vivado Tools

Base TRD with PCIe Configured as x4 at a 5 Gb/s Link Rate

1. Open a terminal window (Linux) or a Vivado tool Tcl command prompt (Windows).
2. For the Vivado design tools flow for Windows and Linux, navigate to `hardware/vivado/scripts`.
3. Run the following command to invoke the Vivado design tool GUI. The design with x4 gen2 PCIe configuration is loaded:

```
$ launch_x4gen2.bat
```

 (for Windows)

```
$/launch_x4gen2.bat
```

 (for Linux)
4. Click **Run Synthesis** in the Project Manager window. A window with the message `Synthesis Completed Successfully` appears after the Vivado tools generate a design netlist. Close the message window.
5. Click **Run Implementation** in the Project Manager window. A window with the message `Implementation Completed Successfully` appears after the mapping and placement and routing processes are done. Close the message window.
6. Click **Generate Bitstream**. A window with the message `Generate Bitstream Completed Successfully` appears at the end of this process and a design bit file is available in `hardware/vivado/vivado_proj_x4gen2/k7_pcie_dma_ddr3_base_x4_gen2.runs/`.
7. Close the Vivado design tools GUI.
8. Navigate to the `hardware/vivado/scripts` folder and run this command to generate an MCS file:

```
$ vivado -source k7_base_x4_gen2_flash.tcl
```

9. An MCS file (KC705.mcs) is available in the `k7_pcie_dma_ddr3_base/ready_to_test` folder.

Base TRD with PCIe Configured as x8 at a 2.5 Gb/s Link Rate

1. Open a terminal window (Linux) or a Vivado tool Tcl command prompt (Windows).
2. Navigate to `hardware/vivado/scripts`.
3. Run the following command to invoke the Vivado design tools GUI. The design with x8gen1 PCIe configuration is loaded:

```
$ launch_x8gen1.bat
```

 (for Windows)

```
$ ./launch_x8gen1.bat
```

 (for Linux)
4. Click **Run Synthesis** in the Project Manager window. A window with the message **Synthesis Completed Successfully** appears after the Vivado tools generate a design netlist. Close the message window.
5. Click **Run Implementation** in the Project Manager window. A window with the message **Implementation Completed Successfully** appears after mapping and placement and routing processes are completed. Close the message window.
6. Click **Generate Bitstream**. A window with the message **Generate Bitstream Completed Successfully** appears at the end of this process and a design bit file is available in `hardware/vivado/vivado_proj_x8gen1/k7_pcie_dma_ddr3_base_x8_gen1.runs/impl_1`.
7. Close the Vivado design tools GUI.
8. Navigate to the `hardware/vivado/scripts` folder and run this command to generate an MCS file:

```
$ vivado -source k7_base_x8_gen1_flash.tcl
```
9. An MCS file (KC705_x8gen1.mcs) is available in the `k7_pcie_dma_ddr3_base/ready_to_test` folder.

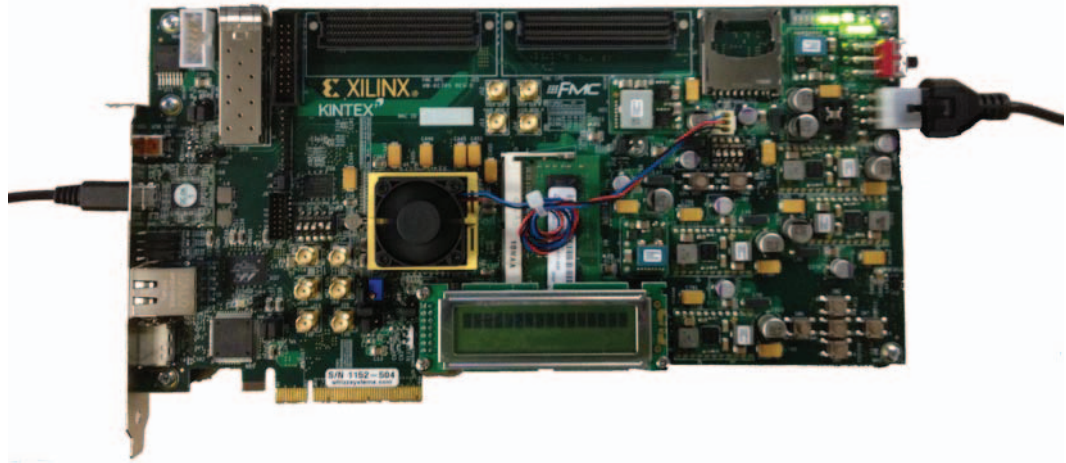
Note: If the configuration width selected is x8 gen1, driver changes are required for the Base TRD to run successfully. Refer to [Hardware and Software Modifications, page 68](#) for details.

Reprogramming the Base TRD

The KC705 board is shipped preprogrammed with the Base TRD, where the PCIe link is configured as x4 at a 5 Gb/s link rate. This procedure shows how to return the KC705 board to its original condition after another user has programmed it for a different operation or as a training aid for users to program their boards. The PCIe operation requires the use of the BPI Linear Flash mode of the KC705 board. This is the only configuration option that meets the strict programming time of PCI Express. Refer to the *7 Series FPGAs Integrated Block for PCI Express: Product Guide for Vivado Design Suite* (PG054) [Ref 3] for more information on PCIe.

Configuration Requirements

1. Check the KC705 board switch and jumper settings as shown in [Table 2-1](#) and [Figure 2-1](#). Connect the micro USB cable and use the wall power adapter to provide 12V power to the 6-pin connector as shown in [Figure 2-15](#).



UG882_c2_15_032513

Figure 2-15: Cable Installation for KC705 Board Programming

2. Copy the `k7_pcie_dma_ddr3_base` files to the PC with Vivado Design Suite installed.
3. To program the flash using the Vivado tool:
 - a. Open a hardware session in the Vivado GUI (see [Figure 2-16](#)).
 - b. Connect to the hardware device (the KC705 board).
 - c. Navigate to the `k7_pcie_dma_ddr3_base/ready_to_test` directory and source `program_flash_x4_gen2.tcl` script (see [Figure 2-17](#)).

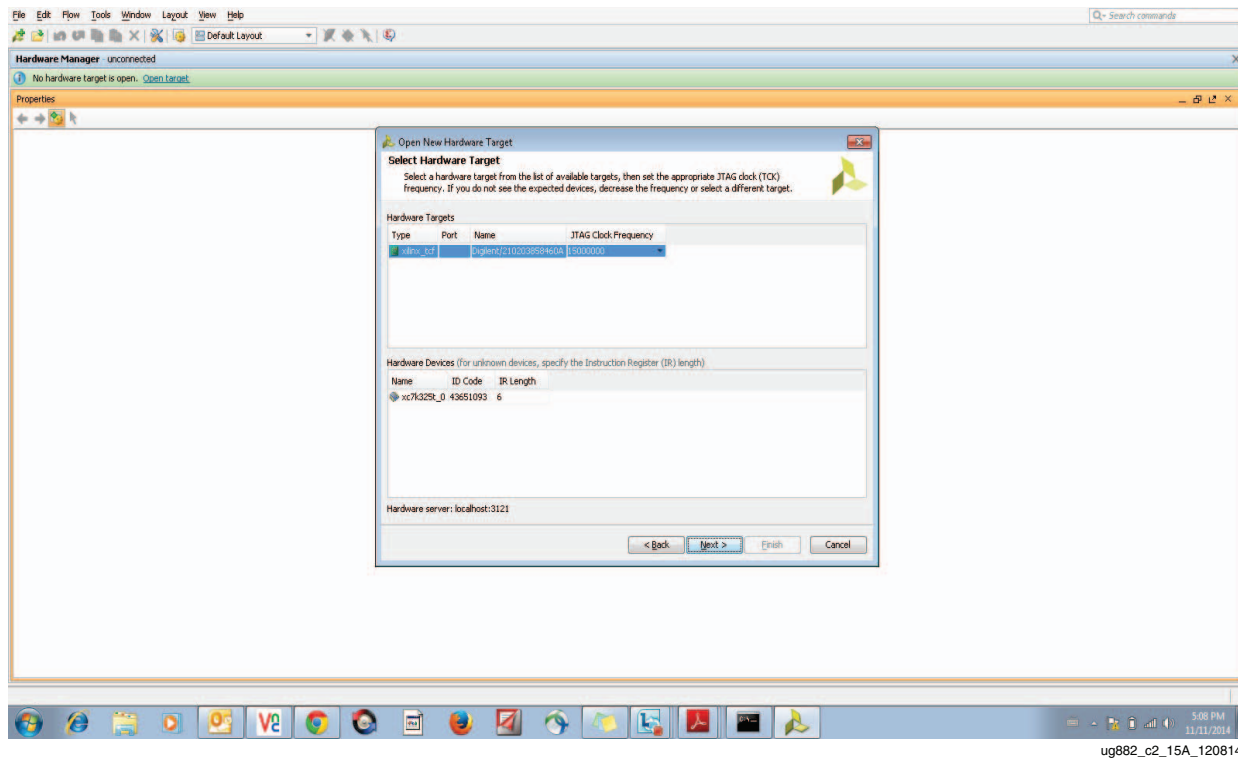
The Kintex-7 Base TRD is now programmed into the BPI Linear Flash memory and automatically configures at power up (see [Figure 2-18](#)).

To program the flash with the `KC705_x8gen1.mcs` file using the Vivado tool:

- a. Open a hardware session in the Vivado GUI (see [Figure 2-16](#)).
- b. Connect to the hardware device (the KC705 board).
- c. Navigate to the `k7_pcie_dma_ddr3_base/ready_to_test` directory and source `program_flash_x8_gen1.tcl` script (see [Figure 2-17](#)).

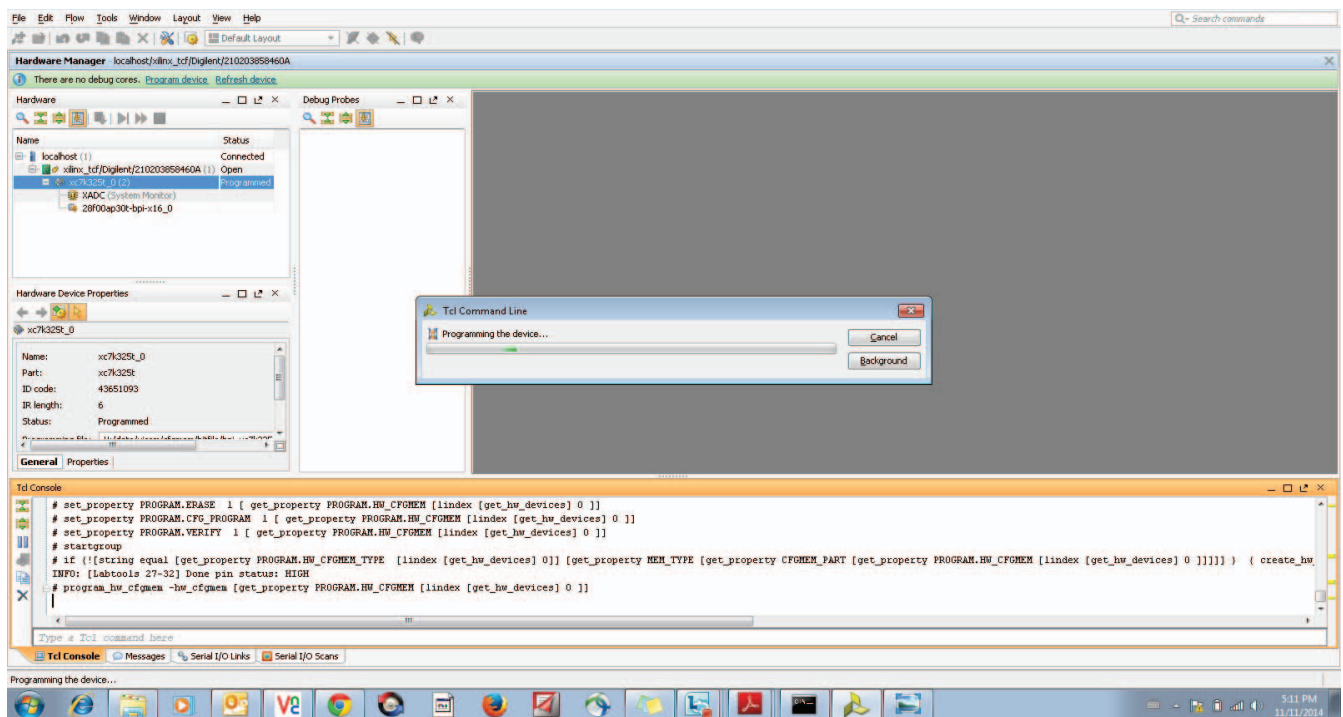
The Kintex-7 Base TRD is now programmed into the BPI Linear Flash memory and automatically configures at power up (see [Figure 2-18](#)).

If the design has been rebuilt according to the instructions in [Rebuilding the Base TRD](#), [page 25](#), the MCS files and the FPGA programming scripts are available at `k7_pcie_dma_ddr3_base/configuring_kc705`.



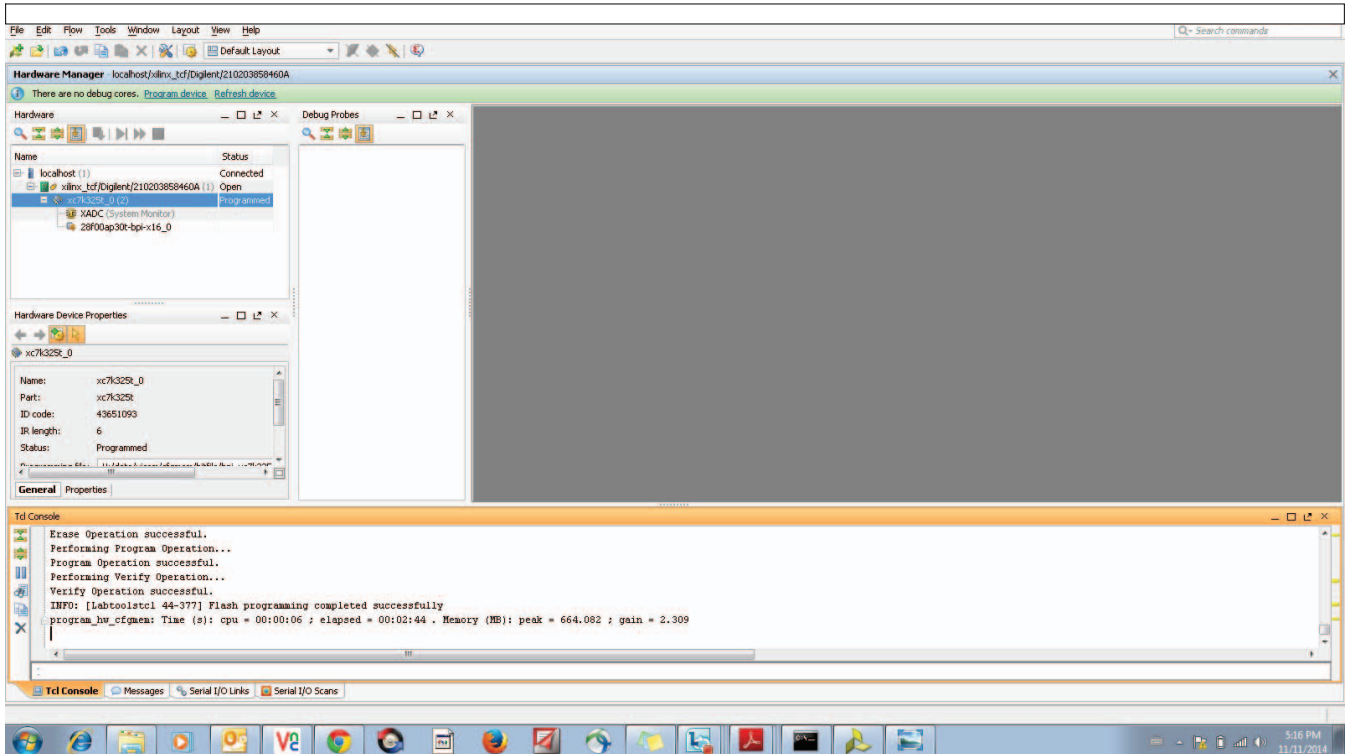
ug882_c2_15A_120814

Figure 2-16: Open New Hardware Target



ug882_c2_15b_120814

Figure 2-17: Program the Flash Memory



ug882_c2_15c_120814

Figure 2-18: Programming is Successful

Simulation

The out-of-box simulation environment consists of the design under test (DUT) connected to the Kintex-7 FPGA Root Port Model for PCI Express. This simulation environment demonstrates the basic functionality of the Base TRD through various test cases. The out-of-box simulation environment covers these traffic flows:

- **Raw Data Transmit:** Raw data traffic from the Root Port Model through the Endpoint PCIe, Packet DMA, and DDR3 memory to the Loopback module
- **Raw Data Receive:** Raw data traffic from the Loopback module through the DDR3 memory, Packet DMA, and Endpoint PCIe to the Root Port Model

The Root Port Model for PCI Express is a limited test bench environment that provides a test program interface. The purpose of the Root Port Model is to provide a source mechanism for generating downstream PCI Express traffic to simulate the DUT and a destination mechanism for receiving upstream PCI Express traffic from the DUT in a simulation environment.

The out-of-box simulation environment (see [Figure 2-19](#)) consists of:

- Root Port Model for PCI Express connected to the DUT
- Transaction Layer Packet (TLP) generation tasks for various programming operations
- Test cases to generate different traffic scenarios

In order to speed up the simulation, Physical Interface for PCI Express (PIPE) mode simulation is used in the reference design. For more details on PIPE mode simulation, refer to the *7 Series FPGAs Integrated Block for PCI Express: Product Guide for Vivado Design Suite* (PG054) [Ref 3].

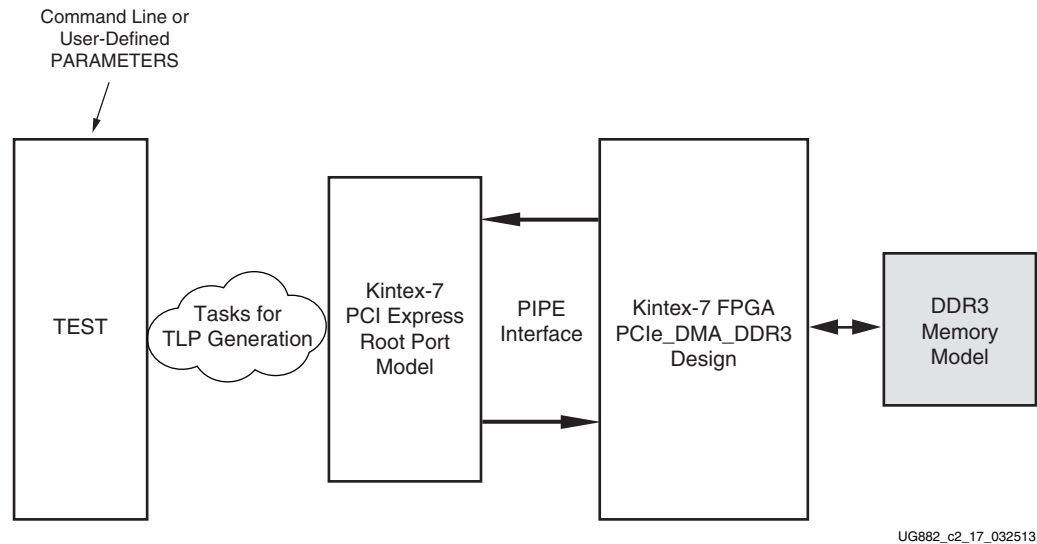


Figure 2-19: Out-of-Box Simulation Overview

The simulation environment creates log files during simulation. These log files contain a detailed record of every TLP that was received and transmitted by the Root Port Model.

