AN 813: Hierarchical Partial Reconfiguration over PCI Express* Reference Design for Arria® 10 Devices

Updated for Intel® Quartus® Prime Design Suite: 18.0
1. Hierarchical Partial Reconfiguration over PCI Express* Reference Design for Arria® 10 Devices

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1. Hierarchical Partial Reconfiguration over PCI Express* Reference Design for Arria® 10 Devices

The Hierarchical Partial Reconfiguration (HPR) over PCI Express* (PCIe*) reference design demonstrates reconfiguring the FPGA fabric through the PCIe link in Arria® 10 devices. This reference design runs on a Linux system with the Arria 10 GX FPGA development board. Adapt this reference design to your requirements by implementing the PR region logic using the given template. Run your custom design on this fully functional system that enables communication over PCIe.

Arria 10 devices use the PR over PCIe solution to reconfigure the device, rather than Configuration via Protocol (CvP) update. Partial reconfiguration allows you to reconfigure a portion of the FPGA dynamically, while the remaining FPGA design continues to function. Create multiple personas for a particular region in your design, without impacting operation in areas outside this region. Partial reconfiguration enables the implementation of more complex FPGA systems.

You can also include multiple parent and child partitions, or create multiple levels of partitions in your design. This flow, referred to as the hierarchical partial reconfiguration (HPR), includes a static region that instantiates the parent PR region, and the parent PR region instantiating the corresponding child PR region. You can perform the same PR region reprogramming for either the child or the parent partition. Reprogramming a child PR region does not affect the parent or the static region. Reprogramming the parent region reprograms the associated child region with the default child persona, without affecting the static region.

Note: The HPR flow does not impose any restrictions on the number of sub-partitions you can create in your design.

Partial reconfiguration provides the following advancements to a flat design:

- Allows run-time design reconfiguration
- Increases scalability of the design through time-multiplexing
- Lowers cost and power consumption through efficient use of board space
- Supports dynamic time-multiplexing functions in the design
- Improves initial programming time through smaller bitstreams
- Reduces system down-time through line upgrades
- Enables easy system update by allowing remote hardware change

The current version of the software introduces a new and simplified compilation flow for partial reconfiguration.

Related Information

- Creating a Partial Reconfiguration Design
  For complete information on the partial reconfiguration design flow.
1. Hierarchical Partial Reconfiguration over PCI Express® Reference Design for Arria® 10 Devices

- Hierarchical Partial Reconfiguration of a Design on Arria 10 GX FPGA Development Board
  For a step-by-step tutorial on creating a hierarchical partial reconfiguration design.

- Arria 10 FPGA Development Kit User Guide
  For information on Arria 10 GX FPGA development board overview and setup procedure.

1.1. Reference Design Overview

The reference design consists of the following components:

- **a10_PCIE_reference_design**—top-level wrapper for the reference design, connecting the board support package (BSP) subsystem to the device pins.

- **bsp_top**—top-level of the design that contains all subsystems of the design. This module consists of three main sub-components - the PCIe IP core, the DDR4 External Memory Interfaces IP core, and the design top module. This layer of abstraction allows simulation of the design top module through simulated Avalon-MM transactions.

- **design_core**—core of the design that handles generation of the PR region, the interface components such as clock crossing Avalon-MM logic and pipeline logic, clocks, and the global reset.
1. Hierarchical Partial Reconfiguration over PCI Express* Reference Design for Arria® 10 Devices

1.1.1. Clocking Scheme

The reference design creates a separate Altera IOPLL IP core-generated clock. This clock creation decouples the PR logic clocking from both the PCIe clocking domain that runs at 250 MHz, and the EMIF clocking domain that runs at 330 MHz. The clock for PR Logic is set at 250 MHz. To ensure timing closure, modify the parameterization of the IOPLL IP core to a lower clock frequency.
1.1.2. Memory Address Mapping

The PCIe IP core connects to the design core through two BARs (base address registers) - BAR 2 and BAR 4, which in turn connect to their exclusive Avalon-MM interface.

In addition to connecting to the interface controls such as the Avalon-MM freeze bridges and the PR region controller for the PR region, BAR 4 also connects directly to up to 8 kB of memory in the PR region. Driver accessed components, such as the PR IP core and the system description ROM use BAR 2. The following table lists the memory address mapping for the PCIe IP core:

<table>
<thead>
<tr>
<th>Domain</th>
<th>Address Map</th>
<th>Base</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAR 2</td>
<td>System Description ROM</td>
<td>0x0000_0000</td>
<td>0x0000_0FFF</td>
</tr>
<tr>
<td>BAR 2</td>
<td>PR IP</td>
<td>0x0000_1000</td>
<td>0x0000_103F</td>
</tr>
<tr>
<td>BAR 4</td>
<td>PR Region</td>
<td>0x0000_0000</td>
<td>0x0000_FFFF</td>
</tr>
<tr>
<td>BAR 4</td>
<td>PR Region Controller</td>
<td>0x0001_0000</td>
<td>0x0001_000F</td>
</tr>
<tr>
<td>BAR 4</td>
<td>DDR4 Calibration Export</td>
<td>0x0001_0010</td>
<td>0x0001_001F</td>
</tr>
</tbody>
</table>

The reference design exports the status of the DDR4 calibration, provided by the External Memory Interfaces IP core. Upon initialization, the EMIF IP core performs training to reset the DDR4 interface. The EMIF reports the success or the failure of the reset in its calibration flag. The host decides the necessary action in the event of DDR4 failing the reset training, so this interface is exported to the host.

