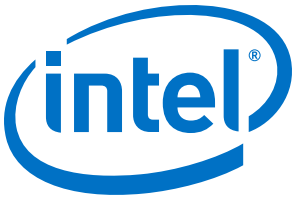

Intel® Stratix® 10 Avalon®-MM Hard IP for PCIe* Design Example User Guide

Updated for Intel® Quartus® Prime Design Suite: **17.1**

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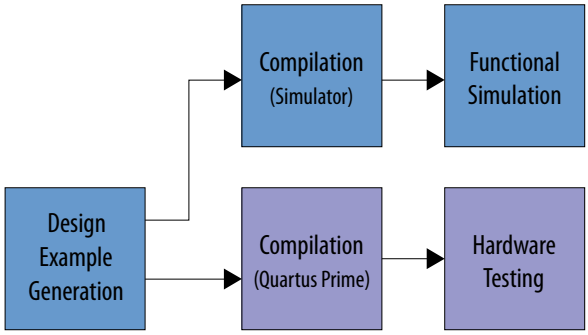
Contents

1 Quick Start Guide

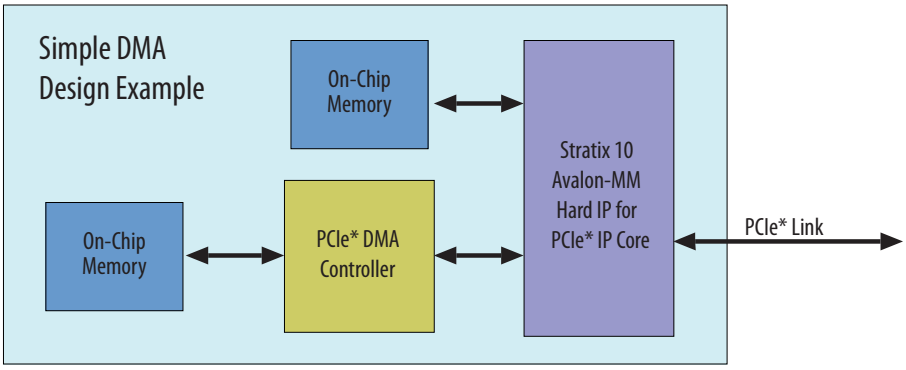
Using Intel® Quartus® Prime Pro Edition, you can generate a simple DMA design example for the Avalon®-MM Intel Stratix® 10 Hard IP for PCI Express* IP core. The generated design example reflects the parameters that you specify. It automatically creates the files necessary to simulate and compile in the Intel Quartus Prime Pro Edition software. You can download the compiled design to the Intel Stratix 10-GX Development Board. To download to custom hardware, update the Intel Quartus Prime Settings File (`.qsf`) with the correct pin assignments .

