Lattice mVision CSI-2 PCIe Bridge Demo

User Guide

FPGA-UG-02125-1.1

March 2022
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Acronyms in This Document

A list of acronyms used in this document.

<table>
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<th>Acronym</th>
<th>Definition</th>
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<tr>
<td>C2H</td>
<td>Card to Host (Endpoint to Root)</td>
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<tr>
<td>CSI</td>
<td>Camera Serial Interface</td>
</tr>
<tr>
<td>DMA</td>
<td>Direct Memory Access</td>
</tr>
<tr>
<td>FPGA</td>
<td>Field Programmable Gate Array</td>
</tr>
<tr>
<td>ISP</td>
<td>Image Signal Processing</td>
</tr>
<tr>
<td>MIPI</td>
<td>Mobile Industry Processor Interface</td>
</tr>
<tr>
<td>OS</td>
<td>Operating System</td>
</tr>
<tr>
<td>PCIe</td>
<td>Peripheral Component Interconnect Express</td>
</tr>
<tr>
<td>SG-DMA</td>
<td>Scatter-Gather DMA</td>
</tr>
<tr>
<td>SG-Element</td>
<td>Scatter-Gather Element</td>
</tr>
<tr>
<td>SG-List</td>
<td>Scatter-Gather List</td>
</tr>
<tr>
<td>TLP</td>
<td>Transaction Layer Packet</td>
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1. Introduction

This document provides technical information and instructions of CrossLink™-NX/CertusPro™-NX MIPI CSI-2 to PCIe Bridge Demo. This design demonstrates the functionality of transferring MIPI CSI-2 camera video data to computer via PCIe with a Direct Memory Access (DMA) engine. This DMA solution can provide up to 3.1Gbps for data throughput Card to Host (C2H) without onboard DDR3 Memory, via PCIe Gen2x1 interface.

This demo is based on Lattice CrossLink-NX PCIe Bridge Board (or CertusPro-NX Versa Board), with Windows 7/Windows 10 and Linux Operating System (OS) drivers support. Total there are two modes: camera mode and color bar mode. The demo defaults to the camera mode, with the functionality of transferring camera data to computer memory and then software on a computer shows the video with the data. You can change to the color bar mode via the demo switch on the board. You can use the color bar mode to evaluate the maximum data throughput with the OS and hardware environments. Details of exchange between the two modes are discussed in later sections.

The demo package includes the following files:
- CrossLink-NX bitstream (.bit), or CertusPro-NX bitstream
- Windows driver
- Windows application software
- Linux driver source code
- Linux application software source code

Demo design hardware requirements:
- CrossLink-NX PCIe Bridge Board (Figure 1.1), or CertusPro-NX Versa Board (Figure 1.2)
- Sony IMX258 sensor module
- Computer with Linux OS, or
- Computer with Windows OS. Dual-Channel Memory is needed if there is no graphics card on Windows OS.
- USB cable for programming the CrossLink-NX/CertusPro-NX device

Demo design software requirements:
- Radiant 3.1 programmer software

Figure 1.1. CrossLink-NX PCIe Bridge Board
Figure 1.2. CertusPro-NX Versa Board
2. Demo Design Overview

2.1. FPGA Design Description

Figure 2.1 shows the block diagram of FPGA Design. The CrossLink-NX/CertusPro-NX PCIe hard core is configured as TLP interface. PCIe Interface block implements TLP decoder, generator, and some bridge logic to exchange data with DMA Engine module. The DMA Engine checks the computer-side frame buffer status, and then transfers video data to a specific frame buffer (allocated by OS) via PCIe interface. The video data format from IMX258 sensor is RAW8 (1080p50), so that ISP module is used to convert RAW to RGB, and then YUV422. The color Bar Gen module can generate a video test pattern whenever PCIe interface is ready to transfer.

![FPGA Design Block Diagram](image)

Figure 2.1. FPGA Design Block Diagram

2.2. DMA Architecture

DMA is a technique for transferring blocks of data between the computer system memory and peripherals (such as PCIe Endpoint) without a processor (such as system CPU) involved in each transfer. DMA not only offloads the system processing elements, but also transfers data at much higher rates than processor for read and write.