Simulating the Design

This section describes the actions required to simulate the design.

Simulation Using QuestaSim

This section describes running the QuestaSim simulator.

For information on how to run simulations with different simulators, refer to *Vivado Design Suite User Guide: Synthesis* (UG901) [Ref 4] and *Vivado Design Suite Logic Simulation User Guide* (UG900) [Ref 5]. To run the simulation using QuestaSim, execute one of the two listed scripts at the command prompt. Make sure to compile the required libraries and set the QuestaSim environment variables before running the script:

- For the Base TRD with the PCIe link configured as x4 at 5 Gb/s, execute `sim_x4gen2_mti.tcl` script found in the `hardware/vivado/scripts` directory. This can be done by executing the following command:

```
$ vivado -source sim_x4gen2_mti.tcl
```
- For the Base TRD with the PCIe link configured as x8 at 2.5 Gb/s, execute `sim_x8gen1_mti.tcl` script found in the `hardware/vivado/scripts` directory. This can be done by executing the following command:

```
$ vivado -source sim_x8gen1_mti.tcl
```

Simulation Using the Vivado Simulator

To run the simulation using the Vivado simulator:

1. Set the environment variables required to set up simulation for the Vivado simulator. For information on how to run simulation with different simulators, refer to *Vivado Design Suite Logic Simulation User Guide* (UG900) [Ref 5].
2. Navigate to the `hardware/vivado/scripts` directory.
 - For the Base TRD with the PCIe link configured as x4 at 5 Gb/s, execute `sim_x4gen2_xsim.tcl` script. This can be done by executing the following command:


```
$ vivado -source sim_x4gen2_xsim.tcl.
```
 - For the Base TRD with the PCIe link configured as x8 at 2.5 Gb/s, execute `sim_x8gen1_xsim.tcl` script. This can be done by executing the following command:


```
$ vivado -source sim_x8gen1_xsim.tcl.
```

User-Controlled Macros

The simulation environment allows the user to define macros that control DUT configuration. These values can be changed in the `user_defines.v` file.

Table 2-3: User-Controlled Macro Descriptions

Macro Name	Default Value	Description
CH0	Defined	Enables raw data Path0 initialization and traffic flow.
CH1	Defined	Enables raw data Path1 initialization and traffic flow.
DETAILED_LOG	Not defined	Enables a detailed log of each transaction.

Test Selection

For the raw datapath, fixed length packets of 1024 bytes are generated.

Table 2-4 describes the various tests provided by the out-of-box simulation environment.

Table 2-4: Test Description

Test Name	Description
basic_test	Basic test. This test runs six packets for each DMA channel. One buffer descriptor defines one full packet in this test.
packet_spanning	Packet spanning multiple descriptors. This test spans a packet across two buffer descriptors. It runs six packets for each DMA channel.
test_interrupts	Interrupt test. This test sets the interrupt bit in the descriptor and enables the interrupt registers. This test also shows interrupt handling by acknowledging relevant registers. Note: Only one channel should be enabled for this test.

Table 2-4: Test Description (Cont'd)

Test Name	Description
dma_disable	DMA disable test. This test shows the DMA disable operation sequence on a DMA channel.
break_loop	Enable checker and generator in hardware and disable loopback. This test shows the receive path running independent of the transmit path. The data source for the receive path is the generator, not the looped back transmit data.

By default, the simulation script file specifies the basic test to be run with the string:

```
TESTNAME=basic_test
```

The name of the test to be run can be specified in `sim_x4gen2_mti/sim_x4gen2_xsim` or `sim_x8gen1_mti/sim_x8gen1_xsim` depending on the simulator used. The test selection can be changed by specifying a different test case as specified in [Table 2-4](#).

Functional Description

This chapter describes the hardware design and software driver components. It also describes how the data and control information flow through the various connected IPs.

Hardware Architecture

Figure 3-1 provides a detailed block level overview of the TRD. The base system components and the applications components enable data flow to/from the host memory at high data rates.

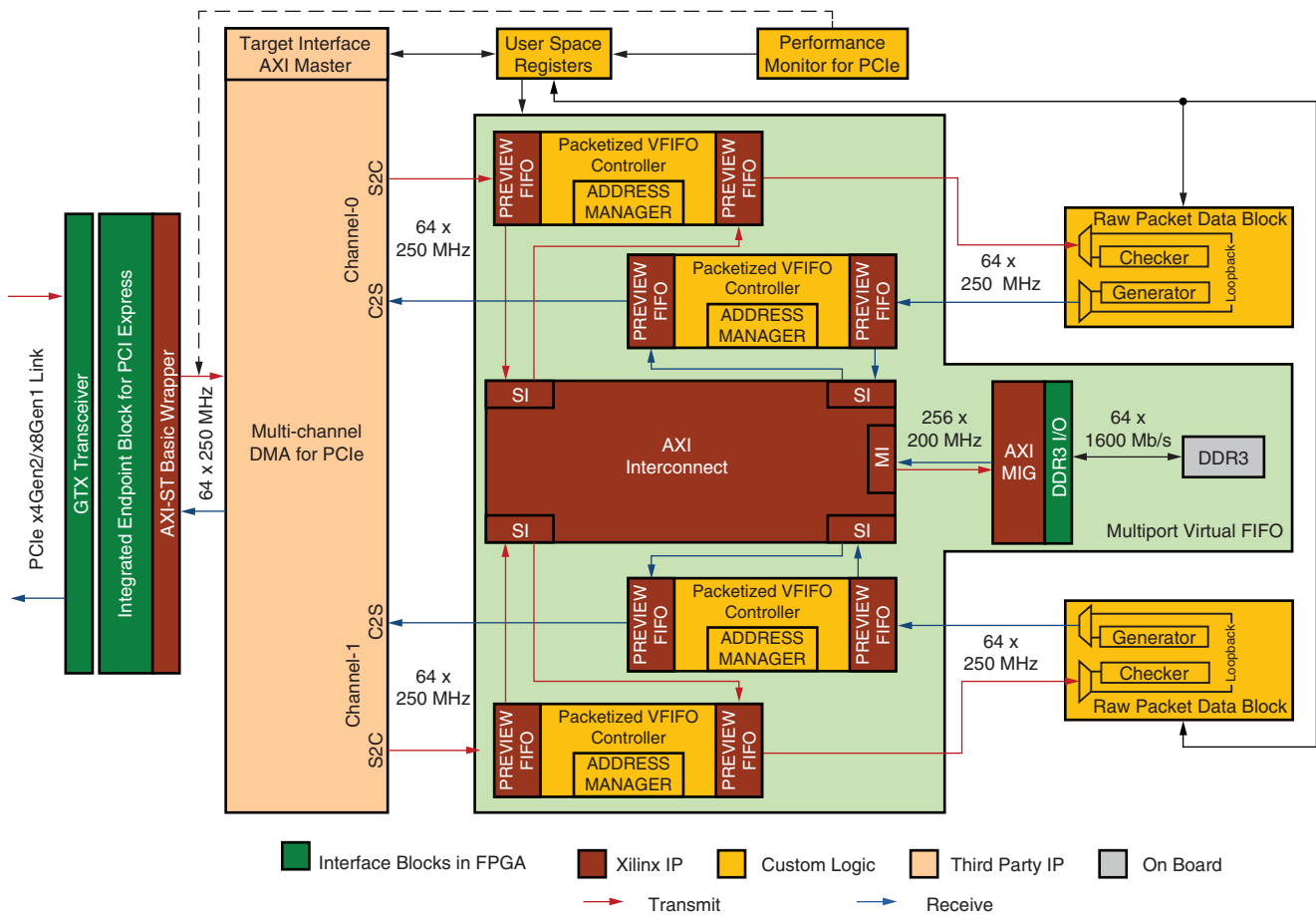


Figure 3-1: Detailed Design Block Diagram

The hardware architecture is detailed under these sections:

- [Base System Components](#) describes the Kintex®-7 FPGA integrated Endpoint block for PCI Express, DMA, and Multiport Virtual FIFO.
- [Application Components](#) describes a simple packet data generator.

Base System Components

PCI Express is a high-speed serial protocol that allows transfer of data between host systems and Endpoint cards. To efficiently use the processor bandwidth, a bus mastering scatter-gather DMA controller is used to push and pull data from the system memory. All data to and from the system is stored in the DDR3 memory through a Multiport Virtual FIFO abstraction layer before interacting with the user application.

PCI Express

The Kintex-7 FPGA Integrated Block for PCI Express provides a wrapper around the integrated block in the FPGA. The integrated block is compliant with the PCI Express v2.0 specification. It supports x1, x2, x4, x8 lane widths operating at 2.5 Gb/s (Gen1) or 5 Gb/s (Gen2) line rate per direction. The wrapper combines the Kintex-7 FPGA Integrated Block for PCI Express with transceivers, clocking, and reset logic to provide an industry standard AXI4-Stream interface as the user interface.

For details on the Kintex-7 FPGA integrated Endpoint block for PCI Express, refer to the *7 Series FPGAs Integrated Block for PCI Express: Product Guide for Vivado Design Suite* (PG054) [Ref 3].

Performance Monitor for PCI Express

The monitor block snoops for PCIe® transactions on the AXI4-Stream interface ports and keeps track of utilization. A timer within the block counts out the clocks until one second has elapsed, during which time several counters have collected data about the usage of the transaction layer. [Table 3-1](#) shows the ports on the monitor.

Table 3-1: Monitor Ports for PCI Express

Port Name	Type	Description
reset	Input	Synchronous reset
clk	Input	250 MHz clock
Transmit Ports on the AXI4-Stream Interface		
s_axis_tx_tdata[63:0]	Input	Data to be transmitted via PCIe link

Table 3-1: Monitor Ports for PCI Express (Cont'd)

Port Name	Type	Description
s_axis_tx_tkeep[7:0]		<p>The transmit data strobe is used to determine which data bytes are valid on s_axis_tx_tdata during a given beat (this signal is valid only if s_axis_tx_tvalid and s_axis_tx_tready are both asserted).</p> <p>Bit 0 corresponds to the least significant byte on s_axis_tx_tdata and bit 7 corresponds to the most significant byte, for example:</p> <ul style="list-style-type: none"> s_axis_tx_tkeep[0] == 1b, s_axis_tx_tdata[7:0] is valid. s_axis_tx_tkeep[7] == 0b, s_axis_tx_tdata[63:56] is not valid. When s_axis_tx_tlast is not asserted, the only valid value is 0xFF. When s_axis_tx_tlast is asserted, valid values are 0x0F and 0xFF.
s_axis_tx_tlast	Input	End-of-frame indicator on transmit packets. Valid only along with assertion of s_axis_tx_tvalid.
s_axis_tx_tvalid	Input	Source ready to provide transmit data. Indicates that the DMA is presenting valid data on s_axis_tx_tdata.
s_axis_tx_tuser[3] (src_dsc)	Input	Source discontinue on a transmit packet. Can be asserted any time starting on the first cycle after start-of-file (SOF). s_axis_tx_tlast should be asserted along with s_axis_tx_tuser[3] assertion.
s_axis_tx_tready	Input	Destination ready for transmit. Indicates that the core is ready to accept data on s_axis_tx_tdata. The simultaneous assertion of s_axis_tx_tvalid and s_axis_tx_tready marks the successful transfer of one data beat on s_axis_tx_tdata.
Receive Ports on the AXI4-Stream Interface		
m_axis_rx_tdata[63:0]	Input	Data received on the PCIe link. Valid only if m_axis_rx_tvalid is also asserted.
m_axis_rx_tkeep[7:0]	Input	<p>The receive data keep signal is used to determine which data bytes are valid on m_axis_rx_tdata[63:0] during a given beat (this signal is valid only when m_axis_rx_tvalid and m_axis_rx_tready are both asserted). Bit 0 corresponds to the least significant byte on m_axis_rx_tdata and bit 7 corresponds to the most significant byte.</p> <p>When m_axis_rx_tlast is not asserted, this signal can be ignored.</p> <p>When m_axis_rx_tlast is asserted, valid values are 0x0F and 0xFF.</p>
m_axis_rx_tlast	Input	End-of-frame indicator for received packet. Valid only if m_axis_rx_tvalid is also asserted.

Table 3-1: Monitor Ports for PCI Express (Cont'd)

Port Name	Type	Description
m_axis_rx_tvalid	Input	Source ready to provide receive data. Indicates that the core is presenting valid data on m_axis_rx_tdata.
m_axis_rx_tready	Input	Destination ready for receive. Indicates that the DMA is ready to accept data on m_axis_rx_tdata. The simultaneous assertion of m_axis_rx_tvalid and m_axis_rx_tready marks the successful transfer of one data beat on m_axis_rx_tdata.
Byte Count Ports		
tx_byte_count[31:0]	Output	Raw transmit byte count
rx_byte_count[31:0]	Output	Raw receive byte count
tx_payload_count[31:0]	Output	Transmit payload byte count
rx_payload_count[31:0]	Output	Receive payload byte count

Note: Start of packet is derived based on the signal values of source valid, destination ready and end of packet indicator. The clock cycle after end of packet is deasserted and source valid is asserted indicates start of a new packet.

Four counters collect information on the transactions on the AXI4-Stream interface:

- **TX Byte Count.** This counter counts bytes transferred when the s_axis_tx_tvalid and s_axis_tx_tready signals are asserted between the Packet DMA and the Kintex-7 FPGA Integrated Block for PCI Express. This value indicates the raw utilization of the PCIe transaction layer in the transmit direction, including overhead such as headers and non-payload data such as register access.
- **RX Byte Count.** This counter counts bytes transferred when the m_axis_rx_tvalid and m_axis_rx_tready signals are asserted between the Packet DMA and the Kintex-7 FPGA Integrated Block for PCI Express. This value indicates the raw utilization of the PCIe transaction layer in the receive direction, including overhead such as headers and non-payload data such as register access.
- **TX Payload Count.** This counter counts all memory writes and completions in the transmit direction from the Packet DMA to the host. This value indicates how much traffic on the PCIe transaction layer is from data, which includes the DMA buffer descriptor updates, completions for register reads, and the packet data moving from the user application to the host.
- **RX Payload Count.** This counter counts all memory writes and completions in the receive direction from the host to the DMA. This value indicates how much traffic on the PCIe transaction layer is from data, which includes the host writing to internal registers in the hardware design, completions for buffer description fetches, and the packet data moving from the host to user application.

The actual packet payload by itself is not reported by the performance monitor. This value can be read from the DMA register space. The method of taking performance snapshots is similar to the Northwest Logic DMA performance monitor (refer to the *Northwest Logic DMA Back-End Core User Guide* and *Northwest Logic DMA AXI DMA Back-End Core User Guide*, available in the k7_pcie_dma_ddr3_base/design/ipcores/dma/doc directory). The byte counts are truncated to a four-byte resolution, and the last two bits of the register indicate the sampling period. The last two bits transition every second from 00 to 01 to 10 to 11. The software polls the performance register every second. If the

sampling bits are the same as the previous read, then the software needs to discard the second read and try again. When the one-second timer expires, the new byte counts are loaded into the registers, overwriting the previous values.

Scatter Gather Packet DMA

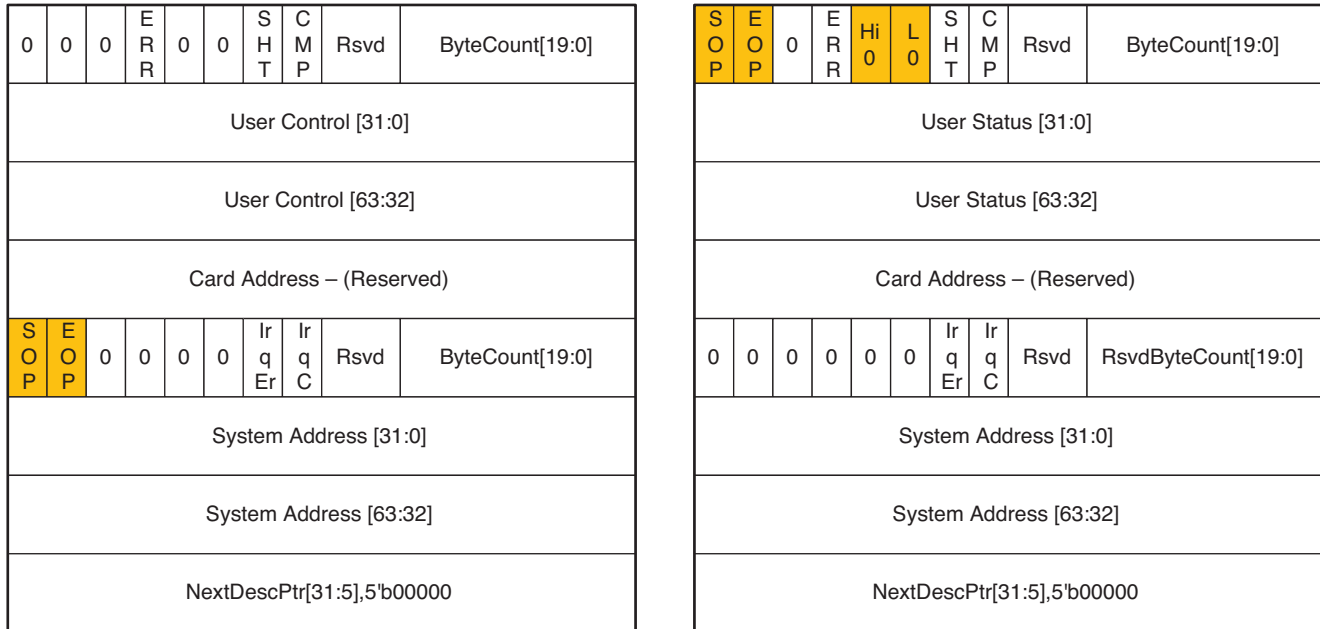
The scatter-gather Packet DMA IP is provided by Northwest Logic, a Xilinx third-party alliance partner. The Packet DMA is configured to support simultaneous operation of two user applications. This involves four DMA channels: two system-to-card (S2C) or transmit channels and two card-to-system (C2S) or receive channels. The DMA controller requires a 64 KB register space mapped to BAR0. All DMA registers are mapped to BAR0 from 0x0000 to 0x7FFF. The address range from 0x8000 to 0xFFFF is available to the user via this interface. Each DMA channel has its own set of independent registers. Registers specific to this TRD are described in [Appendix B, Register Description](#). Further details of various registers can be obtained from the *Northwest Logic DMA Back-End Core User Guide*, available in the `k7_pcie_dma_ddr3_base/design/ipcores/dma/doc` directory.

The front end of DMA interfaces to the AXI4-Stream interface. The backend of the DMA provides an AXI4-Stream interface as well which connects to the ports on Virtual FIFO. Further details of the signal definitions can be obtained from the *Northwest Logic AXI DMA Back-End Core User Guide*, available in the `k7_pcie_dma_ddr3_base/design/ipcores/dma/doc` directory.