Figure 1. Development Steps for the Design Example



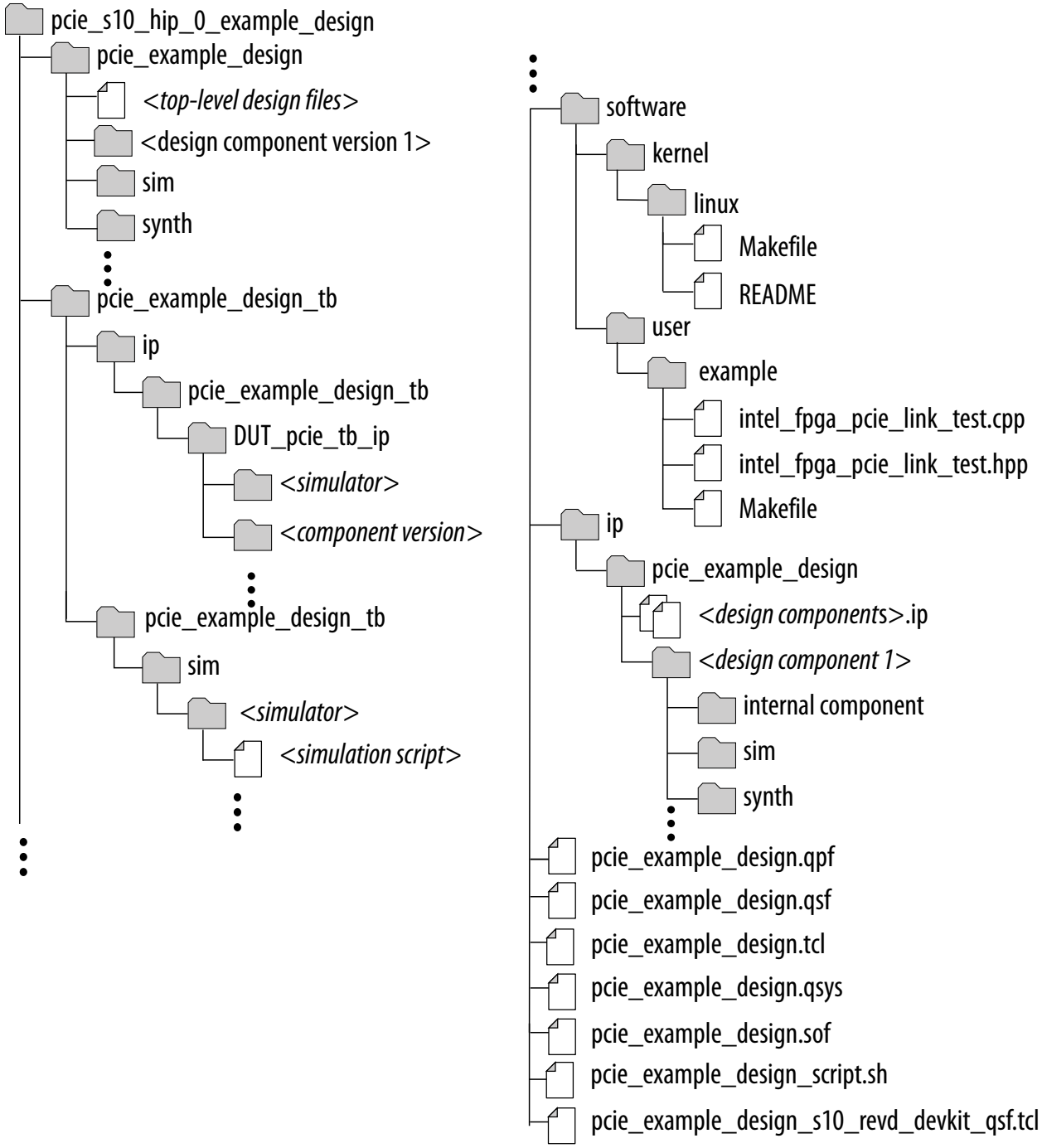
1.1 Design Components

Figure 2. Block Diagram for the Simple DMA for PCIe* Design Example



1.2 Directory Structure

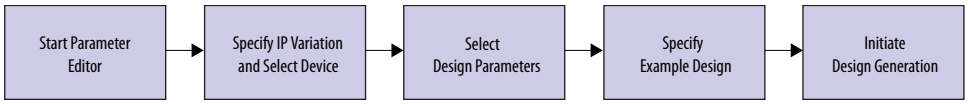
Figure 3. Directory Structure for the Generated Design Example



1.3 Generating the Design Example

Follow these steps to generate your design:

Figure 4. Procedure



1. In the Intel Quartus Prime Pro Edition software, create a new project (**File ➤ New Project Wizard**).
2. Specify the **Directory, Name**, and **Top-Level Entity.**
3. For **Project Type**, accept the default value, **Empty project**. Click **Next**.
4. For **Add Files** click **Next**.
5. For **Family, Device & Board Settings** under **Family**, select **Intel Stratix 10** and the **Target Device** for your design.
6. Click **Finish**.
7. In the IP Catalog locate and add the **Intel Stratix 10 -MM Hard IP forPCI Express**. Click **Create**.
8. In the **New IP Variant** dialog box, specify a name for your IP.
9. On the **IP Settings** tabs, specify the parameters for your IP variation.
10. On the **Example Designs** tab, make the following selections:
    a. For **Available Example Designs,** select **Simple DMA**.