Scatter-Gather DMA (SG-DMA) augments this technique by providing data transfers from one non-contiguous block of memory to another by means of a series of smaller contiguous-block transfers. The DMA solution inside this demo implements a stream based DMA engine with scatter-gather capability. Stream based data is ready for transmission via PCIe continuously, and the data does not have a unique local address. Without this DMA solution, a large external memory is needed to buffer local data at FPGA side, and to wait for PCIe to be ready to transfer these data. Compared to stream based DMA, the DMA engine which needs external large memory is usually referred as memory mapped DMA.

The driver and application software implements several frame buffers for video data receive from the PCIe Endpoint (FPGA), and each frame buffer has a descriptor buffer to record the scatter gather list (SG-List). Figure 2.2 shows the relationship between the DMA frame buffer and description buffer. The SG-List records the necessary control information for data transfers:
• Numbers of SG-Elements
• The Location of each SG-Element
Each SG-Element contains:
• Physical address for each small buffer
• Length for each small buffer

After the DMA engine is enabled and started, the PCIe Endpoint (FPGA) launches Memory Read (MRd) operations from descriptor buffer to get these control information. Then the PCIe Endpoint launches Memory Write (MWr) operations to the specific frame buffer whenever the PCIe interface is not busy and the FPGA has data to transfer. The driver and application software on the computer side read the video data inside the frame buffer, and then display them on the screen.

The demo implements 16 frame buffers to evaluate the maximum data rate on different OS and hardware. Eight frame buffers are enough for most PCIe video bridge design.

Figure 2.2. DMA Frame Buffer and Descriptor Buffer
3. CrossLink-NX PCIe Bridge Board

This section describes the CrossLink-NX PCIe Bridge Board for the CSI-2 to PCIe Bridge demo.

3.1. Hardware Description

The CrossLink-NX PCIe Bridge Board has an on-board camera connector (CN1, at the top left corner of this board). Sony IMX258 sensor module should be connected to CN1 for the demonstration.

There is a 5-bit demo switch (SW1) at the top right corner of this board. The CSI-2 to PCIe Bridge demo uses this demo switch to select the current function between the default camera mode and the color bar mode.

The CrossLink-NX device and SPI flash device on the board can be programmed over JTAG via the USB port. The instructions to set up the CrossLink-NX PCIe Bridge Board for this demo are discussed later in this document.

3.2. Jumper Settings

Following jumper settings of CrossLink-NX PCIe Bridge Board (Table 3.1) are required to enable the CSI-2 to PCIe Bridge demo.

<table>
<thead>
<tr>
<th>Jumper Name</th>
<th>Settings</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>J48</td>
<td>Connects 2-3</td>
<td>Using PCIe Edge Connector</td>
</tr>
<tr>
<td>J51</td>
<td>Connects 2-4</td>
<td>—</td>
</tr>
<tr>
<td>SW2</td>
<td>Switch to UP</td>
<td>Using 12V_PCIe_CONN power</td>
</tr>
</tbody>
</table>
4. CertusPro-NX Versa Board

This section describes the CertusPro-NX Versa Board for the CSI-2 to PCIe Bridge demo.

4.1. Hardware Description

The CertusPro-NX Versa Board has an on-board camera connector (J37, at the top left corner of this board). Sony IMX258 sensor module should be connected to J37 for the demonstration.

There is a 5-bit demo switch (SW1) on this board. The CSI-2 to PCIe Bridge demo uses this demo switch to select the current function between the default camera mode and the color bar mode.

The CertusPro-NX device and SPI flash device on the board can be programmed over JTAG via the USB port. The instructions to set up the CertusPro-NX Versa Board for this demo are discussed later in this document.

4.2. Jumper Settings

Following jumper settings of CertusPro-NX Versa Board (Table 4.1) are required to enable the CSI-2 to PCIe Bridge demo.