Scatter Gather Operation

The term scatter gather refers to the ability to write packet data segments into different memory locations and gather data segments from different memory locations to build a packet. This allows for efficient memory utilization because a packet does not need to be stored in physically contiguous locations. Scatter gather requires a common memory resident data structure that holds the list of DMA operations to be performed. DMA operations are organized as a linked list of buffer descriptors. A buffer descriptor describes a data buffer. Each buffer descriptor is eight doublewords in size (a doubleword is 4 bytes), which is a total of 32 bytes. The DMA operation implements buffer descriptor chaining, which allows a packet to be described by more than one buffer descriptor.

Figure 3-2 shows the buffer descriptor layout for S2C and C2S directions.



UG882_c3_02_121711

Figure 3-2: S2C Buffer Descriptor and C2S Buffer Descriptor Layout

The descriptor fields are described in Table 3-2.

Table 3-2: Buffer Descriptor Fields

Descriptor Fields	Functional Description
SOP	Start of packet. In S2C direction, indicates to the DMA the start of a new packet. In C2S, DMA updates this field to indicate to software start of a new packet.
EOP	End of packet In S2C direction, indicates to the DMA the end of current packet. In C2S, DMA updates this field to indicate to software end of the current packet.
ERR	Error This is set by DMA on descriptor update to indicate error while executing that descriptor
SHT	Short Set when the descriptor completed with a byte count less than the requested byte count. This is common for C2S descriptors having EOP status set but should be analyzed when set for S2C descriptors.
CMP	Complete This field is updated by the DMA to indicate to the software completion of operation associated with that descriptor.

Table 3-2: Buffer Descriptor Fields (Cont'd)

Descriptor Fields	Functional Description
Hi 0	User Status High is zero Applicable only to C2S descriptors - this is set to indicate Users Status [63:32] = 0
L 0	User Status Low is zero Applicable only to C2S descriptors - this is set to indicate User Status [31:0] = 0
Irq Er	Interrupt On Error This bit indicates DMA to issue an interrupt when the descriptor results in error
Irq C	Interrupt on Completion This bit indicates DMA to issue an interrupt when operation associated with the descriptor is completed
ByteCount[19:0]	Byte Count In S2C direction, this indicates DMA the byte count queued up for transmission. In C2S direction, DMA updates this field to indicate the byte count updated in system memory.
RsvdByteCount[19:0]	Reserved Byte Count In S2C direction, this is equivalent to the byte count queued up for transmission. In C2S direction, this indicates the data buffer size allocated - the DMA might or might not utilize the entire buffer depending on the packet size.
User Control/User Status	User Control or Status Field (The use of this field is optional.) In S2C direction, this is used to transport application specific data to DMA. Setting of this field is not required by this reference design. In C2S direction, DMA can update application specific data in this field.
Card Address	Card Address Field This is a reserved for Packet DMA
System Address	System Address This defines the system memory address where the buffer is to be fetched from or written to.
NextDescPtr	Next Descriptor Pointer This field points to the next descriptor in the linked list. All descriptors are 32-byte aligned.

This field points to the next descriptor in the linked list. All descriptors are 32-byte aligned.

Packet Transmission

The software driver prepares a ring of descriptors in system memory and writes the start and end addresses of the ring to the relevant S2C channel registers of the DMA. When enabled, the DMA fetches the descriptor followed by the data buffer it points to. Data is fetched from the host memory and made available to the user application through the DMA S2C streaming interface.

The packet interface signals (for example, user control and the end of packet) are built from the control fields in the descriptor. The information present in the user control field is made available during the start of packet. The reference design does not use the user control field.

To indicate data fetch completion corresponding to a particular descriptor, the DMA engine updates the first doubleword of the descriptor by setting the complete bit of the 'Status and Byte Count field to 1. The software driver analyzes the complete bit field to free up the buffer memory and reuse it for later transmit operations.

Figure 3-3 shows the system to card data transfer.

Note: Start of Packet is derived based on the signal values of source valid (s2c_tvalid), destination ready (s2c_tready) and end of packet (s2c_tlast) indicator. The clock cycle after end of packet is deasserted and source valid is asserted indicates start of a new frame.

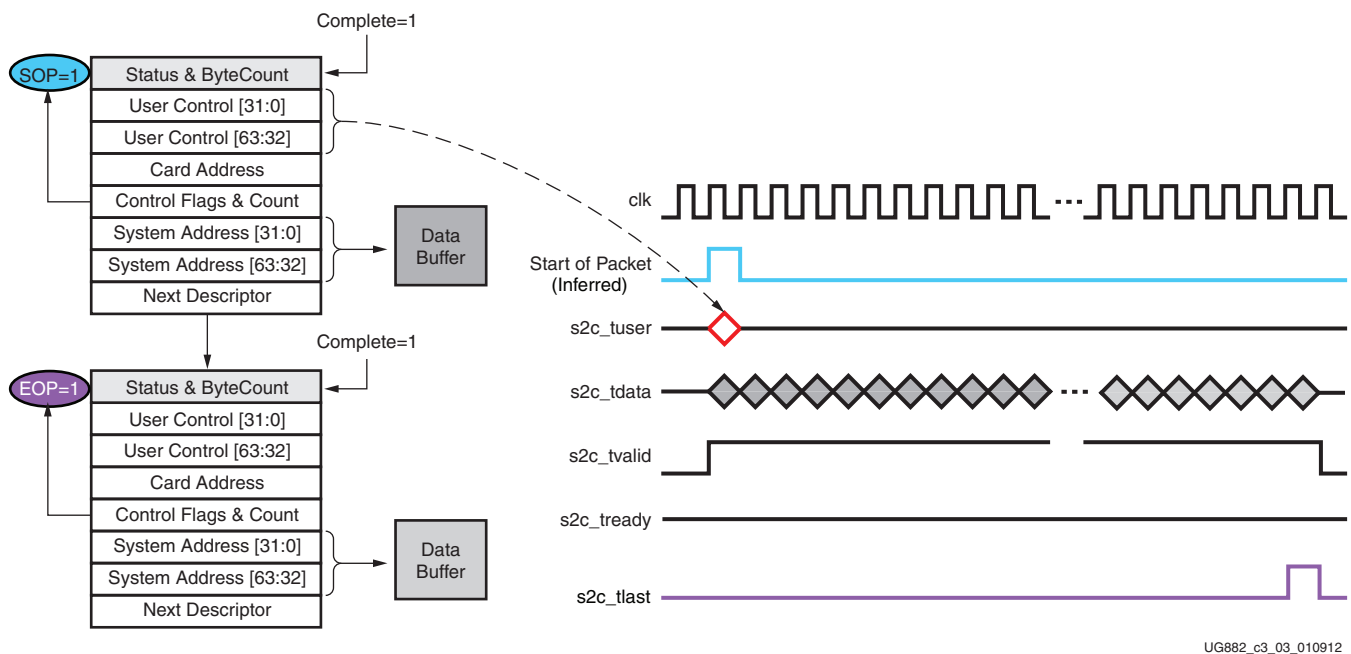


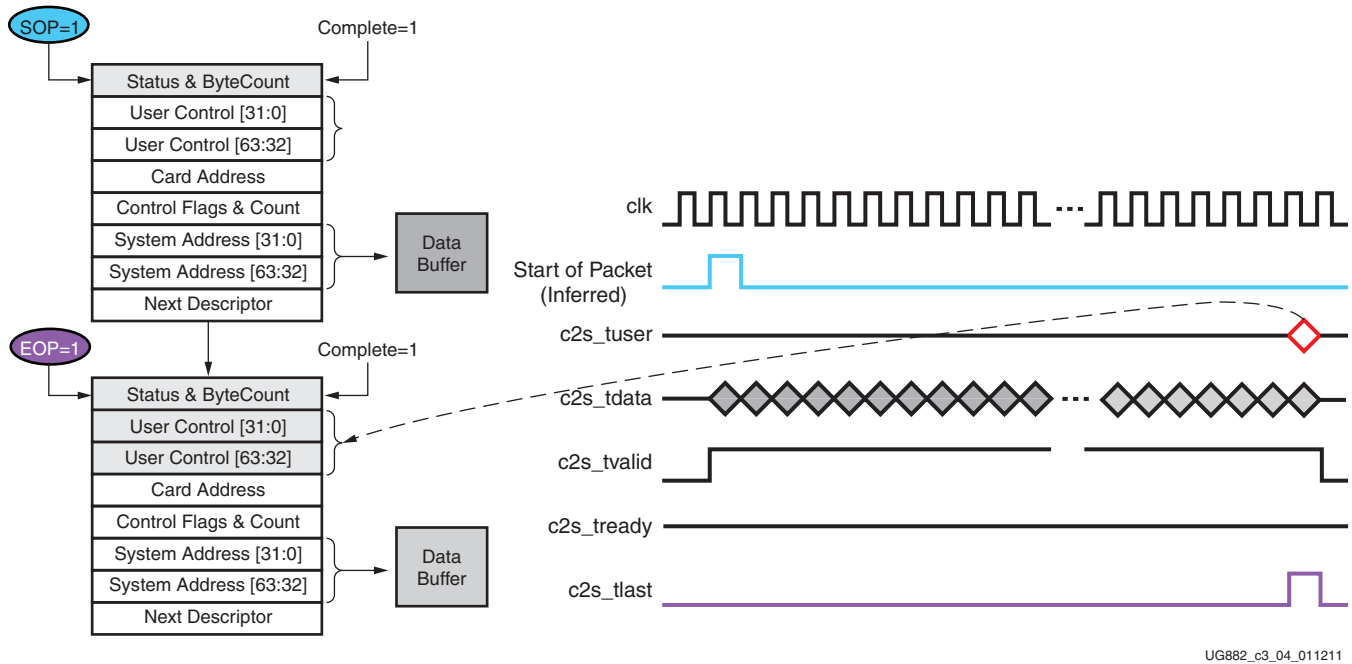
Figure 3-3: Data Transfer from System to Card

Packet Reception

The software driver prepares a ring of descriptors with each descriptor pointing to an empty buffer. It then programs the start and end addresses of the ring in the relevant C2S DMA channel registers. The DMA reads the descriptors and waits for the user application to provide data on the C2S streaming interface. When the user application provides data, the DMA writes the data into one or more empty data buffers pointed to by the prefetched descriptors. When a packet fragment is written to host memory, the DMA updates the status fields of the descriptor. The c2s_tuser signal on the C2S interface is valid only during c2s_tlast. Hence, when updating the EOP field, the DMA engine also needs to update the

User Status fields of the descriptor. In all other cases, the DMA updates only the Status and Byte Count field. The completed bit in the updated status field indicates to the software driver that data was received from the user application. When the software driver processes the data, it frees the buffer and reuses it for later receive operations.

Figure 3-4 shows the card to system data transfer.



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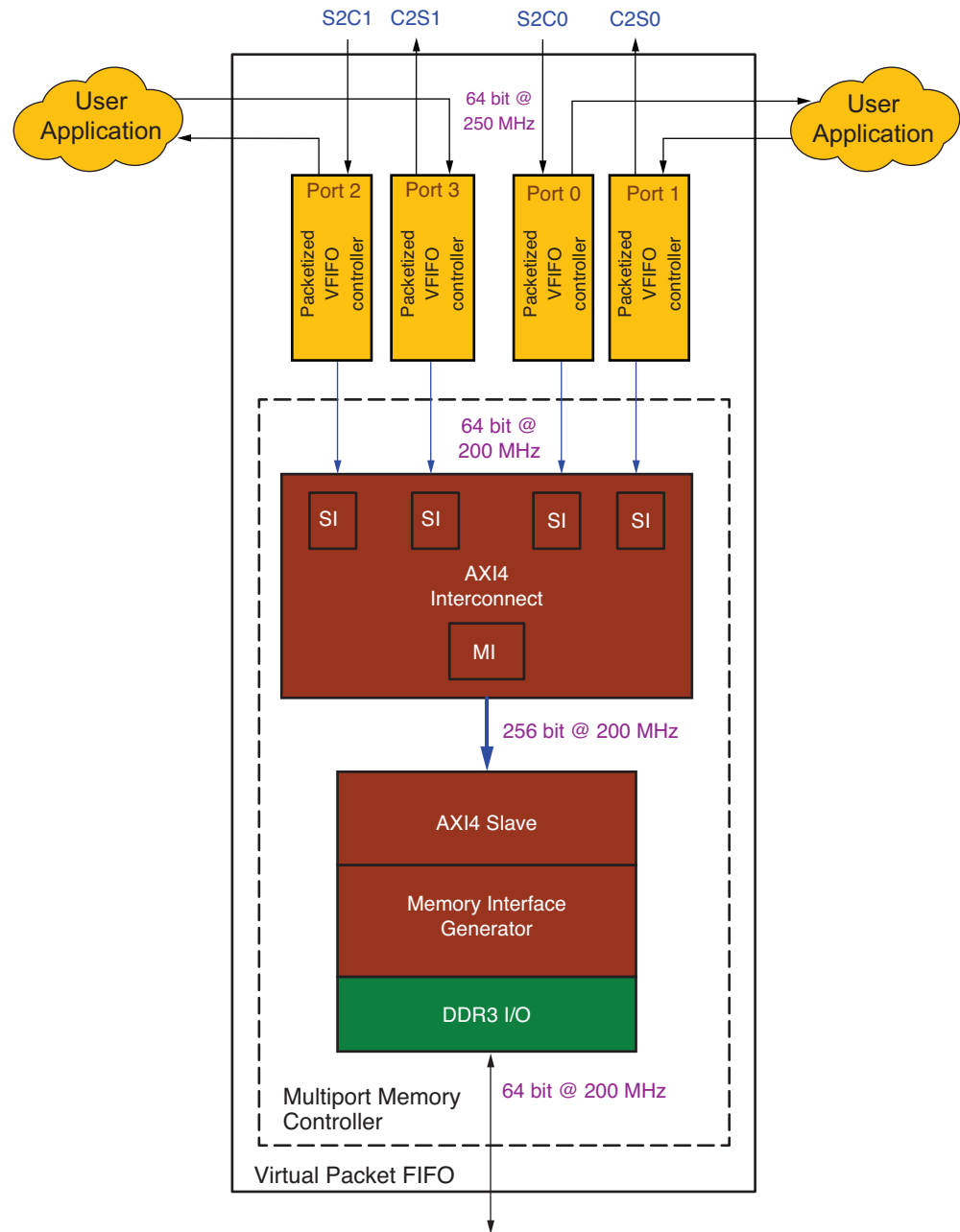
Figure 3-4: Data Transfer from Card to System

Note: Start of Packet is derived based on the signal values of source valid (c2s_tvalid), destination ready (c2s_tready) and end of packet (c2s_tlast) indicator. The clock cycle after end of packet is deasserted and source valid is asserted indicates start of a new frame.

The software periodically updates the end address register on the Transmit and Receive DMA channels to ensure uninterrupted data flow to and from the DMA.

Multiport Virtual Packet FIFO

The Multiport Virtual Packet FIFO is built using LogiCORE™ IP MIG (Memory Interface Controller) and LogiCORE IP AXI Interconnect. The Packetized VFIFO controller logic around the IPs converts the external DDR3 memory into a multiport FIFO. Figure 3-5 is the block level representation of Multiport Virtual Packet FIFO.



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Figure 3-5: Virtual Packet FIFO

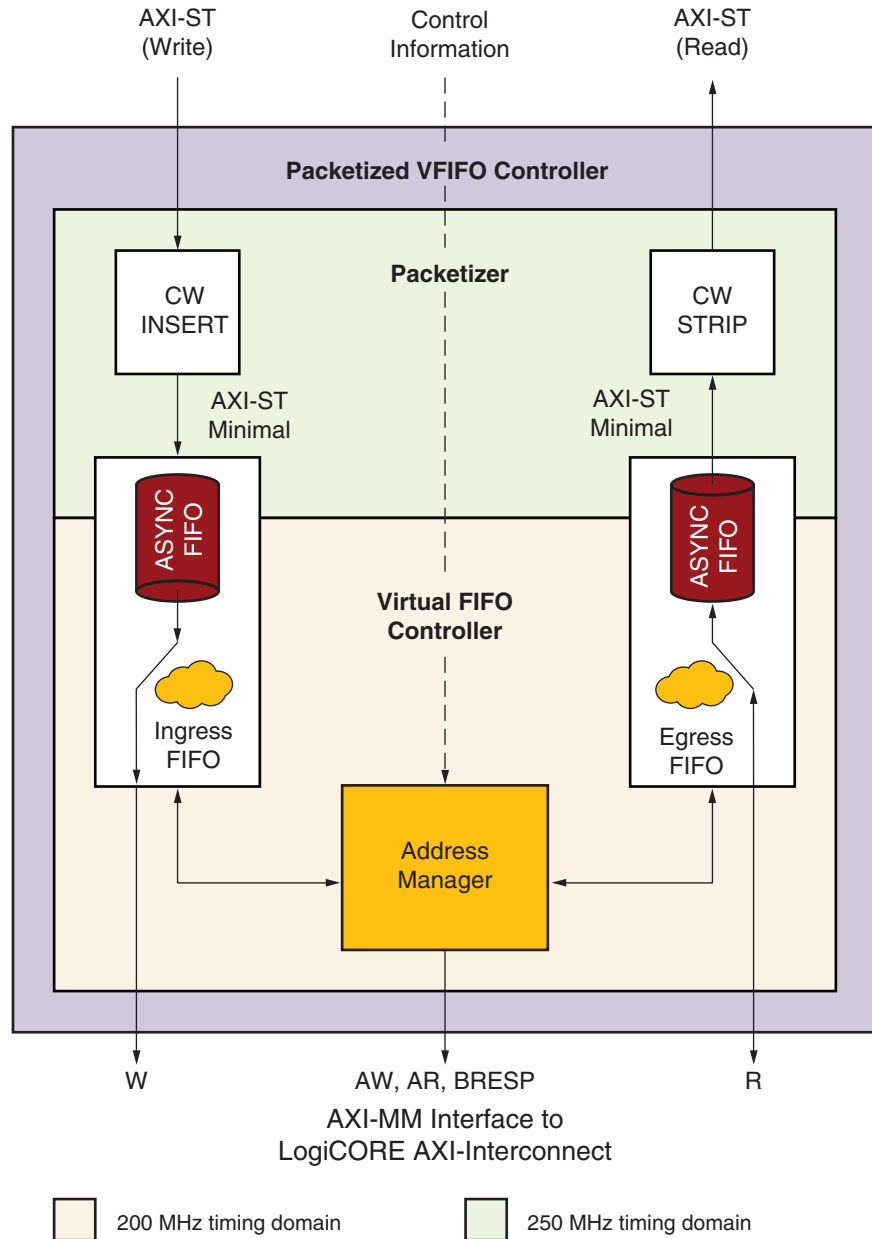
Multiport Memory Controller

The Memory Interface controller and the AXI Interconnect constitute the Multiport Memory Controller. The LogiCORE IP MIG provides a single port with AXI4 interface. Because this reference design supports two user applications, four ports are required on Memory Controller—two ports for DMA to push data and user applications to pull data and two ports for user application to push data and DMA to pull data. Using the AXI4 interconnect a single port Memory Controller can be converted into a multiport Memory Controller. In this design AXI4 interconnect is used in a 4x1 configuration. The DMA

engines and the user applications are 4 masters to drive 4 slave interfaces (SI). The master interface (MI) on the Interconnect drives the single port Memory Controller Interface which is a slave.