       Note: The **Simple DMA** design example is only available when you enable **Enable high performance bursting Avalon-MM Slave interface (HPTXS)** on the **Avalon-MM Settings** tab.

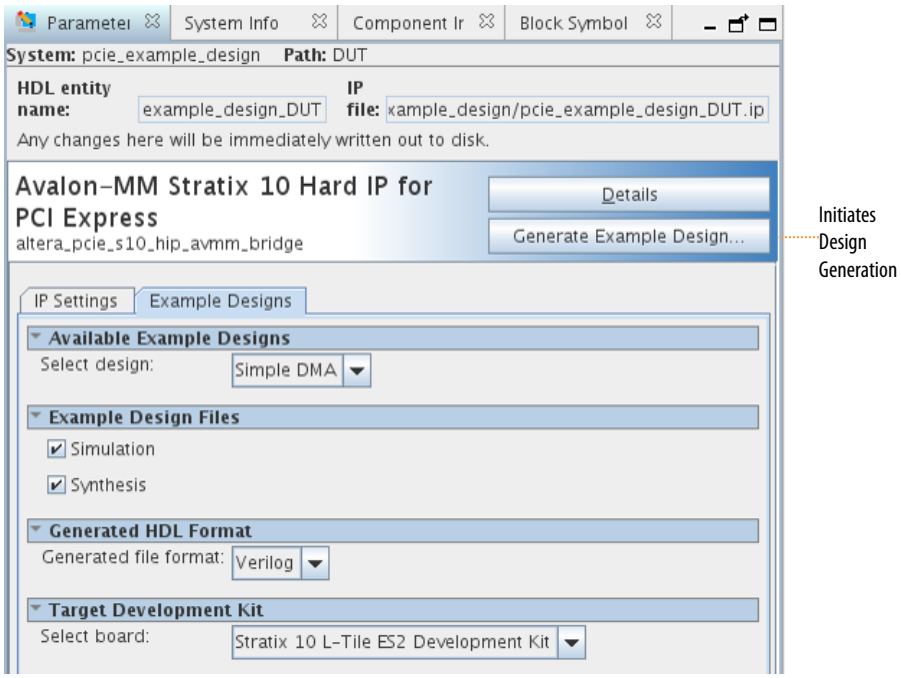
       (The **DMA** design example is only available when you turn on **Enable Avalon-MM DMA** on the **Avalon-MM Settings** tab.)

    b. For **Example Design Files**, turn on the **Simulation** and **Synthesis** options.
    c. If you have selected a x16 configuration, for **Select simulation Root Ccomplex BFM**, choose the appropriate BFM:
       - **Intel FPGA BFM**: for all configurations up to Gen3 x8. This bus functional model (BFM) supports x16 configurations by downtraining to x8.
       - **Third-party BFM**: for x16 configurations if you want to simulate all 16 lanes using a third-party BFM. Refer to AN-811: Using the Avery BFM for PCI Express Gen3x16 Simulation on Intel Stratix 10 Devices for information about simulating with the Avery BFM.

    d. For **Generated HDL Format**, only Verilog is available in the current release.
    e. For **Target Development Kit**, select the appropriate option.

       Note: If you select **None**, the generated design example targets the device specified. If you intend to test the design in hardware, make the appropriate pin assignments in the `.qsf` file.
11. Select **Generate Example Design** to create a design example that you can simulate and download to hardware. If you select one of the Intel Stratix 10 development boards, the device on that board overwrites the device previously

selected in the Intel Quartus Prime project if the devices are different. When the prompt asks you to specify the directory for your example design, accept the default directory, *<example_design>/*`pcie_s10_hip_ast_0_example_design`



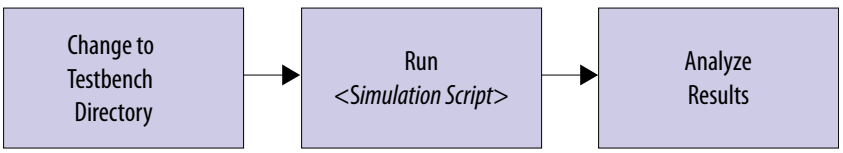
12. Click **Finish**. Save your `.ip` file when prompted.
13. The prompt, **Recent changes have not been generated. Generate now?**, allows you to create files for simulation and synthesis of the design example. Click **No** to simulate the testbench design example you have generated. The `.sof` file for the complete example design is what you download to a board to perform hardware verification.
14. Close your project.