<table>
<thead>
<tr>
<th>Jumper Name</th>
<th>Settings</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>J1</td>
<td>Connects 1-2</td>
<td>Using PCIe x1 mode</td>
</tr>
<tr>
<td>SW6</td>
<td>Switch to UP</td>
<td>Using 12V_PCIE_CONN power</td>
</tr>
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</table>
5. **Program CrossLink-NX/CertusPro-NX Device**

The following steps show you how to download the bitstream to CrossLink-NX device on CrossLink-NX PCIe Bridge board (or CertusPro-NX device on CertusPro-NX Versa board):

1. Connect the board to PC via USB mini port.
2. Connect the board to DC power adapter (12V).
3. Select 12 V DC power.
4. Start Radiant Programmer, Version 3.1 or later version, from your computer.
5. The Radiant Programmer – Getting Started dialog box pops up (Figure 5.1). By default, the **Create a new project from a JTAG scan** option is selected. Check and confirm other settings are correctly reflected the real components connected. Click OK, if everything is correct.

![Figure 5.1. Getting Started Dialog in Lattice Radiant Programmer](image)

6. A new window pops up as Figure 5.2 shows. Double-click Fast Configuration from the Operation column.

![Figure 5.2. Radiant Programmer Main Window](image)
7. The Device Properties dialog pops up. Changed the settings as shown in Figure 5.3. Click OK.

![Figure 5.3. Device Properties Dialog](image)

8. Click the Program icon from the toolbar, or choose the Design > Program menu item from Radiant Programmer, to program the CrossLink-NX/CertusPro-NX board. Wait for the programming to finish. Check the programming status and result from the output pane, as shown in Figure 5.4.

![Figure 5.4. Programmer Output Window](image)

9. Select 12 V power from PCIe edge connector.
6. Install Driver for OS

This section provides the processes and guidelines of installing drivers on both Linux OS and Windows OS.

6.1. Linux OS

Linux systems require device drivers to correspond to specific kernel versions, so we provide the driver and application software directly to support different version Linux OS.

Follow steps below to install drivers on Linux OS:

1. Start Linux OS. Take Ubuntu 20.04 LTS for example [Kernel Version: 5.4.0-42].
2. Open the Terminal. Find LatticeDMADemo folder location.
3. Input: cd LatticeDMADemo/DriverandApplication/linux
4. Input: cd Driver
5. Input: sudo apt-get install dkms
6. Input: make
7. Input: sudo insmod pcie-dma.ko

Now the driver of the requested Linux OS is ready for the application software.

Note: The driver must be reinstalled using only Step 7 (Input: sudo insmod pcie-dma.ko) every time the computer is restarted.

6.2. Windows 7 OS

You need to temporarily disable the operating system digital signature enforcement checking, considering this driver does not have a valid digital signature certification. Follow steps below:

1. Start Windows 7 OS, and log in using the Administrator account.
2. Open cmd.exe. Input “bcdedit.exe -set loadoptions DDISABLE_INTEGRITY_CHECKS”.
3. Restart computer. Press the F8 key on keyboard to enter Advanced Boot Options window. Refer to Figure 6.1.
4. Open the Device Manager, and find “PCI Data Capture and Signal Processing Controller” under Other Devices.

5. You need to uninstall device and delete the old version driver, if it is previously installed. After that, install the new version driver for this device. Refer to Figure 6.2.

6. Right-click the device, then select update driver, and select the driver location.
7. During the installation procedure, Windows inform you that it cannot verify the publisher of this driver software. Ignore the warning message, and choose *Install this driver software anyway* to complete the installation, as shown in Figure 6.3.

![Image of installation process]

**Figure 6.3. Install This Driver Software Anyway**

8. The installation completes successfully if no error message is shown. Now the operating system digital signature enforcement checking is disabled, and the driver is ready for the demo. **Note:** After the next restart, Driver Signature Enforcement is automatically enabled again to prevent new drivers from being installed.
6.3. Windows 10 OS
You need to temporarily disable the operating system digital signature enforcement checking, considering this driver does not have a valid digital signature certification. Follow steps below:
1. Start Windows 10 OS, and log in using the Administrator account.
2. Open the cmd.exe. Input “bcdedit.exe -set loadoptions DDISABLE_INTEGRITY_CHECKS”.
3. Open Settings page.
4. Click Update & Security
5. Select Recovery from the right pane. Click the Restart now button below Advanced startup.
6. Once the computer reboots, you need to choose the Troubleshoot option (Figure 6.4).