Packetized VFIFO Controller

Figure 3-6 provides a block level overview of the Packetized VFIFO controller.



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Figure 3-6: Packetized VFIFO Controller

The DDR3 memory is required to store packets (size ranging from 64B to 32 KB). Because the interface width on DDR3 is 64-bits, there are no extra bits to store control information. Therefore, the reference design needs a way to find the start and end of the packet and valid data bytes when data is read out of the DDR3. Inserting a control word in a data

packet before it is written into the DDR3 and using the control word when data is read out of the DDR3 is a simple scheme to determine packet delineations. Using the Packetizer logic does not have a large performance impact and avoids use of a store and forward scheme.

The input and output interfaces on Packetized VFIFO controller are AXI-Stream compliant. The DMA engines and the user application interface with this module. On the write port, the packet length should be available with the first data beat to enable control word insertion. This control word is discarded before the packet is made available on the read port.

The Virtual FIFO Controller comprises of three modules Ingress FIFO, Egress FIFO and address manager.

The address manager implements the addressing scheme to manage DDR3 as FIFO. Users have control to set the DDR3 start and end address boundary to be used as FIFO. The users can also set the burst size to be used on write and read AXI-MM interfaces. These values are guidance to what the maximum burst size could be. For example, say burst size is programmed as 256 for both read and write interfaces. Effort is made to operate at this burst size, but a sub-optimal burst (lesser than 256) can be issued based on timeout in lean traffic scenarios

(Refer to [Memory Controller Registers in Appendix B](#) to set the start and end addresses and burst size.)

The Ingress and Egress FIFO blocks communicate to the AXI Interconnect block based on the control signals from the address manager.

The Ingress FIFO block handles the write data and is responsible for driving the write interface of AXI-MM. The asynchronous preview FIFO in this block helps with clock domain crossing. It also allows storing up enough data to create a transaction of write burst size and then sending it to the AXI Interconnect.

The Egress FIFO block handles the read data and is responsible for draining the read data interface of AXI-MM after a read command is issued and when read data is available. The asynchronous preview FIFO in this block helps with clock domain crossing. It also allows storing up enough data to store a transaction of read burst size received from AXI Interconnect.

The preview FIFOs in the Ingress FIFO block and Egress FIFO block are generated using the LogiCORE FIFO Generator IP with a data width of 64-bit and depth of 1024. The FIFOs internally use block RAMs.

[Table 3-3](#) shows the signals on the Multiport Virtual Packet FIFO. The read and writes interface signals and the user-specified register widths scale with the number of ports.

Table 3-3: Ports on the Packetized VFIFO Controller

Port Name	Type	Description
Write Interface		
axi_str_wr_tlast	Input	Indicates end of a packet
axi_str_wr_tdata	Input	Data packets received from the DMA engines and User Applications
axi_str_wr_tvalid	Input	Source is ready, and data is valid on the data bus
axi_str_wr_tready	Output	Destination is ready, and can receive data

Table 3-3: Ports on the Packetized VFIFO Controller (Cont'd)

Port Name	Type	Description
axi_str_wr_tkeep	Input	Byte enables on data, qualified by tvalid. Can be deasserted only when tlast is asserted
axi_str_wr_aclk	Input	Clock for write transactions
axi_str_wr_tuser	Input	Length of the data packet is defined by this signal. This information should be available on the first data beat of a packet.
wr_reset_n	Input	User reset to the write port
Read Interface		
axi_str_rd_tlast	Output	Indicates end of a packet
axi_str_rd_tdata	Output	Data transmitted to the DMA engines and User Applications
axi_str_rd_tvalid	Output	Source is ready, and data is valid on the data bus
axi_str_rd_tready	Input	Destination is ready, and can receive data
axi_str_rd_tkeep	Output	Byte enables on data, qualified by tvalid. Can be deasserted only when tlast is asserted
axi_str_rd_aclk	Input	Clock for read transactions
axi_str_rd_tuser	Output	Length of the data packet is defined by this signal. This information is available on the first data beat of a packet.
rd_reset_n	Input	User reset to the read port
User-Specified Registers		
start_addr	Input	DDR3 start address boundary
end_addr	Input	DDR3 end address boundary
wrburst_size	Input	Write burst size on the AXI-MM interface to the LogiCOREIP AXI Interconnect
rdburst_size	Input	Read burst size on the AXI-MM interface to the LogiCORE IP AXI Interconnect
DDR3 Memory Interface		
ddr_addr	Output	PHY signal
ddr_ba	Output	PHY signal
ddr_cas_n	Output	PHY signal
ddr_ck_p	Output	PHY signal
ddr_ck_n	Output	PHY signal
ddr_cke	Output	PHY signal
ddr_cs_n	Output	PHY signal
ddr_dm	Output	PHY signal
ddr_odt	Output	PHY signal

Table 3-3: Ports on the Packetized VFIFO Controller (Cont'd)

Port Name	Type	Description
ddr_ras_n	Output	PHY signal
ddr_reset_n	Output	PHY signal
ddr_we_n	Output	PHY signal
ddr_dq	Inout	PHY signal
ddr_dqs_p	Inout	PHY signal
ddr_dqs_n	Inout	PHY signal
sda	Inout	PHY signal
scl	Output	PHY signal
Other		
calib_done	Output	DDR3 Memory calibration is complete
clk_ref_p	Input	200 MHz differential clock
clk_ref_n	Input	200 MHz differential clock
mcb_clk	Output	User interface 200 MHz clock for the LogiCORE IP MIG
mcb_rst	Output	User interface reset for the LogiCORE IP MIG
ddr3_fifo_empty	Output	Indicates the DDR3 FIFOs, Egress and Ingress preview FIFOs are empty. Width of the signals is equal to the number of ports on the Virtual Packet FIFO.
axi_ic_shim_rst_n	Input	This signal resets the AXI interconnect IP and AXI interface of the MIG IP. The software verifies the DDR3 FIFO and preview FIFOs are empty before issuing this reset.
user_reset	Input	This signal resets the MIG IP core. It is connected PCIe Endpoint card reset (perst_n) driven by the PC motherboard.

Application Components

This section describes the block that interfaces with the base components to support Raw Packet Data flow. It is a simple application which can be replaced with any other application protocol like XAUI or Aurora.

Raw Data Packet Path

The Raw Data application is an example of a data streaming protocol. Because the DMA provides a packetized interface on its backend, a fixed length packet is defined on this path, though the data itself does not have any packet annotations in the user space. The fixed length is configurable through a register write (refer to [Packet Length \(0x9104\) in Appendix B](#) and [Packet Length \(0x9204\) in Appendix B](#) for details).

The Raw Data Packet module implements a loopback function, a data checker function, and a data generator function. The module enables specific functions depending on the GUI configuration options selected by the user. On the transmit path, the data checker

verifies the data transmitted from the host system via the Packet DMA. On the receive path, data can be sourced either by the data generator or transmit data can be looped back and sent to the host system.

Based on user inputs, the driver programs user space registers to enable checker, enable generator, or enable loopback (see [Enable Generator \(0x9100\)](#), [Enable Loopback/Checker \(0x9108\)](#), [Enable Generator \(0x9200\)](#), [Enable Loopback/Checker \(0x9208\)](#) in [Appendix B, Register Description](#)).

If the Enable Loopback bit is set, as soon as Virtual FIFO receive is ready, the block is ready to accept data from the Virtual FIFO transmit. The data on the Virtual FIFO transmit is then passed on to Virtual FIFO receive. This cycles the data from one port of the Virtual FIFO back into another port (Port 0 to Port 1 and Port 2 to Port 3 as shown in [Figure 3-5](#)) with no change to the data. In the loopback mode, data is not verified by the checker; the software driver on the receive end checks for data integrity.

If the Enable Checker bit is set, as soon as data is valid on the Virtual FIFO transmit (Port 0 and 2 in [Figure 3-5](#)) each data byte received is checked against a fixed data pattern. If there is a mismatch during a comparison, the data_mismatch signal is asserted. This signal can be accessed through the register space (see [Checker Status \(0x910C\)](#) and [Checker Status \(0x920C\)](#) in [Appendix B](#)).

If the Enable Generator bit is set and the Virtual FIFO receive is ready to accept data, the data produced by the generator is passed to the Virtual FIFO (Port 1 and 3 in [Figure 3-5](#)). The data from the generator also follows the same data pattern as the checker. The data received and transmitted by the module is divided into packets. The first two bytes of each packet define the length of packet. All other bytes carry the tag/sequence number of the packet. The tag number increases by one per packet. [Table 3-4](#) shows the packet format used in the Raw Packet Data module.

Table 3-4: Packet Format

[63:56] [48:55]	[47:40] [39:32]	[31:24] [23:16]	[15:8] [7:0]
TAG	TAG	TAG	PACKET LEN
TAG	TAG	TAG	TAG
-	-	-	-
-	-	-	-
TAG	TAG	TAG	TAG

Note: The data uses a fixed pattern to enable data checking. The data could be any random data otherwise.

[Table 3-5](#) shows the ports on the Raw Packet Data module.

Table 3-5: Ports on Raw Packet Data Module

Port Name	Type	Description
clk	Input	250 MHz clock
reset	Input	Synchronous reset
Read Interface		
axi_str_tx_tdata	Input	Data available from VFIFO transmit
axi_str_tx_tkeep	Input	Number of bytes valid per data beat on axi_str_tx_tdata

Table 3-5: Ports on Raw Packet Data Module (Cont'd)

Port Name	Type	Description
axi_str_tx_tvalid	Input	Indicates data on axi_str_tx_tdata is valid
axi_str_tx_tlast	Input	Indicates the end of packet on axi_str_tx_tdata
axi_str_tx_tuser	Input	VFIFO passes the length of the packet being transmitted
axi_str_tx_tready	Output	Indicates the Raw Packet Data module is ready to accept data from VFIFO transmit
Write Interface		
axi_str_tx_tdata	Output	Data available for VFIFO receive
axi_str_tx_tkeep	Output	Number of bytes valid per data beat on axi_str_rx_tdata
axi_str_tx_tvalid	Output	Indicates data on axi_str_rx_tdata is valid
axi_str_tx_tlast	Output	Indicates the end of packet on axi_str_tx_tdata
axi_str_tx_tuser	Output	Raw Packet Data module passes the length of the packet to VFIFO receive
axi_str_tx_tready	Input	Indicates VFIFO receive is ready to accept data from Raw Packet Data module
Register Interface		
enable_loopback	Input	Enables looping back of transmit data
enable_generator	Input	Enables data generator
pkt_len	Input	Length of packets produced by the generator
enable_checker	Input	Enable data checker
data_mismatch	Output	Indicates the transmit data is incorrect

Clocking

This section describes the clocking requirements for this Kintex-7 FPGA Base TRD.

Two differential clocks are needed in this TRD:

- 200 MHz clock and 800 MHz clock for the Memory Controller
- 100 MHz clock for PCI Express integrated Endpoint block

The KC705 board used for this reference design has a 100 MHz differential clock coming from the PCIe edge connector is passed on to the PCIe wrapper. The 200 MHz differential clock for the DDR3 Memory Controller comes from an oscillator on the KC705 board, and an 800 MHz clock is generated inside the Memory Controller by adjusting the MMCM multipliers and dividers.

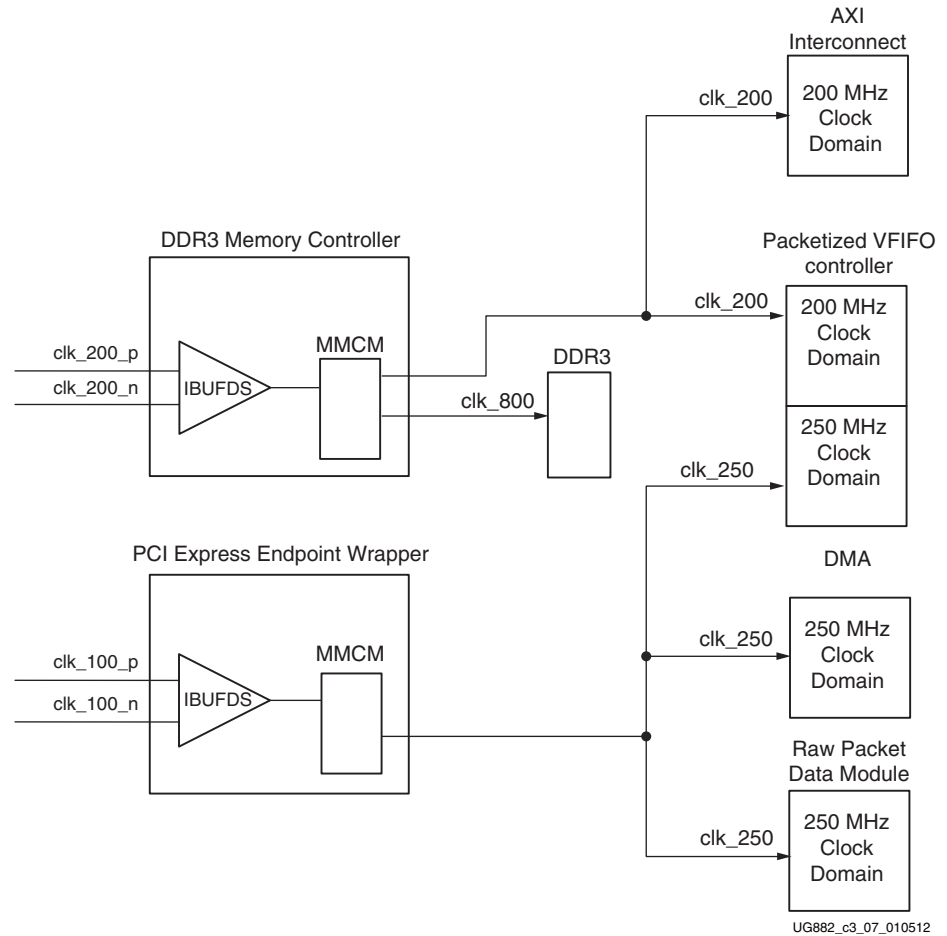


Figure 3-7: Clocking Diagram

Figure 3-7 shows the clocking connections. The wrapper for PCI Express generates a 250 MHz single-ended clock that goes to the DMA, Packetized Virtual FIFO Controller, and Raw Packet Data modules. The DDR3 Memory Controller generates a single-ended 200 MHz clock for the Packetized Virtual FIFO Controller and AXI Interconnect, and an 800 MHz single/differential clock for various parts of the Memory Controller and the external DDR3 device.

Resets

This section describes the reset requirements for Kintex-7 FPGA Base TRD.

Table 3-6: Resets by Function

Modules	PERSTn Asserted	PCIe Link Down	Software Requests DMA Abort
PCIe Wrapper	X		
DMA IP	X	X	
DDR3 Memory Controller IP	X		
AXI Interconnect	X		

Table 3-6: Resets by Function (Cont'd)

Modules	PERSTn Asserted	PCIe Link Down	Software Requests DMA Abort
Packetized VFIFO controller	X	X	X
Raw Packet Data	X	X	X

Table 3-6 shows how the different blocks get reset depending on the events that can happen. The primary reset for the Kintex-7 FPGA Base TRD is driven from the PERSTn pin of the PCIe edge connector. When this asynchronous pin is active-Low, the Kintex-7 FPGA Integrated Block for PCI Express, GT transceivers for PCIe and DDR3 Memory Controller IP are held in reset. When PERSTn is released, the initialization sequences start on these blocks. The initialization sequence for each of these blocks takes a long time, which is why they get the PERSTn pin directly. Each of these blocks has an output that reflects the status of its initialization sequence. PCIe asserts user_lnk_up, and the Memory Controller asserts init_calib_complete when the respective initialization is complete. These status signals are combined to generate the user logic resets. Figure 3-8 shows the connections for the resets used in the design.