Related Links

AN-811: Using the Avery BFM for PCI Express Gen3x16 Simulation on Intel Stratix 10 Devices

1.4 Simulating the Design Example

Figure 5. Procedure



1. Change to the testbench simulation directory, `pcie_example_design_tb`.
2. Run the simulation script for the simulator of your choice. Refer to the table below.
3. Analyze the results.

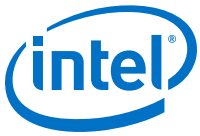


Table 1. Steps to Run Simulation

Simulator	Working Directory	Instructions
ModelSim*	*<example_design>*/pcie_example_design_tb/pcie_example_design_tb/sim/mentor/	1. do msim_setup.tcl 2. ld_debug 3. run -all 4. A successful simulation ends with the following message, "Simulation stopped due to successful completion!"
VCS*	<example_design>/pcie_example_design_tb/pcie_example_design_tb/sim/synopsys/vcs	1. sh vcs_setup.sh USER_DEFINED_SIM_OPTIONS="" 2. A successful simulation ends with the following message, "Simulation stopped due to successful completion!"
NCSim*	*<example_design>*/pcie_example_design_tb/pcie_example_design_tb/sim/cadence	1. sh ncsim_setup.sh USER_DEFINED_SIM_OPTIONS="" USER_DEFINED_ELAB_OPTIONS ="-timescale\ 1ns/1ps" 2. A successful simulation ends with the following message, "Simulation stopped due to successful completion!"

The simple DMA testbench completes the following tasks:

1. Writes to the Endpoint memory using the DUT Endpoint Avalon-MM RX master interface.
2. Reads from Endpoint memory using the DUT Endpoint Avalon-MM RX master interface.
3. Verifies the data using the shmem_chk_ok task.
4. Writes to the Endpoint DMA controller, instructing the DMA controller to perform a MemRd request to the PCIe* address space in host memory.
5. Writes to the Endpoint DMA controller, instructing the DMA controller to perform a MemWr request to PCIe address space in host memory. This MemWr uses the data from the previous MemRd.
6. Verifies the data using the shmem_chk_ok task.

The simulation reports, "Simulation stopped due to successful completion" if no errors occur.

Figure 6. Partial Transcript from Successful Simulation Testbench

```
# INFO:           88656 ns        Maximum Link Width: x8
# INFO:           88656 ns      Supported Link Speed: 8.0GT/s or 5.0GT/s or 2.5GT/s
# INFO:           88656 ns                 L0s Entry: Supported
# INFO:           88656 ns                 L1  Entry: Not Supported
# INFO:           88656 ns          L0s Exit Latency: 2 us to 4 us
# INFO:           88656 ns          L1  Exit Latency: Less Than 1 us
# INFO:           99928 ns BAR Address Assignments:
# INFO:           99928 ns BAR    Size       Assigned Address  Type
# INFO:           99928 ns ---    ----       ----------------
# INFO:           99928 ns BAR1:0   4 KBytes 00000000 80000000 Prefetchable
# INFO:           99928 ns BAR3:2  64 KBytes 00000000 80010000 Prefetchable
# INFO:           99928 ns BAR4   Disabled
# INFO:           99928 ns BAR5   Disabled
# INFO:           99928 ns ExpROM Disabled
# INFO:          100704 ns Completed configuration of Endpoint BARs.
# INFO:          101608 ns Starting Target Write/Read Test.
# INFO:          101608 ns   Target BAR = 0
# INFO:          101608 ns   Length = 000512, Start Offset = 000000
# INFO:          103096 ns   Target Write and Read compared okay!
# INFO:          103096 ns Starting DMA Read/Write Test.
# INFO:          103096 ns   Setup BAR = 2
# INFO:          103096 ns   Length = 000512, Start Offset = 000000
# INFO:          106882 ns Clear Interrupt INTA
# INFO:          111416 ns MSI recieved!
# INFO:          111416 ns   DMA Read and Write compared okay!
# SUCCESS: Simulation stopped due to successful completion!
# Simulation passed
```

1.5 Compiling the Design Example and Programming the Device

1. Navigate to `<project_dir>/pcie_s10_hip_ast_0_example_design/` and open `pcie_example_design.qpf`.
2. On the Processing menu, select **Start Compilation**.
3. After successfully compiling your design, program the targeted device with the Programmer.