![Figure 6.4. Choose the Troubleshoot Option](image)

7. Go to Advanced Options (Figure 6.5).
8. In the Advanced Options window, choose **Startup Settings** (Figure 6.6).
9. Click the **Restart** button on from the **Startup Settings** to reboot the computer again (Figure 6.7).
10. After restart in Startup Settings window, press the F7 key from the keyboard to select “Disable driver signature enforcement” (Figure 6.8).

11. The computer is rebooted to proceed to install unsigned drivers. You need to uninstall the device and delete the driver that was previously installed, if you updated the driver for that device (Figure 6.2).
12. During the installation procedure, Windows informs you that it cannot verify the publisher of this driver software. Ignore the warning message, and choose Install this driver software anyway to complete the installation, as shown in Figure 6.3.

13. The installation completes successfully if the last window shows no error message. Now the operating system digital signature enforcement checking is disabled, and the driver is ready for the demo.

**Note:** After the next restart, Driver Signature Enforcement is automatically enabled again to prevent new drivers from being installed.
7. Run This Demo

This section shows you how to run this demo design on target computer with either Linux OS or Window OS.

7.1. Linux OS

As mentioned earlier, we provide the driver and application software source code directly. You need to compile the application source code at first. Follow steps below to compile the application source code:

1. Start Linux OS. Take Ubuntu 20.04 LTS for example [Kernel Version: 5.4.0-42].
2. Open the Terminal. Find LatticeDMADemo folder location.
3. Input: cd LatticeDMADemo/DriverandApplication/linux/App
4. Input: mkdir build, then input: cd build
5. Input: sudo apt-get install libglew-dev
6. Input: sudo apt-get install libglfw3 libglfw3-dev
7. Input: cmake ..
8. Input: make
9. Input: cd src
10. Now, you can run this demo by inputting sudo ./pcie_dma

The default functionality is MIPI CSI-2 to PCIe Bridge. Sony IMX258 sensor data is transferred to computer memory via PCIe, then display on screen (Figure 7.1). You can change from the default camera mode to the color bar mode by changing the demo switch state. After changing to color bar mode, you can see screen as shown in Figure 7.2. You can exchange between the two modes.

![Figure 7.1. CSI-2 to PCIe Bridge](image)
As shown in Figure 7.3, the top left of the window displays the following information:

- Displayed frames per second
- Displayed data rate
- PCIe transmitted frames per second
- PCIe transmitted throughput rate
- The number of frames discarded by software
- The total number of frames transmitted via PCIe

7.2. Windows OS

For Windows OS, double-click pcie_dma_test.exe. A window similar to Figure 7.1 pops up, showing the default camera mode. You can switch between the camera mode and the color bar mode by changing the demo switch state.
8. Demo Package Directory Structure

Figure 8.1 shows the directory structure of this demo package. The DriverandApplication/linux folder contains driver and application software source code for Linux OS; the DriverandApplication/windows folder contains driver and application software files for both Win7 and Win10 OS. The “FPGA_Bitstream” folder contains the bitstream file for CrossLink-NX FPGA device.
References

- PCIe X1 IP Core - Lattice Radiant Software (FPGA-IPUG-02091)
- CrossLink-NX PCIe Bridge Board Hardware (FPGA-EB-02040)
- PCIe X4 IP Core - Lattice Radiant Software (FPGA-IPUG-02126)
- CertusPro-NX Versa Board (FPGA-EB-02053)
Technical Support Assistance
Submit a technical support case through www.latticesemi.com/techsupport.
Revision History
Revision 1.1, February 2022

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<td>• updated to Radiant 3.1 Programmer software.</td>
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<td>• updated Figure 1.1. CrossLink-NX PCIe Bridge Board and Figure 1.2. CertusPro-NX Versa Board.</td>
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Revision 1.0, March 2021

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