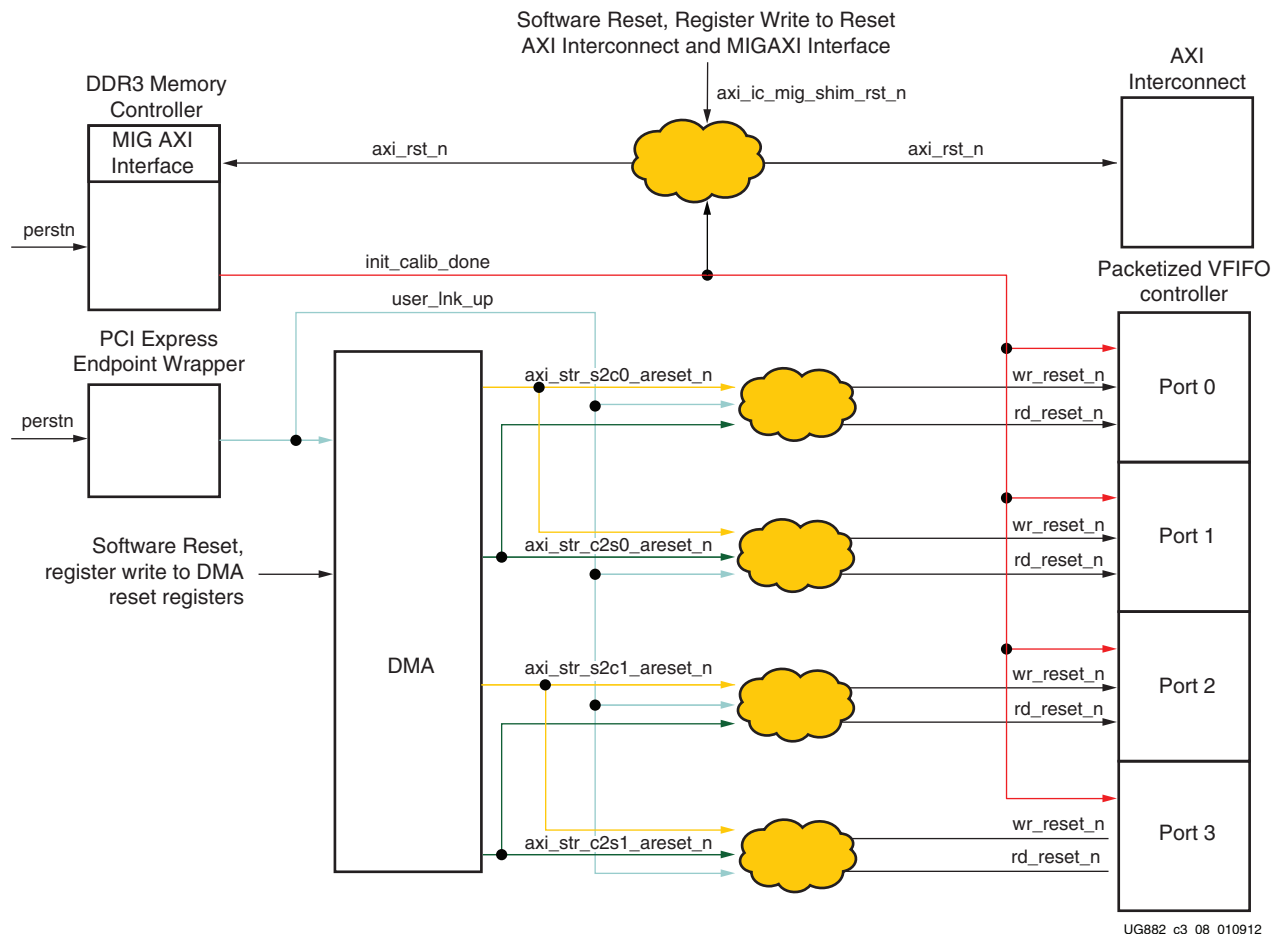
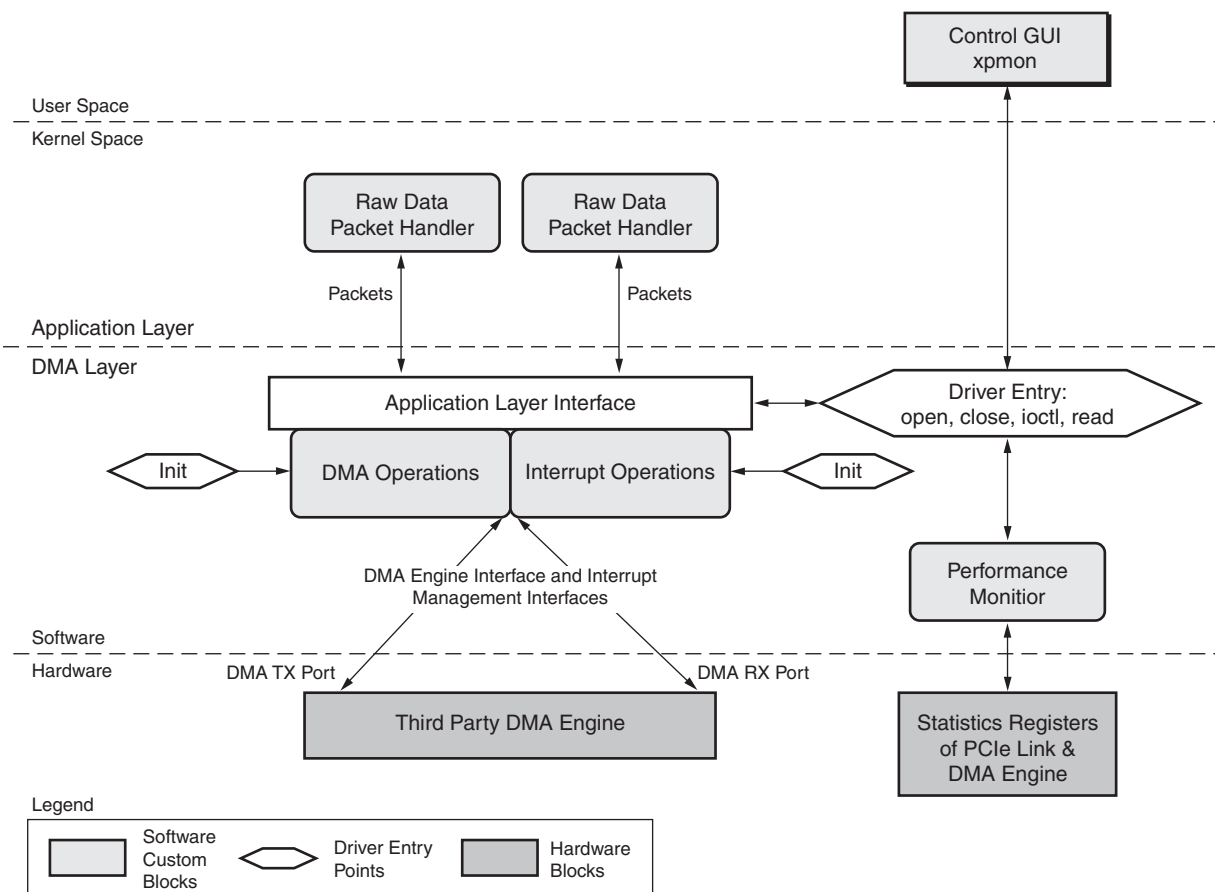


Figure 3-8: Reset Diagram

In addition, a software reset is implemented through the Packet DMA ports `axi_str_s2c_areset_n` and `axi_str_c2s_areset_n`, for each DMA channel. It is used when the software wants to reset the entire design without bringing the PCIe link down. This is done when unloading the driver. The DMA reset signals, resets the Packetized VFIFO controller and the Raw Packet Data modules. Another reset `axi_ic_mig_shim_rst_n` is issued by the software when unloading the driver. The software makes sure that DDR3 FIFO and the preview FIFOs are empty before resetting the AXI Interconnect IP and the MIG AXI interface. This is to ensure that all packets were received by the software and there are no partial packets left in the FIFOs.

Software Architecture

Figure 3-9 shows the software components of the Kintex-7 FPGA Base TRD. The software comprises several Linux kernel-space drivers and a user-space application.



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Figure 3-9: Software Architecture Overview

Kernel-space Drivers are responsible for:

- Configuration of the DMA engine to enable data transfer between the hardware design and main system memory
- Generation and transfer of raw data streams from host memory to hardware (Transmit). Transfer of the looped or generated streaming data back to the host memory (Receive).

User-space Application (xpmon) is a graphical user interface (GUI) used to:

- Manage the driver and device - for example setting configuration controls for packet generation and display options
- Display of performance statistics reported by PCIe performance monitor and DMA performance monitor

The software developed:

- Can generate adequate data to enable the hardware design to operate at throughput rates of up to 10 Gb/s end to end.
- Showcases the ability of the multichannel DMA to transfer large amounts of data.
- Provides a user interface that is easy to use and intuitive.
- Is modular and allows for reuse in similar designs.

Kernel Components

Driver Entry Points

The driver has several entry points, some of which are described here. The system invokes the driver entry function when a hardware match is detected after driver insertion (when the PCIe device probed by the driver is found). After reading the device configuration space, various initialization actions are done. These are initialization of the DMA engine(s), setting up of receive and transmit buffer descriptor rings, and, finally, initialization of interrupts. The other driver entry points are when the GUI starts up and shuts down; when a new performance test is started or stopped; and to convey periodic status information and performance statistics results to the GUI.

On a Linux OS, the system invokes the probe() function when a hardware match is detected. A device node is created for xdma (the node name is fixed and the major/minor numbers are allocated by the system). The base DMA driver appears as a device table entry in Linux.

DMA Operations

For each DMA channel, the driver sets up a buffer descriptor ring. At initialization, the receive ring (associated with a C2S channel) is fully populated with buffers meant to store incoming packets, and the full receive ring is submitted for DMA. On the other hand, the transmit ring (associated with S2C channel) is empty. As packets arrive for transmission, they are added to the buffer descriptor ring, and submitted for DMA.

Raw Data Packet Handler

Data payload for raw data flow is being generated and consumed in two instances of the Raw Data Packet Handler. These are referred to as xrawdata0 and xrawdata1 drivers. When a test is started, data buffers are generated of a fixed size based on user selection and then queued for transmit DMA. The hardware design loops this data back through the

Raw Packet Data module, and the data buffers arrive in the system as receive DMA. The handler does a data integrity check on the received data after which it discards the data and returns the buffer to a free pool for future use.

Interrupt Operations

If interrupts are enabled (by setting the compile-time macro `TH_BH_ISR`), the interrupt service routine (ISR) handles interrupts from the DMA engine and other errors from hardware, if any. The driver sets up the DMA engine to interrupt after every `N` descriptors that it processes. This value of `N` can be set by a compile-time macro. The ISR invokes the functionality in the block handler routines pertaining to handling received data and housekeeping of completed transmit and receive buffers.

Performance Monitor

The Performance Monitor is a handler that reads all the performance-related registers (PCIe link level, DMA Engine level). Each of these is read periodically at an interval of one second.

User Space Components

The Control & Monitor GUI (`xpmon`) is a graphical user interface tool used to monitor device status, run performance tests and display statistics. It conveys the user-configured test parameters to the DMA driver, which in turn passes this information to the Raw Data Packet driver through user registered functions. The Raw Data Packet drivers start an appropriate test according to the test value set by the user. Performance statistics gathered during the test are periodically conveyed to the GUI through the base DMA driver, where they are displayed in several graphs. For screen captures of the graphs, refer to [Chapter 2, Getting Started](#).

The GUI uses the OS-specific methods to communicate with the driver, which results in the appropriate driver entry points being invoked.

Control

The GUI allows the user to specify these items before starting a test:

- Packet size
- Enable Loopback or Enable Generator or Enable Checker

When the user starts a test, the GUI informs the DMA driver of the parameters of the test (unidirectional or bidirectional, the fixed buffer size). The driver sets up the test parameters and informs the Raw Data Packet Handler, which then starts setting up data buffers for transmission, reception or both. Similarly, if the user were to abort a test, the GUI informs the driver, which stops the packet generation mechanism. The test is aborted by stopping the transmit side flow, and then allowing the receive side flow to drain.

Monitor

The driver always maintains information on the status of the hardware. The GUI periodically invokes an `ioctl()` to read this status information.

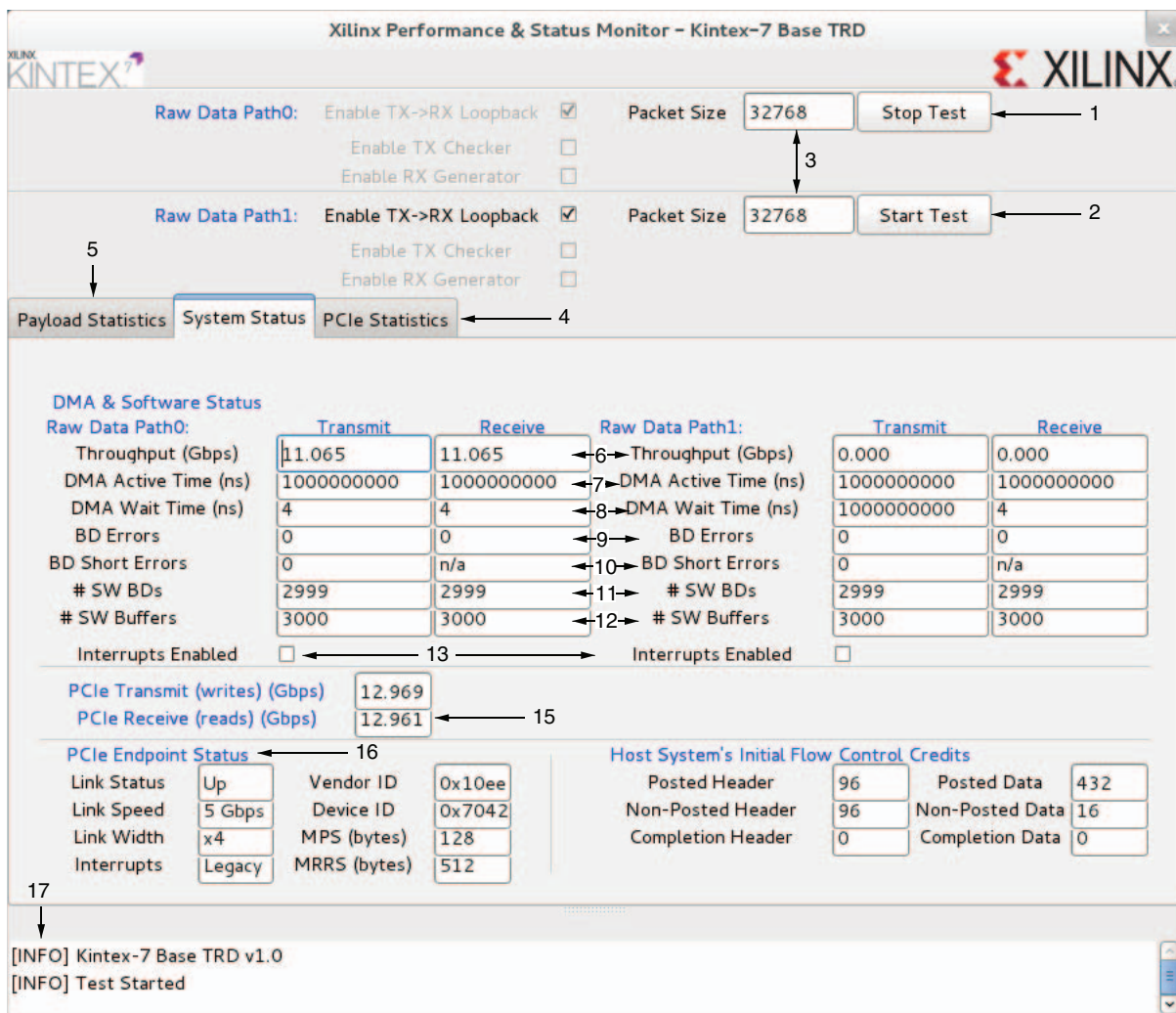
- PCIe link status, device status
- DMA Engine status
- BDs and buffer information from drivers

- Interrupt status

The driver maintains a set of arrays to hold per-second sampling points of different kinds of statistics, which are periodically collected by the performance monitor handler. The arrays are handled in a circular fashion. The GUI periodically invokes an `ioctl()` to read these statistics, and then displays them.

- PCIe link statistics provided by hardware
- DMA engine statistics provided by DMA hardware
- Graph display of all of the above

Figure 3-10 shows a screen capture of the GUI with the **System Status** tab selected.



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Figure 3-10: Software Application Screen Capture

The GUI Fields (indicated by the numbers in the [Figure 3-10](#)) are explained here.

1. **Stop Test:** Test start/stop control for raw data Path0.
2. **Start Test:** Test start/stop control for raw data Path1.
3. **Packet Size:** Fixed packet size selection in bytes for the raw datapath.
4. **PCIe Statistics tab:** Plots the PCIe transactions on the AXI4-Stream interface.
5. **Payload Statistics tab:** Shows the payload statistics graphs based on DMA engine performance monitor.
6. **Throughput (Gb/s):** DMA payload throughput in gigabits per second for each engine.
7. **DMA Active Time (ns):** The time in nanoseconds that the DMA engine has been active in the last second.
8. **DMA Wait Time (ns):** The time in nanosecond that the DMA was waiting for the software to provide more descriptors.
9. **BD Errors:** Indicates a count of descriptors that caused a DMA error. Indicated by the error status field in the descriptor update.
10. **BD Short Errors:** Indicates a short error in descriptors in the transmit direction when the entire buffer specified by length in the descriptor could not be fetched. This field is not applicable for the receive direction.
11. **# SW BDs:** Indicates the count of total descriptors set up in the descriptor ring.
12. **# SW Buffers:** Indicates the count of total data buffers associated with the ring.
13. **Interrupts Enabled:** Indicates the interrupt enable status for that DMA engine. The driver enables interrupts on a DMA engine by writing to the DMA engine register space. To enable interrupts, the compile-time macro TH_BH_ISR needs to be set.
14. **PCIe Transmit (writes) (Gb/s):** Reports the transmit (Endpoint card to host) utilization as obtained from the PCIe performance monitor in hardware.
15. **PCIe Receive (reads) (Gb/s):** Reports the receive (host to Endpoint card) utilization as obtained from the PCIe performance monitor in hardware.
16. **PCIe Endpoint Status:** Reports the status of various PCIe fields as reported in the Endpoint configuration space.
17. **Host System's Initial Flow Control Credits.** Initial Flow control credits advertised by the host system after link training with the Endpoint. A value of zero implies infinite flow control credits.
18. The text pane at the bottom shows informational messages, warnings, or errors.

GUI programming environment

After looking at various options, it was decided to choose GTK+ as the GUI programming environment. It has several advantages

- GTK+ libraries are native to Linux. Nothing has to be installed for basic features. This makes it easy to distribute source code and binaries for the GUI.
- It supports C/C++ programming.
- The code can be reused on Windows (where GTK+ would need to be installed).
- It is widely used and popular in the Linux community and is free.

DMA Descriptor Management

This section describes the DMA operation in terms of the descriptor management. It also describes data alignment needs of the DMA engine.

Traffic patterns could be bursty or sustained. To deal with different traffic scenarios, the software does not decide in advance the number of packets to be transferred, and accordingly sets up a descriptor chain for it. Packets can fit in a single descriptor, or might be required to span across multiple descriptors. Also, on the receive side, the actual packet might be smaller than the original buffer provided to accommodate it.

It is therefore required that:

- The software and hardware are each able to independently work on a set of buffer descriptors in a supplier-consumer model
- The software is informed of packets being received and transmitted as it happens
- On the receive side, the software needs a way of knowing the size of the packet

The rest of this section describes how the driver uses the features provided by DMA to achieve the above requirements. Refer to [Scatter Gather Packet DMA, page 37](#) and the *Northwest Logic Packet DMA User Guide* to get an overview of the DMA descriptors and DMA register space [Ref 6].

Dynamic DMA Updates

This section describes how the descriptor ring is managed in the Transmit or System-to-Card (S2C) and Receive or Card-to-System (C2S) directions.

Initialization Phase

Driver prepares descriptor rings for each DMA channel, each containing a number of descriptors that can be set via a compile-time macro. In the current design, the driver thus prepares four rings.

Transmit (S2C) Descriptor Management

In [Figure 3-11](#), the dark blocks indicate descriptors that are under hardware control, and the light blocks indicate descriptors that are under software control.

[Table 3-7](#) presents some of the terminology used in this section.

Table 3-7: Terminology Summary

Term	Description
HW_Completed	Register with the address of the last descriptor that DMA engine has completed processing
HW_Next	Register with the address of the next descriptor that DMA engine processes
SW_Next	Register with the address of the next descriptor that software submits for DMA

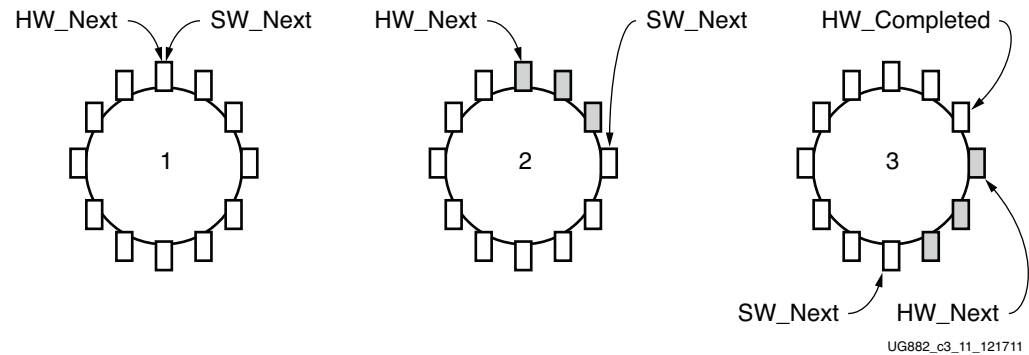


Figure 3-11: Transmit Descriptor Ring Management

S2C Initialization Phase

- Driver initializes HW_Next and SW_Next registers to start of ring.
- Driver resets HW_Completed register.
- Driver initializes and enables DMA engine.

Packet Transmission

- Packet is generated by the packet handler.
- Packet is attached to one or more descriptors in ring.
- Driver marks SOP, EOP and IRQ_on_completion in descriptors.
- Driver updates SW_Next register.

Post-Processing

- Driver checks for completion status in descriptor.
- Driver frees packet buffer.