1.6 Installing the Linux Kernel Driver

Before you can test the design example in hardware, you must install the Linux kernel driver. You can use this driver to perform the following tests:

- A PCIe link test that performs 100 writes and reads
- Memory space DWORD(1) reads and writes
- Configuration Space DWORD reads and writes

In addition, you can use the driver to change the value of the following parameters:

- The BAR
- The selects device by specifying the bus, function and device (BDF) numbers for the required device

(1) Throughout this user guide, the terms word, DWORD and QWORD have the same meaning that they have in the PCI Express Base Specification. A word is 16 bits, a DWORD is 32 bits, and a QWORD is 64 bits.

Complete the following steps to install the kernel driver:

1. Navigate to `./software/kernel/Linux` under the example design generation directory.
2. Change the permissions on the `install`, `load`, and `unload` files:

   ```
   $ chmod 777 install load unload
   ```
3. Install the driver:

   ```
   $ sudo ./install
   ```
4. Verify the driver installation:

   ```
   $ lsmod | grep intel_fpga_pcie_drv
   ```

   Expected result:

   ```
   intel_fpga_pcie_drv 17792 0
   ```
5. Verify that Linux recognizes the PCIe design example:

   ```
   $ lspci -d 1172:000 -v | grep intel_fpga_pcie_drv
   ```

   Note: If you have changed the Vendor ID, substitute the new Vendor ID for Altera®'s

   Vendor ID in this command.

   Expected result:

   ```
   Kernel driver in use: intel_fpga_pcie_drv
   ```

1.7 Running the Design Example Application

1. Navigate to `./software/user/example` under the design example directory.
2. Compile the design example application:

   ```
   $ make
   ```
3. Run the test:

   ```
   $ ./intel_fpga_pcie_link_test
   ```

   You can run the Intel FPGA IP PCIe link test in manual or automatic mode.

   — In automatic mode, the application automatically selects the device. The test selects the Intel Stratix 10 PCIe device with the lowest BDF by matching the Vendor ID. The test also selects the lowest available BAR.

   — In manual mode, the test queries you for the bus, device, and function number and BAR.

   For the Intel Stratix 10-GX Development Kit, you can determine the BDF by typing the following command:

   ```
   $ lspci -d 1172
   ```
4. Here are sample transcripts for automatic and manual modes:

   ```
   Intel FPGA PCIe Link Test - Automatic Mode
   Version 1.0
   0: Automatically select a device
   1: Manually select a device
   ************************************************
   >0
   Opened a handle to BAR 0 of a device with BDF 0x100
   ```

```
**************************************************
0: Link test - 100 writes and reads
1: Write memory space
2: Read memory space
3. Write configuration space
4. Read configuration space
5. Change BAR
6. Change device
7. Enable SR-IOV
8. Quit program
**************************************************
> 0
Doing 100 writes and 100 reads . .
Number of write errors:     0
Number of read errors:      0
Number of DWORD mismatches: 0
```

```
Intel FPGA PCIe Link Test - Manual Mode
Version 1.0
0: Automatically select a device
1: Manually select a device
**************************************************
> 1
Enter bus number:
> 1
Enter device number:
> 0
Enter function number:
> 0
BDF is 0x100
Enter BAR number (-1 for none):
> 4
Opened a handle to BAR 4 of a device with BDF 0x100
```

Related Links

PCIe Link Inspector Overview

Use the PCIe Link Inspector to monitor the link at the Physical, Data Link and Transaction Layers.