This process continues as the driver keeps adding packets for transmission, and the DMA engine keeps consuming them. Because the descriptors are already arranged in a ring, post-processing of descriptors is minimal and dynamic allocation of descriptors is not required.

Receive (C2S) Descriptor Management

In [Figure 3-12](#), the dark blocks indicate descriptors that are under hardware control, and the light blocks indicate descriptors that are under software control.

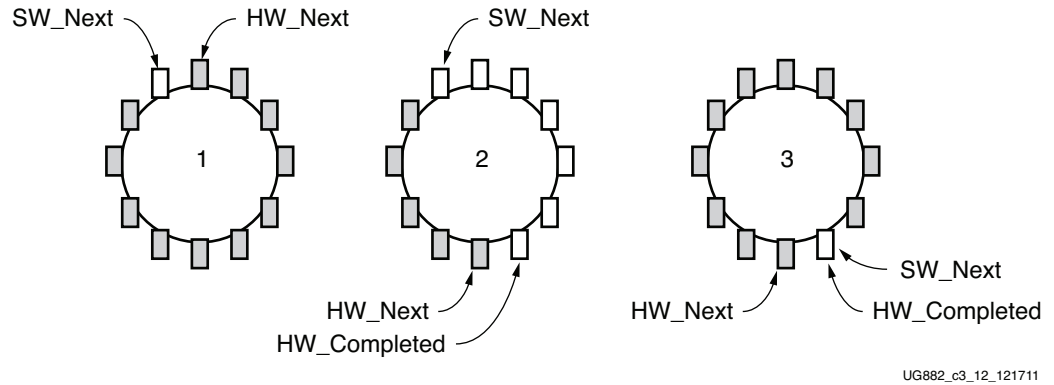


Figure 3-12: Receive Descriptor Ring Management

C2S Initialization Phase

- Driver initializes each receive descriptor with an appropriate Data buffer.
- Driver initializes HW_Next register to start of ring and SW_Next register to end of ring.
- Driver resets HW_Completed register.
- Driver initializes and enables DMA engine.

Post-Processing after Packet Reception

- Driver checks for completion status in descriptor.
- Driver checks for SOP, EOP and User Status information.
- Driver discards the completed packet buffer(s).
- Driver allocates new packet buffer for descriptor.
- Driver updates SW_Next register.

This process continues as the DMA engine keeps adding received packets in the ring, and the driver keeps consuming them. Because the descriptors are already arranged in a ring, post-processing of descriptors is minimal and dynamic allocation of descriptors is not required.

Performance Estimation

This chapter presents a theoretical estimation of performance on the PCI Express interface and the Packetized Virtual FIFO. It also presents a method to measure performance.

PCI Express Performance

PCI Express is a serialized, high bandwidth and scalable point-to-point protocol which provides highly reliable data transfer operations. The maximum transfer rate for a device that is version 2.0 compliant per lane is 2.5 Gb/s at Gen1 and 5 Gb/s at Gen2. This rate is the raw bit rate per lane per direction and not the actual data transfer rate. The effective data transfer rate is lower due to protocol overheads and other system design tradeoffs. Refer to the white paper *Understanding Performance of PCI Express Systems (WP350)* [Ref 7] for more information.

The PCI Express link performance together with scatter-gather DMA is estimated under these assumptions:

- Each buffer descriptor points to a 4 KB data buffer space.
- Maximum Payload Size (MPS) = 128B
- Maximum Read Request Size (MRRS) = 128B
- Read Completion Boundary (RCB) = 64B
- Transaction layer packets (TLPs) of three data words (3DWs) considered without extended cyclic redundancy check (ECRC), overhead = 20B
- One ACK packet (acknowledgment packet) assumed per TLP, DLLP (ACK is a Data link layer packet) overhead = 8B
- Update FC DLLPs are not accounted for, but they do affect the final throughput slightly.

The performance is projected by estimating overheads, then calculating the effective throughput by deducting these overheads.

These conventions are used in the calculations in [Table 4-1](#) and [Table 4-2](#):

Term	Description
MRD	Memory Read transaction
MWR	Memory Write transaction
CPLD	Completion with Data
C2S	Card to System
S2C	System to Card

Calculations are done considering unidirectional data traffic that is either transmit (data transfer from System to Card) or receive (data transfer from Card to System).

Traffic on the upstream (Card to System) PCIe link is bolded and traffic on the downstream (System to Card) PCIe link is italicized.

The C2S DMA engine (which deals with data reception, that is, writing data to system memory) first does a buffer descriptor fetch. Using the buffer address in the descriptor, it issues Memory Writes to the system. After the actual payload is transferred to the system, it sends a Memory Write to update the buffer descriptor. [Table 4-1](#) shows the overhead incurred during data transfer in the C2S direction.

Table 4-1: PCI Express Performance Estimation with DMA in the C2S Direction

Transaction Overhead	ACK Overhead	Comment
MRD for C2S Desc = 20/4096 = 0.625/128	<i>8/4096 = 0.25/128</i>	One descriptor fetch from C2S engine for 4 KB data (TRN-TX); 20B of TLP overhead and 8 bytes DLLP overhead
<i>CPLD for C2S Desc = 20+32/4096 = 1.625/128</i>	8/4096=0.25/128	Descriptor reception by C2S engine (TRN-RX). CPLD Header is 20 bytes, and the C2S Desc data is 32 bytes.
MWR for C2S buffer = 20/128	<i>8/128</i>	MPS = 128B; Buffer write from C2S engine (TRN-TX)
MWR for C2S Desc update = 20+12/4096 = 1/128	<i>8/4096 = 0.25/128</i>	Descriptor update from C2S engine (TRN-TX). MWR header is 20 bytes, and the C2S Desc update data is 12 bytes.

For every 128 bytes of data sent from the card to the system, the overhead on the upstream link (in bold) is 21.875 bytes.

$$\% \text{ Overhead} = 21.875 / (128 + 21.875) = 14.60\%$$

The throughput per PCIe lane is 2.5 Gb/s, but because of 8B/10B encoding, the throughput comes down to 2 Gb/s.

$$\text{Maximum theoretical throughput per lane for Receive} = (100 - 14.60) / 100 * 2 \text{ Gb/s} = 1.70 \text{ Gb/s}$$

$$\text{Maximum theoretical throughput for a x4 Gen2 or x8 Gen1 link for Receive} = 13.6 \text{ Gb/s}$$

The S2C DMA engine (which deals with data transmission, that is, reading data from system memory) first does a buffer descriptor fetch. Using the buffer address in the descriptor, it issues Memory Read requests and receives data from system memory through completions. After the actual payload is transferred from the system, it sends a Memory Write to update the buffer descriptor. [Table 4-2](#) shows the overhead incurred during data transfer in the S2C direction.

Table 4-2: PCI Express Performance Estimation with DMA in the S2C Direction

Transaction Overhead	ACK Overhead	Comment
MRD for S2C Desc=20/4096=0.625/128	<i>8/4096 = 0.25/128</i>	Descriptor fetch from S2C engine (TRN-TX)
<i>CPLD for S2C Desc=20+32/4096=1.625/128</i>	8/4096 = 0.25/128	Descriptor reception by S2C engine (TRN-RX). CPLD Header is 20 bytes and the S2C Desc data is 32 bytes.

Table 4-2: PCI Express Performance Estimation with DMA in the S2C Direction (Cont'd)

Transaction Overhead	ACK Overhead	Comment
MRD for S2C Buffer = 20/128	8/128	Buffer fetch from S2C engine (TRN-TX). MRRS=128B
<i>CPLD for S2C buffer = 20/64 = 40/128</i>	8/64=16/128	Buffer reception by S2C engine (TRN-RX). Because RCB=64B, 2 completions are received for every 128 byte read request
MWR for S2C Desc=20+4/4096=0.75/128	8/4096=0.25/128	Descriptor update from S2C engine (TRN-TX). MWR Header is 20 bytes and the S2C Desc update data is 12 bytes.

For every 128 bytes of data sent from system to card, the overhead on the downstream link (italicized) is 50.125 bytes.

$$\% \text{ Overhead} = 50.125/128 + 50.125 = 28.14\%$$

The throughput per PCIe lane is 2.5 Gb/s, but because of 8B/10B encoding, the throughput comes down to 2 Gb/s.

$$\text{Maximum theoretical throughput per lane for Transmit} = (100 - 28.14)/100 * 2 = 1.43 \text{ Gb/s}$$

$$\text{Maximum theoretical throughput for a x4 Gen2 or x8 Gen1 link for Transmit} = 11.44 \text{ Gb/s.}$$

Because the TRD has two raw datapaths, there are two C2S DMA engines and two S2C DMA engines. Each C2S and S2C engine should be able to theoretically operate at the 13.6 Gb/s and 11.44 Gb/s, respectively. If both data are enabled, the DMA splits the available bandwidth between the two C2S engines and two S2C engines.

The throughput numbers are theoretical and could go down further due other factors, such as:

- With an increase in lane width, PCIe credits are consumed at a faster rate, which could lead to throttling on the PCIe link reducing throughput.
- The transaction interface of PCIe is 64 bits wide. The data sent is not always 64-bit aligned, and this could cause some reduction in throughput.
- Changes in MPS, MRRS, RCB, and buffer descriptor size also have significant impact on the throughput. The MPS and MRRS values are negotiated between the host PC and all the endpoints plugged into the host PC. The RCB value is specific to the host PC.
- If bidirectional traffic is enabled, then overhead incurred further reduces throughput.
- Software overhead/latencies also contribute to reducing throughput.

Packetized Virtual FIFO Performance

For the Packetized Virtual FIFO, the theoretical maximum bandwidth to the DDR3 @ 800 MHz is 102.4 Gb/s.

$$\text{Maximum I/O Rate (double data rate)} = 800 \text{ MHz} * 2 = 1,600 \text{ Mb/s}$$

$$\text{Maximum Bandwidth} = (\text{Maximum I/O rate}) * (\text{Number of I/Os}) = 1600 \text{ Mb/s} * 64 = 102.4 \text{ Gb/s.}$$

The data bandwidth to and from the DDR3 is a percentage of the total bandwidth on the 64-bit I/O lines. For the Virtual FIFO, data bandwidth efficiency is expected to be 80–90%.

An estimate of Memory Controller performance for burst size of 128 is calculated as follows:

With larger burst lengths, higher efficiency can be achieved.

With 64-bit port using a burst length of 128, a total of 8192 bits are transferred.

The number of bits transferred per cycle is:

$$64 \text{ (bit width)} * 2 \text{ (double data rate)} = 128 \text{ bits per cycle}$$

The total cycles used for 8192 bits is:

$$8192/128 = 64 \text{ cycles per transfer}$$

Assuming 10 cycles read to write overhead:

$$64/74 = 86\% \text{ efficiency}$$

Assuming 5% efficiency overhead for refresh, the total efficiency is about 81%.

[Table 4-4](#) lists the estimated performance of the Packetized Virtual FIFO.

Table 4-3: Projected Performance of Packetized Virtual FIFO with DDR3 Running @ 800 MHz

Virtual FIFO	Throughput (Gb/s)	Comments
Total throughput	$102.4 * 0.8 = 81.92$	80% efficiency
Total throughput	$102.4 * 0.9 = 92.16$	90% efficiency

If one S2C and one C2S DMA engine is enabled, the throughput required on the DDR3 interface is

$$[13.6 \text{ Gb/s (S2C)} + 11.44 \text{ (C2S)}] * 2 \text{ (Writes and Read, in and out of the DDR3)} = 50.08 \text{ Gb/s}$$

Because the maximum theoretical throughput numbers on the PCIe link with the DMA overhead is less than what the Virtual FIFO can handle, the limiting component in this Base TRD system performance is the PCIe and DMA.

Measuring Performance

This section shows how performance is measured in the TRD.

It should be noted that PCI Express performance depends on factors like maximum payload size, maximum read request size, and read completion boundary, which are dependent on the systems used. With higher MPS values, performance improves as packet size increases.

Hardware provides the registers listed in [Table 4-4](#) for software to aid performance measurement.

Table 4-4: Performance Registers in Hardware

Register	Description
DMA Completed Byte Count	DMA implements a completed byte count register per engine which counts the payload bytes delivered to the user on the streaming interface.
PCIe AXI TX Utilization	This register counts traffic on PCIe AXI TX interface including TLP headers for all transactions.
PCIe AXI RX Utilization	This register counts traffic on PCIe AXI RX interface including TLP headers for all transactions.
PCIe AXI TX Payload	This register counts payload for memory write transactions upstream which includes buffer write and descriptor updates.
PCIe AXI RX payload	This register counts payload for completion transactions downstream which includes descriptor or data buffer fetch completions.

These registers are updated once every second by hardware. Software can read them periodically at one second intervals to directly get the throughput.

The PCIe monitor registers can be read to understand PCIe transaction layer utilization. The DMA registers provide throughput measurement for actual payload transferred.

These registers give a good estimate of the TRD performance.

Designing with the TRD Platform

The TRD platform acts as a framework for system designers to derive extensions or modify designs. This chapter outlines various ways for a user to evaluate, modify, and re-run the TRD. The suggested modifications are grouped under these categories:

- *Software-only* modifications are made by modifying software components only (drivers, demo parameters, and so on.). The design does not need to be re-implemented.
- *Design modifications* are changes made to design parameters. These changes modify hardware components only, i.e., parameters of individual IP components, custom logic, or the top level. The design must be re-implemented through the Vivado® design tools.
- *Architectural changes* modify both hardware and software components. The design must be re-implemented through the Vivado design tools. An example would be to add or replace IP blocks. The user needs to do some design work to ensure the new blocks can communicate with the existing interfaces in the framework. The user is also responsible to make sure that the new IP does not break the functionality of the existing framework. Relevant software changes might also be required to support the new IP.

All of these use models are fully supported by the framework, provided that the modifications do not require the supported IP components to operate outside the scope of their specified functionality.

This chapter provides examples to illustrate some of these use models. While some are simple modifications to the design, others involve replacement or addition of new IP. The new IP could come from Xilinx (and its partners) or from the customer's internal IP activities.

Software-Only Modifications

This section describes modifications to the platform done directly in the software driver. The same hardware design (BIT/MCS files) works. After any software modification, the code needs to be recompiled. The Linux driver compilation procedure is detailed in [Appendix D, Compiling Linux Drivers](#).

Macro-Based Modifications

This section describes the modifications, which can be realized by compiling the software driver with various macro options, either in the Makefile or in the driver source code.

Descriptor Ring Size

The number of descriptors to be set up in the descriptor ring can be defined as a compile time option.

To change the size of the buffer descriptor ring used for DMA operations, modify `DMA_BD_CNT` in `linux_driver/xdma/xdma_base.c`.

Smaller rings can affect throughput adversely, which can be observed by running the performance tests.

A larger descriptor ring size uses additional memory, but improves performance, because more descriptors can be queued to hardware. Also see section [Size of Block Data, page 66](#).

Note: The `DMA_BD_CNT` in the driver is set to 2999. Increasing this number might not improve performance.

Log Verbosity Level

To control the log verbosity level in Linux:

- Add `DEBUG_VERBOSE` in the Makefiles in the directories `linux_driver/xdma`, `linux_driver/xrawdata0`, and `linux_driver/xrawdata1` to cause the drivers to generate verbose logs.
- Add `DEBUG_NORMAL` in the Makefiles in the directories `linux_driver/xdma`, `linux_driver/xrawdata0`, and `linux_driver/xrawdata1` to cause the drivers to generate informational logs.
- Remove both these macros from the Makefiles in the directories `linux_driver/xdma`, `linux_driver/xrawdata0`, and `linux_driver/xrawdata1` to cause the drivers to only generate error logs.

Changes in the log verbosity are observed when examining the system logs. Increasing the logging level also causes a drop in throughput.

Driver Mode of Operation

The base DMA driver can be configured to run in either interrupt mode with MSI interrupts or in polled mode. Only one mode can be selected. To control the driver:

- Add `TH_BH_ISR` in the Makefile `linux_driver/xdma` to run the base DMA driver in interrupt mode.
- Remove the `TH_BH_ISR` macro to run the base DMA driver in polled mode.

Note: The interrupt mode has had only limited testing in hardware.

Size of Block Data

To modify the default amount of data being transmitted and received in the raw data drivers:

- Modify `NUM_BUFS` in `xrawdata0/sguser.c` or `xrawdata1/sguser.c` to change the number of buffers in the free pool available to the drivers. This modification changes the throughput observed with these drivers. If `NUM_BUFS` is modified, `DMA_BD_CNT` should also be modified to a value equal to `NUM_BUFS-1`.

Note: The available system memory must not be exceeded when these defaults are changed.

Software Driver Code Modifications

This section describes the modifications that can be made to software driver code to see a change in design behavior or performance.

The Block Data handler for raw datapaths (`xrawdata0/sguser.c`, `xrawdata1/sguser.c`) can be modified as follows.

Data is written into DDR3 memory in a flat, unstructured manner, with known patterns. It is possible to create a packet format with some form of CRC, which can then be verified on the receive path. Packets are generated and verified within the driver and are not conveyed to or from any real user application as data. One suggested modification is to transfer this data between the driver and a user application. This requires significant changes in the driver entry points and in the driver's `PutPkt()` and `GetPkt()` routines. The data is transmitted (written) into DDR3 memory, and is looped back and received (read) from DDR3 memory.

Top-Level Design Modifications

This section describes changes to parameters in the top-level design file that can change the design behavior. Modifications to the software driver might be required based on the parameters being changed.

Hardware-Only Modifications

This section outlines the changes that require only hardware re-implementation.

Configuring the PCIe Link as x4 Lane at 2.5 Gb/s

The Kintex®-7 FPGA integrated Endpoint block for PCI Express can be configured as x4 at a 2.5 Gb/s (Gen1) link rate instead of x4 at a 5 Gb/s (Gen2) link rate, taking a hit in performance. To configure the PCIe link as x4 lane at 2.5 Gb/s, do the following:

1. Open a terminal window (Linux) or an Vivado tool Tcl command prompt (Windows).
2. Navigate to `hardware/vivado/scripts`.
3. Run the following command to invoke the Vivado® design tools GUI. The design with x4gen1 PCIe configuration is loaded:

```
$ launch_x4gen1.bat
```

 (for Windows)

```
$ ./launch_x4gen1.bat
```

 (for Linux)
4. Click **Run Synthesis** in the Project Manager window. A window with the message `Synthesis Completed Successfully` appears after the Vivado tools generate a design netlist. Close the message window.
5. Click **Run Implementation** in the Project Manager window. A window with the message `Implementation Completed Successfully` appears after mapping and placement and routing processes are done. Close the message window.
6. Click **Generate Bitstream**. A window with the message `Generate Bitstream Completed Successfully` appears at the end of this process and a design bit file is available in `hardware/vivado/vivado_proj_x4gen1/k7_pcie_dma_ddr3_base_x4_gen1.runs/impl_1`.
7. Close the Vivado design tools GUI.

8. Navigate to the `hardware/vivado/scripts` folder and run the following command to generate an MCS file:

```
$ vivado -source k7_base_x4_gen1_flash.tcl
```

An MCS file (`KC705_x4gen1.mcs`) is available in the `k7_pcie_dma_ddr3_base/ready_to_test` folder.