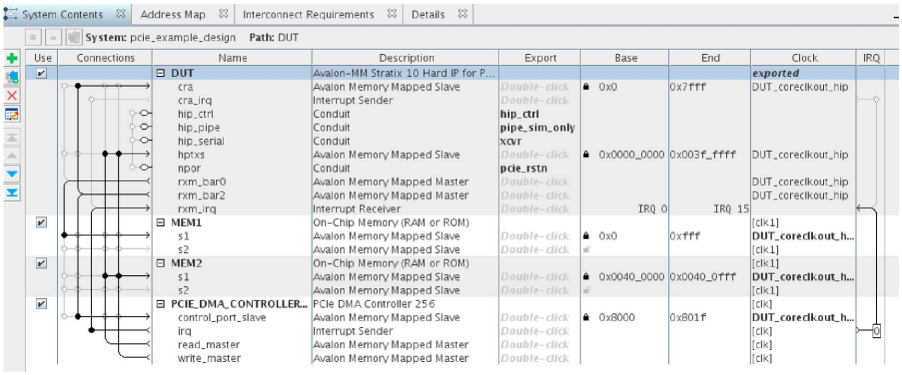
2 Design Example Description

2.1 Functional Description for the Simple DMA Design Example

The simple DMA design example simulation testbench includes the following components:

- DUT: The Intel Stratix 10 Hard IP for PCI Express Endpoint with the **Enable high performance bursting Avalon-MM slave interface (HPTXS)** parameter turned on.
- PCIE_DMA_CONTROLLER_256: A DMA controller that receives control signals from the DUT rxm_bar2 port. Drives the DUT high performance Avalon-MM slave interface (hptxs) using its Avalon-MM write_master interface.
- MEM1: An on-chip RAM that connects to the DUT RXM_bar0, an Avalon-MM master interface.
- MEM2: An on-chip RAM that connects to the PCIE_DMA_CONTROLLER_256 Avalon-MM read and write master interfaces.
- A testbench driver that configures the Root Port, Endpoint, writes to Endpoint memory, and programs the simple DMA controller.
- A testbench monitor that checks expected results.

Figure 7. Simple DMA Design Example



2.1.1 Serial Data Signals

This differential, serial interface is the physical link between a Root Port and an Endpoint.

The PCIe IP Core supports 1, 2, 4, 8, or 16 lanes. Each lane includes a TX and RX differential pair. Data is striped across all available lanes.

Table 2. 1-Bit Interface Signals

In the following table <*n*> is the number of lanes.

Signal	Direction	Description
tx_out[<*n*>-*1*:0]	Output	Transmit output. These signals are the serial outputs of lanes <*n*>-*1*–0.
rx_in[<*n*>-*1*:0]	Input	Receive input. These signals are the serial inputs of lanes <*n*>-*1*–0.

Refer to *Pin-out Files for Intel Devices* for pin-out tables for all Intel devices in **.pdf**, **.txt**, and **.xls** formats.

Transceiver channels are arranged in groups of six. For GX devices, the lowest six channels on the left side of the device are labeled GXB_L0, the next group is GXB_L1, and so on. Channels on the right side of the device are labeled GXB_R0, GXB_R1, and so on. Be sure to connect the Hard IP for PCI Express on the left side of the device to appropriate channels on the left side of the device, as specified in the *Pin-out Files for Intel Devices*.

Related Links

- Pin-out Files for Intel Devices
- Link Inspector Hardware
  Use the PCIe Link Inspector to monitor the link at the Physical, Data Link and Transaction Layers.

A Document Revision History for the Intel Stratix 10 Avalon-MM Hard IP for PCIe Design Example User Guide

A.1 Intel Stratix 10 Avalon-MM Hard IP for PCIe Design Example User Guide Revision History

Date	Software Version	Changes
November 2017	17.1	Made the following changes: • Added compilation support. • Changed design example to demonstrate the simple DMA design. • Added Linux driver for hardware example. • Added simulation support for NCSim. • Revised *Generating the Design* topic to create a single `.ip` for PCIe instead of a complete system design. Generating the testbench creates a design example from the `.ip` . • Added web link to information on using the PCIe Link Inspector.
May 2017	QuartusPrime Pro v17.1 Stratix 10 ES Editions	Initial release.