After configuring the FPGA with the new bitstream, the user can rerun the TRD (refer to [Reprogramming the Base TRD, page 26 in Chapter 2, Getting Started](#) to configure the FPGA). The results of the performance evaluation should be lower than the original version of the TRD.

Hardware and Software Modifications

This section outlines changes to be done to the top-level design file (`k7_pcie_dma_ddr3_base.v`) that also require software driver modifications.

PCIe Vendor and Device ID

PCIe vendor ID and device ID can be updated through these local parameters (`localparam`) in the top-level file:

- `VENDOR_ID` in the file `k7_pcie_dma_ddr3_base/hardware/sources/hdl/k7_pcie_dma_ddr3_base.v` changes the vendor ID.
- `DEVICE_ID` in the file `k7_pcie_dma_ddr3_base/hardware/sources/hdl/k7_pcie_dma_ddr3_base.v` changes the device ID.

The software then requires a corresponding change.

- Change the `PCI_VENDOR_ID_DMA` macro in `k7_pcie_dma_ddr3_base/linux_driver/xdma/xdma_base.c`.
- Change the `PCI_DEVICE_ID_DMA` macro in `k7_pcie_dma_ddr3_base/linux_driver/xdma/xdma_base.c`.

Refer to [Appendix D, Compiling Linux Drivers](#) for how to recompile drivers and install them. Refer to [Appendix C, Directory Structure](#) to navigate to the required files.

Architectural Modifications

This section describes architecture level changes to the functionality of the platform. These changes include adding or deleting IP with similar interfaces used in the framework.

Aurora IP Integration

The LogiCORE IP Aurora 8B/10B core implements the Aurora 8B/10B protocol using the high-speed Kintex-7 FPGA GTX transceivers. The core is a scalable, lightweight link layer protocol for high-speed serial communication. It is used to transfer data between two devices using transceivers. It provides an AXI4-Stream compliant user interface.

A 4-lane Aurora design with 2-byte user interface data width presents a 64-bit AXI4-Stream user interface, which matches the Raw Packet Data module's interface within the framework. Hence, a customer can accelerate the task of creating a PCIe-to-Aurora bridge design through these high-level steps:

1. Generate a four-lane (3.125 Gb/s line rate per lane) and two-byte Aurora 8B/10B LogiCORE IP from the CORE Generator tool. Remove the raw data block instance.

- Remove the Raw Packet Data block and insert the Aurora LogiCORE IP into the framework (see Figure 5-1).
- Add an MMCM block to generate a 156.25 MHz clock, or use an external clock source, to drive a 156.25 MHz clock into the Aurora LogiCORE IP.
- Simulate the design with the out-of-box simulation framework with appropriate modifications to include the Aurora files.
- Implement the design and run the design with Aurora in loopback mode with minimal changes to the implementation flow.

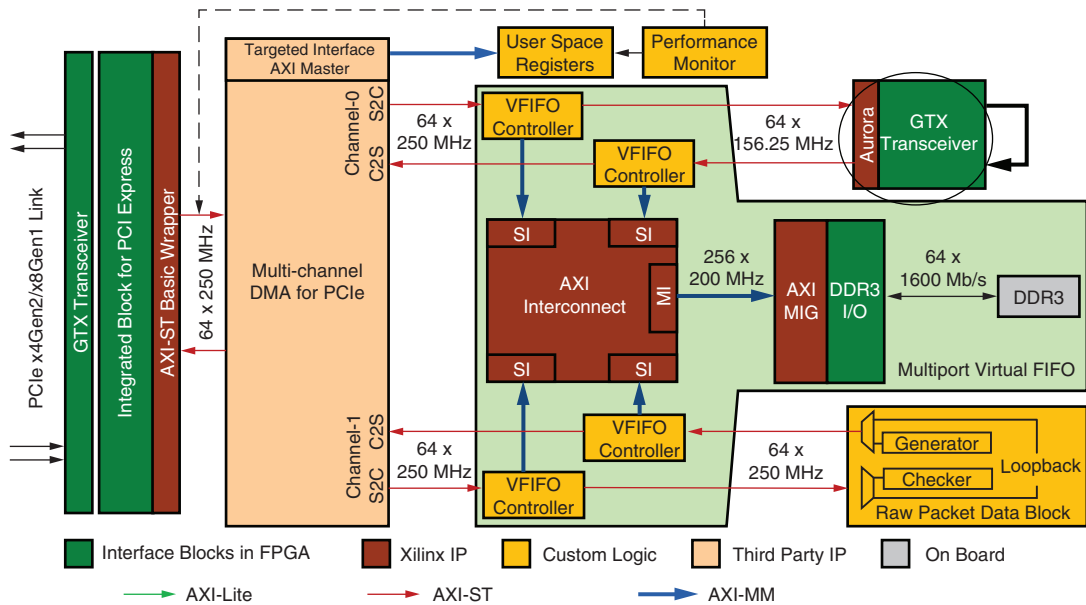


Figure 5-1: Integrating Aurora

Aurora IP does not support throttling in the receive direction, because the core has no internal buffers. The Multiport Virtual FIFO in the datapath allows the user to drain packets at the line rate. The Native Flow Control feature of Aurora can also be used to manage flow control. As per the Aurora protocol, the round trip delay through the Aurora interfaces between the NFC request and the first pause arriving at the originating channel partner must not exceed 256 symbol times.

For 4 lanes, time taken to transmit 4 symbols with each lane running at 3.125 Gb/s
 $40 \text{ bits}/4 \text{ lanes} \times 1/3.125 \text{ Gb/s} = 3.2 \text{ ns}$ (1 symbol = 10 bits because of 8B/10B encoding scheme).

For 256 symbols, time taken to transmit is $256/4 \times 3.2 = 205 \text{ ns}$.

For a 156.25 MHz clock (8 ns period), this is 26 clock cycles (the worst case delay), amounting to a FIFO depth of 26, which is required to hold data received on the Aurora RX interface after an NFC request to pause data is initiated. The user must appropriately configure the preview FIFO thresholds for full and empty in Multiport Virtual Packet FIFO considering this value to prevent overflows.

The Raw Packet Data driver can be reused for Aurora with some modifications. The data generated by the block handler for Raw Packet Data could now drive traffic over Aurora. The Aurora serial interface needs to be looped back externally or connected to another Aurora link partner.

The maximum theoretical throughput that can be achieved on the Aurora path is 10 Gb/s (64 bit * 156.25 MHz). Refer to *LogiCORE IP Aurora 8B/10B Product Guide for Vivado Design Suite* (PG046) [Ref 8] for throughput efficiency.

Resource Utilization

Table A-1 and Table A-2 list resource utilization obtained from the utilization report generated during the Vivado® tool implementation phase. The XC7K325T-2FFG900C is the target FPGA.

Note: The reported utilization numbers are obtained with the default options set for synthesis and implementation of the design. A change in the default options results in a change in the utilization numbers.

Table A-1: Resources for the TRD with the PCIe Link Configured as x4 at a 5 Gb/s Link Rate

Resource	Utilization	Total Available	Percentage Utilization (%)
Slice registers	59284	407,600	14.51%
Slice LUTs	51646	203,800	24.75%
Bonded IOB	125	500	25%
RAMB36E1	69	445	15.73
RAMB18E1	5	890	.56%
BUFG/BUFGCTRL	8	32	25%
MMCM_ADV	3	10	30%
GTXE2_CHANNELS	4	16	25%
GTXE2_COMMONS	1	4	25%
PCIE_2_1	1	1	100%

Table A-2: Resources for the TRD with the PCIe Link Configured as x8 at a 2.5 Gb/s Link Rate

Resource	Utilization	Total Available	Percentage Utilization (%)
Slice registers	60962	407,600	14.92%
Slice LUTs	53163	203,800	25.46%
Bonded IOB	125	500	25%
RAMB36E1	69	445	15.73%
RAMB18E1	5	890	0.56%
BUFG/BUFGCTRL	8	32	25%

Table A-2: Resources for the TRD with the PCIe Link Configured as x8 at a 2.5 Gb/s Link Rate (Cont'd)

Resource	Utilization	Total Available	Percentage Utilization (%)
MMCM_ADV	3	10	30%
GTXE2_CHANNELS	8	16	50%
GTXE2_COMMONS	2	4	50%
PCIE_2_1	1	1	100%

Register Description

This appendix describes registers most commonly accessed by the software driver.

The registers implemented in hardware are mapped to base address register (BAR0) in the PCIe integrated Endpoint block.

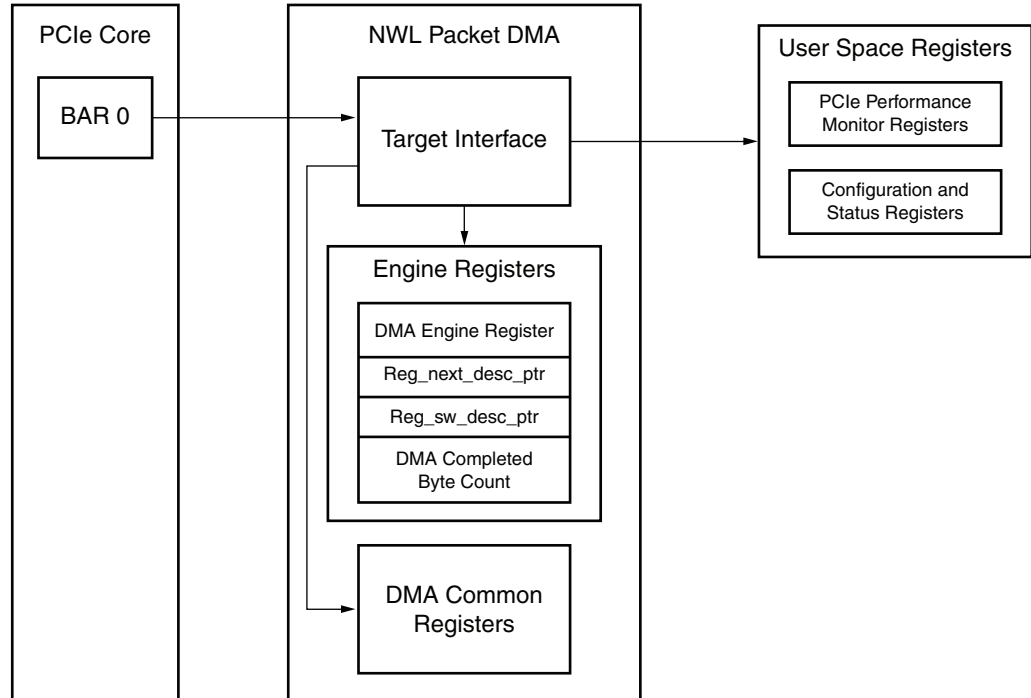
[Table B-1](#) shows the mapping of multiple DMA channel registers across the BAR.

Table B-1: DMA Channel Register Address

DMA Channel	Offset from BAR0
Channel-0 S2C	0x0
Channel-1 S2C	0x100
Channel-0 C2S	0x2000
Channel-1 C2S	0x2100

Registers in DMA for interrupt handling are grouped under a category called common registers, which are at an offset of 0x4000 from BAR0.

Figure B-1 shows the layout of registers.



UG882_aB_01_011012

Figure B-1: Register Map

The user logic registers are mapped as shown in Table B-2.

Table B-2: User Register Address Offsets

User Logic Register Group	Range (Offset from BAR0)
PCIe performance registers Design version and status registers	0x9000–0x90FF
User Application 0 registers	0x9100–0x91FF
User Application 1 registers	0x9200–0x92FF
Packetized VFIFO registers	0x9300–0x93FF

DMA Registers

This section describes certain prominent DMA registers used very frequently by the software driver. For a detailed description of all registers available, refer to the *Northwest Logic DMA Back-End Core User Guide* and *Northwest Logic DMA AXI DMA Back-End Core User Guide*, available in the `k7_pcie_dma_ddr3_base/hardware/sources/ip_cores/dma/doc` directory.

Channel Specific Registers

The registers described in this section are present in all channels. The address of the register is channel address offset from BAR0 (refer to [Table B-1](#)) + the register offset.

Engine Control (0x0004)

Table B-3: DMA Engine Control Register

Bit	Field	Mode	Default Value	Description
0	Interrupt Enable	RW	0	Enables interrupt generation
1	Interrupt Active	RW1C	0	Interrupt active is set whenever an interrupt event occurs. Write '1' to clear.
2	Descriptor Complete	RW1C	0	Interrupt active was asserted due to completion of descriptor. This is asserted when a descriptor with interrupt on completion bit set is seen.
3	Descriptor Alignment Error	RW1C	0	This causes interrupt when a descriptor address is unaligned, and that DMA operation is aborted.
4	Descriptor Fetch Error	RW1C	0	This causes interrupt when a descriptor fetch errors, that is, completion status is not successful.
5	SW_Abort_Error	RW1C	0	This is asserted when a DMA operation is aborted by software.
8	DMA Enable	RW	0	Enables the DMA engine. After enabled, the engine compares the next descriptor pointer and software descriptor pointer to begin execution.
10	DMA_Running	RO	0	Indicates DMA in operation.
11	DMA_Waiting	RO	0	Indicates DMA waiting on software to provide more descriptors.
14	DMA_Reset_Request	RW	0	Issues a request to user logic connected to DMA to abort outstanding operation and prepare for reset. This is cleared when user acknowledges the reset request.
15	DMA_Reset	RW	0	Assertion of this bit resets the DMA engine and issues a reset to user logic.

Next Descriptor Pointer (0x0008)

Table B-4: DMA Next Descriptor Pointer Register

Bit	Field	Mode	Default Value	Description
[31:5]	Reg_Next_Desc_Ptr	RW	0	Next Descriptor Pointer is writable when DMA is not enabled. It is read only when DMA is enabled. This should be written to initialize the start of a new DMA chain.
[4:0]	Reserved	RO	5'b00000	Required for 32-byte alignment

Software Descriptor Pointer (0x000C)

Table B-5: DMA Software Descriptor Pointer Register

Bit	Field	Mode	Default Value	Description
[31:5]	Reg_SW_Desc_Ptr	RW	0	Software Descriptor Pointer is the location of the first descriptor in a chain that is still owned by the software
[4:0]	Reserved	RO	5'b00000	Required for 32-byte alignment

Completed Byte Count (0x001C)

Table B-6: DMA Completed Byte Count Register

Bit	Field	Mode	Default Value	Description
[31:2]	DMA_Completed_Byte_Count	RO	0	Completed byte count records the number of bytes that transferred in the previous one second. This has a resolution of 4 bytes.
[1:0]	Sample Count	RO	0	This sample count increments every time a sample is taken at 1 second interval

Common Registers

The registers described in this section are common to all engines. The register addresses are located at the given offsets from BAR0.

Common Control & Status (0x4000)

Table B-7: DMA Common Control & Status Register

Bit	Field	Mode	Default Value	Description
0	Global Interrupt Enable	RW	0	Global DMA Interrupt Enable This bit globally enables or disables interrupts for all DMA engines
1	Interrupt Active	RO	0	Reflects the state of the DMA interrupt hardware output considering the state is global interrupt enable
2	Interrupt Pending	RO	0	Reflects the state of the DMA interrupt output <i>without</i> considering the state of global interrupt enable
3	Interrupt Mode	RO	0	0 - MSI mode 1 - Legacy interrupt mode
4	User Interrupt Enable	RW	0	Enables generation of user interrupts
5	User Interrupt Active	RW1C	0	Indicates active user interrupt
23:16	S2C Interrupt Status	RO	0	Bit[i] indicates interrupt status of S2C DMA engine[i] If S2C engine is not present, then this bit is read as zero.
31:24	C2S Interrupt Status	RO	0	Bit[i] indicates interrupt status of C2S DMA engine[i] If C2S engine is not present, then this bit is read as zero.

User Space Registers

This section describes the custom registers implemented in the user space. All registers are 32-bit wide. Register bits positions are to be read from 31 to 0 from left to right. All bits undefined in this section are reserved, and return zero on read. All registers would return default values on reset. Address holes return a value of zero on being read.

All registers are mapped to BAR0 and relevant offsets are provided.

Design Version and Status Registers

Design Version (0x9000)

Table B-8: Design Version Register

Bit Position	Mode	Default Value	Description
3:0	RO	0001	Subversion number: 0000: Non-AXI design 0001: AXI design
11:4	RO	0001_0000	Version of the design (e.g., for v1.0, the version is 0001_0000)
15:12	RO	0000	Reserved
27:16	RO	0001_0000_1000	NWL DMA Version
31:28	RO	0001	Device— 0000: Artix®-7 FPGA 0001: Kintex®-7 FPGA 0010: Virtex®-7 FPGA 0011: Virtex®-7 XT FPGA

Design Status (0x9008)

Table B-9: Design Status Register

Bit Position	Mode	Default Value	Description
0	RO	0	DDR3 Memory Controller initialization/calibration done (design operational status from hardware)
1	RW	1	axi_ic_mig_shim_rst_n - Resets the AXI Interconnect IP and MIG AXI Interface. When software writes to this register it self clears after 9 clock cycles
5:2	RO	f	ddr3_fifo_empty - indicates the DDR3 FIFO and the preview FIFOs per port are empty.

Transmit Utilization Byte Count (0x900C)

Table B-10: PCIe Performance Monitor - Transmit Utilization Byte Count Register

Bit Position	Mode	Default Value	Description
1:0	RO	00	Sample count - increments every second
31:2	RO	0	Transmit utilization byte count —This field contains the interface utilization count for active beats on PCIe AXI4-Stream interface for transmit. It has a resolution of 4 bytes.

Receive Utilization Byte Count (0x9010)

Table B-11: Performance Monitor - Receive Utilization Byte Count Register

Bit Position	Mode	Default Value	Description
1:0	RO	00	Sample count - increments every second
31:2	RO	0	Receive utilization payload byte count —This field contains the interface utilization count for active beats on PCIe AXI4-Stream interface for receive. It has a resolution of 4 bytes.

Upstream Memory Write Byte Count (0x9014)

Table B-12: PCIe Performance Monitor - Upstream Memory Write Byte Count Register

Bit Position	Mode	Default Value	Description
1:0	RO	00	Sample count—Increments every second
31:2	RO	0	Upstream memory write byte count —This field contains the payload byte count for upstream PCIe memory write transactions. It has a resolution of 4 bytes.

Downstream Completion Byte Count (0x9018)

Table B-13: PCIe Performance Monitor - Downstream Completion Byte

Bit Position	Mode	Default Value	Description
1:0	RO	00	Sample count—Increments every second
31:2	RO	0	Downstream completion byte count —This field contains the payload byte count for downstream PCIe completion with data transactions. It has a resolution of 4 bytes.

Initial Completion Data Credits for Downstream Port (0x901C)

Table B-14: PCIe Performance Monitor - Initial Completion Data Credits Register

Bit Position	Mode	Default Value	Description
11:0	RO	00	INIT_FC_CD captures initial flow control credits for completion data for host system

Initial Completion Header Credits for Downstream Port (0x9020)

Table B-15: PCIe Performance Monitor - Initial Completion Header Credits Register

Bit Position	Mode	Default Value	Description
7:0	RO	00	INIT_FC_CH captures initial flow control credits for completion header for host system

PCIe Credits Status - Initial Non Posted Data Credits for Downstream Port
(0x9024)

Table B-16: PCIe Performance Monitor - Initial NPD Credits Register

Bit Position	Mode	Default Value	Description
11:0	RO	00	INIT_FC_NPD captures initial flow control credits for non-posted data for host system

PCIe Credits Status - Initial Non Posted Header Credits for Downstream Port
(0x9028)

Table B-17: PCIe Performance Monitor - Initial NPH Credits Register

Bit Position	Mode	Default Value	Description
7:0	RO	00	INIT_FC_NPH captures initial flow control credits for non-posted header for host system

PCIe Credits Status - Initial Posted Data Credits for Downstream Port (0x902C)

Table B-18: PCIe Performance Monitor - Initial PD Credits Register

Bit Position	Mode	Default Value	Description
11:0	RO	00	INIT_FC_PD captures initial flow control credits for posted data for host system

PCIe Credits Status - Initial Posted Header Credits for Downstream Port
(0x9030)

Table B-19: PCIe Performance Monitor - Initial PH Credits Register

Bit Position	Mode	Default Value	Description
7:0	RO	00	INIT_FC_PH captures initial flow control credits for posted header for host system

Generator/Checker/Loopback Registers for User APP 0

This section describes registers that can be configured on the raw data Path0 in the user application space.

Enable Generator (0x9100)

Table B-20: User App 0 - Enable Generator Register

Bit Position	Mode	Default Value	Description
0	RW	0	Enable traffic generator - C2S0

Packet Length (0x9104)

Table B-21: User App 0 - Packet Length Register

Bit Position	Mode	Default Value	Description
15:0	RW	16'd4096	Packet Length to be generated. Maximum supported is 64KB size packets. (C2S0)

Enable Loopback/Checker (0x9108)

Table B-22: User App 0 - Enable Loopback/Checker Register

Bit Position	Mode	Default Value	Description
0	RW	0	Enable traffic checker - S2C0
1	RW	0	Enable Loopback - S2C0 <—> C2S0

Checker Status (0x910C)

Table B-23: User App 0 - Checker Status Register

Bit Position	Mode	Default Value	Description
0	RW1C	0	Checker error—Indicates data mismatch when set (S2C0)

Generator/Checker/Loopback Registers for User APP 1

This section describes registers that can be configured on the raw data Path1 in the user application space.

Enable Generator (0x9200)

Table B-24: User App 1 - Enable Generator Register

Bit Position	Mode	Default Value	Description
0	RW	0	Enable traffic generator - C2S1

Packet Length (0x9204)

Table B-25: User App 1 - Packet Length Register

Bit Position	Mode	Default Value	Description
15:0	RW	16'd4096	Packet Length to be generated. Maximum supported is 64KB size packets. (C2S1)

Enable Loopback/Checker (0x9208)

Table B-26: User App 1 - Enable Loopback/Checker Register

Bit Position	Mode	Default Value	Description
0	RW	0	Enable traffic checker - S2C1
1	RW	0	Enable Loopback - S2C1 <—> C2S1

Checker Status (0x920C)

Table B-27: User App 1 - Checker Status Register

Bit Position	Mode	Default Value	Description
0	RW1C	0	Checker error—Indicates data mismatch when set (S2C1)

Memory Controller Registers

Registers in [Table B-28](#) through [Table B-31](#) are repeated for each of the four ports of the Virtual Packet FIFO. The addresses given for each register are in the ascending order (Port 1, Port 2, Port 3, Port 4). Refer to [Multiport Virtual Packet FIFO, page 41](#), for details.

Start Address (0x9300, 0x9310, 0x9320, 0x9330)

Table B-28: Start Address Register

Bit Position	Mode	Default Value	Description
31:0	RW	0	Start address of the DDR3 memory for that channel

End Address (0x9304, 0x9314, 0x9324, 0x9334)

Table B-29: End Address Register

Bit Position	Mode	Default Value	Description
31:0	RW	32'h0100_0000	End address of the DDR3 memory for that channel. The implemented FIFO logic wraps around at this address.

Write Burst Size (0x9308, 0x9318, 0x9328, 0x9338)

Table B-30: Write Burst Size Register

Bit Position	Mode	Default Value	Description
8:0	RW	9'd256	Write Burst Size for AXI-MM write transactions issued to AXI interconnect SI slot

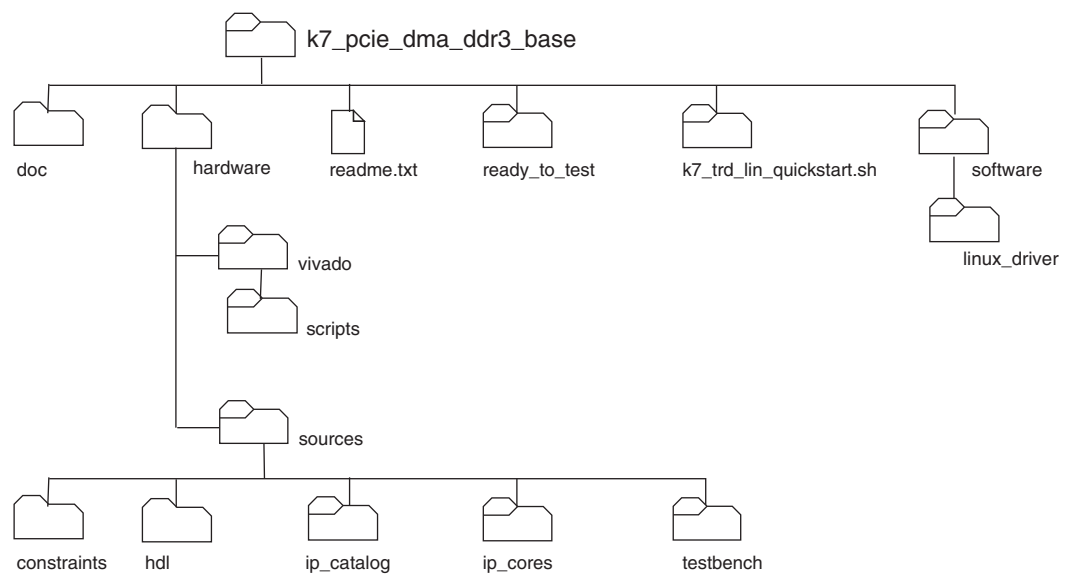
Read Burst Size (0x930C, 0x931C, 0x932C, 0x933C)

Table B-31: Read Burst Size Register

Bit Position	Mode	Default Value	Description
8:0	RW	9'd256	Read Burst Size for AXI-MM read transactions issued to AXI interconnect SI slot

Directory Structure

This appendix describes the directory structure and explains the organization of various files and folders.



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Figure C-1: Directory Structure

The design folder contains all the hardware design deliverables:

- The `sources` subfolder contains source code deliverable files.
- The `testbench` subfolder contains test bench related files for simulation.
- The `scripts` subfolder contains simulation and implementation scripts for the design for both Microsoft Windows and Linux operating systems.
- The `ip_cores` subfolder contains IP cores required for this design and the DMA design files.
- The `ip_catalog` subfolder contains `xci` files of IP cores required for this design.

The `doc` folder contains the Doxygen generated HTML file for software driver details.

The `configuring_kc705` folder contains programming files and scripts to configure the KC705 board.

These files are in the top-level directory:

- The `readme` file provides details on the use of simulation and implementation scripts.

- The `k7_trd_lin_quickstart` script is used to build and insert driver and GUI modules, invoke the GUI, and remove the driver modules when the user closes the GUI window.

Compiling Linux Drivers

This section provides steps on Linux driver compilation. The Linux driver source code for the design is available under the directory `k7_pcie_dma_ddr3_base/linux_driver`.

If the software is modified, rerun `k7_trd_lin_quickstart` to recompile and load the driver. This also launches the Application GUI. (Refer to [Driver Installation, page 17](#).)

The user can also run the individual steps detailed in this appendix to get a better understanding of the driver.

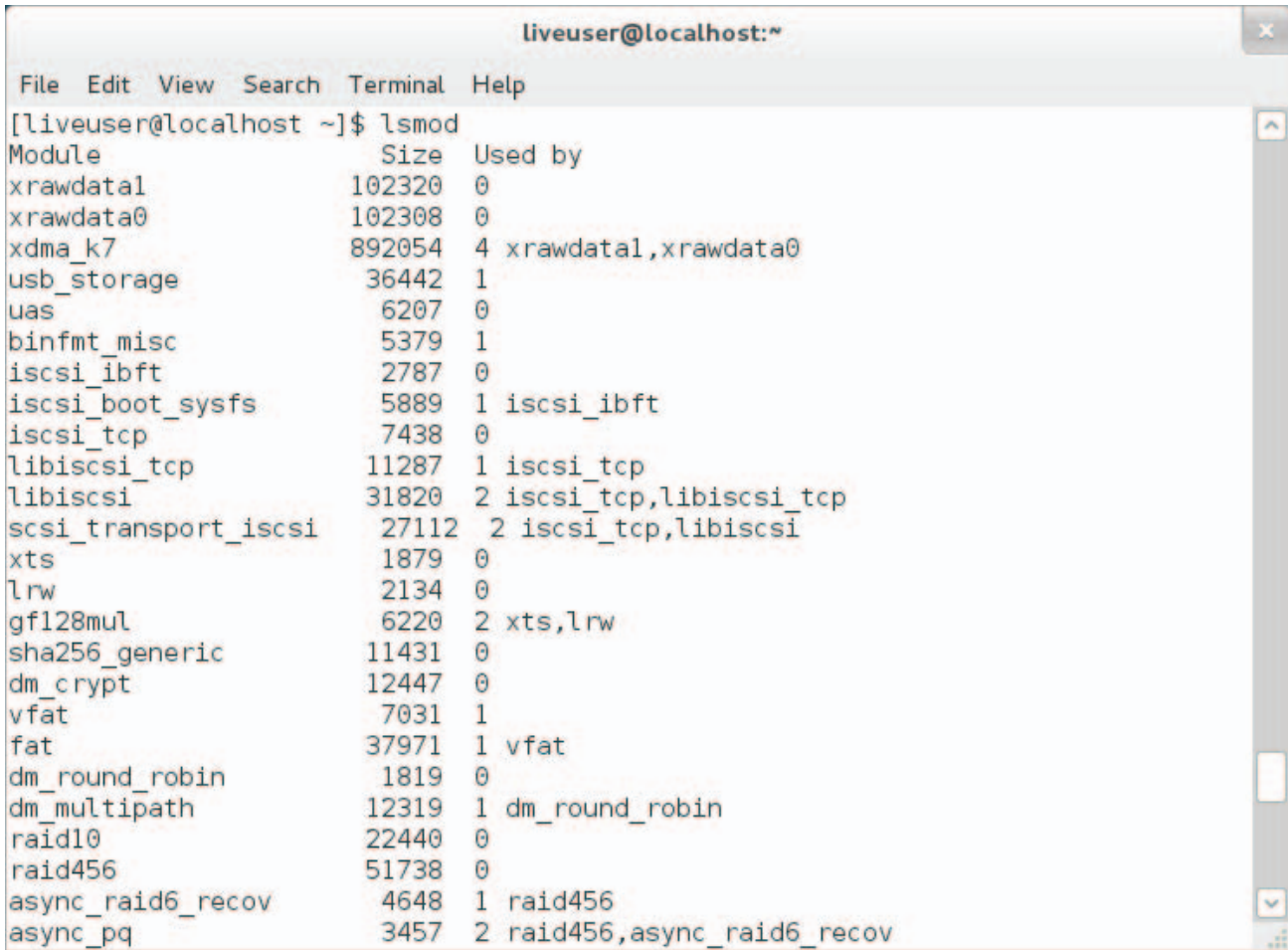
1. Compile the Linux drivers and insert the kernel modules.

Open a terminal window. Navigate to the `k7_pcie_dma_ddr3_base/linux_driver` folder. To compile and insert the driver, follow these steps at the command line in the terminal in the `linux_driver` folder:

- a. To clean the area, type:
`$ make clean`
- b. To compile the files and build the kernel objects, type:
`$ make`
- c. To insert the kernel object files, type:
`$ make insert`

2. To check the status of the device drivers, at the terminal command line, type:
`$ lsmod | more`

Look for the drivers that are loaded. The `xrawdata0` and `xrawdata1` modules depend on the base `xdma` driver. The `lsmod` command displays *Used by* on the `xdma_k7` entry as shown in [Figure D-1](#).



```

liveuser@localhost:~
File Edit View Search Terminal Help
[liveuser@localhost ~]$ lsmod
Module                Size  Used by
xrawdatal             102320  0
xrawdatab             102308  0
xdma_k7               892054  4 xrawdatab,xrawdatab
usb_storage           36442   1
uas                   6207   0
binfmt_misc           5379   1
iscsi_ibft            2787   0
iscsi_boot_sysfs     5889   1 iscsi_ibft
iscsi_tcp             7438   0
libiscsi_tcp         11287   1 iscsi_tcp
libiscsi              31820   2 iscsi_tcp,libiscsi_tcp
scsi_transport_iscsi 27112   2 iscsi_tcp,libiscsi
xts                   1879   0
lrw                   2134   0
gf128mul              6220   2 xts,lrw
sha256_generic       11431   0
dm_crypt              12447   0
vfat                  7031   1
fat                   37971   1 vfat
dm_round_robin        1819   0
dm_multipath          12319   1 dm_round_robin
raid10                22440   0
raid456               51738   0
async_raid6_recov    4648   1 raid456
async_pq              3457   2 raid456,async_raid6_recov

```

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Figure D-1: Loaded Drivers `xdma_k7`, `xrawdatab0`, `xrawdatab1`

3. GUI compilation: Steps are provided for compiling and invoking the GUI.

To compile and invoke the GUI, navigate to the `k7_pcie_dma_ddr3_base/linux_driver/xpmon` folder and follow these steps:

 - a. To clean the area, type:


```
$ make clean
```
 - b. To compile the files, type:


```
$ make
```
 - c. To invoke the GUI, type:


```
$. /xpmon
```

To run the application GUI, go to [Using the Application GUI, page 18](#).
4. Remove the device drivers. Steps are provided for unloading the driver.

To unload the driver modules, navigate to the `k7_pcie_dma_ddr3_base/linux_driver` folder and execute this command at the command line in the terminal:


```
$ make remove
```

This step takes a few seconds to free the allocated buffers and remove the three device drivers. To check that the drivers have been successfully removed, use the `lsmod` command in the terminal window again (see [Figure D-2](#)).

```

liveuser@localhost:~
File Edit View Search Terminal Help
[liveuser@localhost ~]$ lsmod
Module                Size  Used by
fuse                  53291  3
ip6t_REJECT           3395   2
nf_conntrack_ipv4     6874   1
nf_conntrack_ipv6     6429   1
nf_defrag_ipv4        1093   1 nf_conntrack_ipv4
nf_defrag_ipv6        7174   1 nf_conntrack_ipv6
xt_state              942    2
nf_conntrack          56146  3 nf_conntrack_ipv4,nf_conntrack_ipv6,xt_state
ip6table_filter       1215   1
ip6_tables            9828   1 ip6table_filter
snd_hda_codec_analog  63109  1
snd_hda_intel         20691  2
snd_hda_codec         73778  2 snd_hda_codec_analog,snd_hda_intel
snd_hwdep             4821   1 snd_hda_codec
snd_seq              43428  0
snd_seq_device        5033   1 snd_seq
snd_pcm               63551  2 snd_hda_intel,snd_hda_codec
snd_timer            15209  2 snd_seq,snd_pcm
snd                   48367  12 snd_hda_codec_analog,snd_hda_intel,snd_hda_code
c,snd_hwdep,snd_seq,snd_seq_device,snd_pcm,snd_timer
soundcore             5027   1 snd
snd_page_alloc        6031   2 snd_hda_intel,snd_pcm
r8169                 34604  0
i7core_edac          13106  0
iTCO_wdt              9956   0
  
```

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Figure D-2: Removed Drivers `xdma_k7`, `xrawdata0`, and `xrawdata1`

Additional Resources

Xilinx Resources

For support resources such as Answers, Documentation, Downloads, and Forums, see the [Xilinx Support website](#).

For continual updates, add the Answer Record to your [myAlerts](#).

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

The most up to date information related to the KC705 board and its documentation is available on these websites:

[Kintex-7 FPGA KC705 Evaluation Kit](#)

[Kintex-7 FPGA KC705 Evaluation Kit documentation](#)

[Kintex-7 FPGA KC705 Evaluation Kit - Known Issues and Release Notes Master Answer Record \(AR 45934\)](#)

[Vivado Design Suite](#)

These documents and sites provide supplemental material useful with this guide:

1. Northwest Logic DMA back-end core:
www.nwlogic.com/products/pci-express-solution/
2. *Vivado Design Suite User Guide: Release Notes, Installation, and Licensing* ([UG973](#))
3. *7 Series FPGAs Integrated Block for PCI Express: Product Guide for Vivado Design Suite* ([PG054](#))
4. *Vivado Design Suite User Guide: Synthesis* ([UG901](#))
5. *Vivado Design Suite Logic Simulation User Guide* ([UG900](#))
6. The GTK+ project API documentation: www.gtk.org/documentation.php. GTK+ is a toolkit for creating graphical user interfaces (GUI).
7. *Understanding Performance of PCI Express Systems* ([WP350](#))
8. *LogiCORE IP Aurora 8B/10B Product Guide for Vivado Design Suite* ([PG046](#))
9. *7 Series FPGAs GTX/GTH Transceivers User Guide* ([UG476](#))
10. *KC705 Kintex-7 FPGA Evaluation Board User Guide* ([UG810](#))

11. *7 Series FPGAs Memory Interface Solutions User Guide* ([UG586](#))
12. *Kintex-7 FPGA KC705 Evaluation Kit Getting Started Guide (Vivado Design Suite)* ([UG883](#))
13. [AXI Interconnect IP](#)
14. Fedora project: fedoraproject.org. Fedora is a Linux-based operating system used in the development of this TRD.

Regulatory and Compliance Information

This product is designed and tested to conform to the European Union directives and standards described in this section.

Declaration of Conformity

The [Kintex-7® FPGA KC705 Declaration of Conformity](#) is online.

Directives

2006/95/EC, *Low Voltage Directive (LVD)*

2004/108/EC, *Electromagnetic Compatibility (EMC) Directive*

Standards

EN standards are maintained by the European Committee for Electrotechnical Standardization (CENELEC). IEC standards are maintained by the International Electrotechnical Commission (IEC).

Electromagnetic Compatibility

EN 55022:2010, *Information Technology Equipment Radio Disturbance Characteristics – Limits and Methods of Measurement*

EN 55024:2010, *Information Technology Equipment Immunity Characteristics – Limits and Methods of Measurement*

This is a Class A product. In a domestic environment, this product can cause radio interference, in which case the user might be required to take adequate measures.

Safety

IEC 60950-1:2005, *Information technology equipment – Safety, Part 1: General requirements*

EN 60950-1:2006, *Information technology equipment – Safety, Part 1: General requirements*

Markings



This product complies with Directive 2002/96/EC on waste electrical and electronic equipment (WEEE). The affixed product label indicates that the user must not discard this electrical or electronic product in domestic household waste.



This product complies with Directive 2002/95/EC on the restriction of hazardous substances (RoHS) in electrical and electronic equipment.



This product complies with CE Directives 2006/95/EC, *Low Voltage Directive (LVD)* and 2004/108/EC, *Electromagnetic Compatibility (EMC) Directive*.

Warranty

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