The following table lists the memory address mapping from the External Memory Interfaces IP core, to the PR logic:

<table>
<thead>
<tr>
<th>Address Map</th>
<th>Base</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDR</td>
<td>0x0000_0000</td>
<td>0x7fff_ffff</td>
</tr>
</tbody>
</table>

The 2 GB DDR4 memory space is available to PR logic through an Avalon-MM interface.

1.1.3. Floorplanning

The floorplan constraints in your partial reconfiguration design physically partitions the device. This partitioning ensures that the resources available to the PR region are the same for any persona that you implement.
To maximize the fabric amount available for the PR region, the reference design constrains the static region to the smallest possible area. This reference design contains two child PR regions of the parent PR region.

**Figure 3. Reference Design Floorplan**

Note: The child regions contained within the parent PR region can be of any size. The small sizing of the child PR regions in the above figure is for demonstration purposes only.

For more information about floorplanning, refer to *Floorplan the Partial Reconfiguration Design* section in Volume 1 of the *Intel® Quartus® Prime Pro Edition Handbook*.

**Related Information**

*Floorplan the Partial Reconfiguration Design*

### 1.2. Getting Started

This section describes the requirements and the procedure to run the reference design.

#### 1.2.1. Hardware and Software Requirements

The reference design requires and uses the following hardware and software tools:

- Arria 10 GX FPGA development board with the DDR4 module connected to Hi-Lo interface
- Linux Operating System - kernel version 3.10 or above
- Super user access on the host machine
1. PCIe slot to plug-in the Arria 10 GX FPGA development board
2. Open source driver for this PR over PCIe reference design
3. Intel Quartus Prime Pro Edition software v.18.0
4. Intel FPGA Download Cable driver

Note:
- The open source driver developed for this PR over PCIe reference design is tested using CentOS 7.
- The Linux driver accompanying this reference design is not a production driver. You must adapt this driver based on your design.

1.2.2. Installing the Arria 10 GX FPGA Development Kit

For complete instructions on installing and powering the Arria 10 GX FPGA development board in your Linux system, refer to Arria 10 FPGA Development Kit User Guide.

Note: Before powering the board, set the switch 4 (FACTORY) of the DIP switch bank (SW6) to ON. Setting this switch to ON loads the factory image area of the flash memory at boot time. Program the reference design into this factory image area. For complete instructions on flashing the reference design onto the board, refer to Bringing Up the Reference Design.

Related Information
- Arria 10 FPGA Development Kit User Guide
- Bringing Up the Reference Design on page 9

1.2.3. Installing the Linux Driver

The reference design includes the complete source code for the open source Linux driver, developed and tested for this reference design.

The Linux driver for this design requires that the debugfs to be mounted. To verify if the debugfs is mounted, run the following command:

```bash
mount | grep "debugfs"
```

For more information on the debugfs file system, please refer to the CentOS documentation.

Important: CentOS 7 is the only supported OS by this driver.

You must install all the per-requisite packages before installing this driver. To install the per-requisite packages, run the following commands:

```bash
yum groupinstall "Development Tools"

yum install ncurses-devel

yum install qt-devel

yum install hmaccalc zlib-devel binutils-devel elfutils-libelf-devel
```

To install the driver, follow these steps:
1. Ensure the driver source code is copied to your machine. The source code can be found at the following location:
   https://github.com/intel/fpga-partial-reconfig/tree/master/software/drivers

2. To compile all the necessary driver modules, run the following command:
   ```
   make
   ```
   Ensure that the following three kernel object files are present in the driver source directory after running this command:
   - fpga-mgr-mod.ko
   - fpga-pcie-mod.ko

3. To copy the modules to the right location and update the module dependency database, run the following command:
   ```
   sudo make install
   ```

4. To deploy an instance of the driver for each Intel FPGA device, run the following command:
   ```
   sudo modprobe fpga-pcie-mod
   ```

5. To verify successful installation of the driver, run the following command:
   ```
   lspci -vvvd1172:
   ```
   Upon successful installation, the resulting output displays the following at the end:
   ```
   Kernel driver in use: fpga-pcie
   Kernel modules: fpga_pcie_mod
   ```
   
   Note: The above command only works when the design has been loaded onto the board and the computer has been power-cycled.

### 1.2.4. Bringing Up the Reference Design

The reference design is available in the following location:

https://github.com/intel/fpga-partial-reconfig

To access the reference design, navigate to the ref_designs sub-folder. Copy the a10_pcie_devkit_cvp_hpr folder to the home directory in your Linux system.

To bring up the reference design on the board:

1. Plug-in the Arria 10 GX FPGA development board to an available PCIe slot in your host machine.
2. Connect the host machine’s ATX auxiliary power connector to the 12 V ATX input J4 of the development board.
3. Power-up the host machine.
4. Verify the micro-USB cable connection to the FPGA development board. Ensure that no other applications that use the JTAG chain are running.
5. Navigate to the a10_pcie_devkit_cvp_hpr/software/installation folder in your system.
6. To overwrite the existing factory image on the board with the reference design, execute the `flash.pl` script.

7. Pass the JTAG cable number of your connected device as an argument to the script (for example, `perl flash.pl 1`).

Running this script configures the device with the contents of the `flash.pof` file. This parallel object file comes directly from the `a10_pcie_devkit_cvp.sof` file present in the `output_files` directory. The `flash.pof` file acts as the base image for the reference design.

*Note:* Ensure successful compilation of the design before running this script.

8. Power-cycle the host machine.

### 1.3. Reference Design Components

The reference design contains the following design components.

#### 1.3.1. BSP Top

This Platform Designer system contains all the subsystems of this reference design. The system comprises of three main components - the top-level design, the PCIe IP core, and the DDR4 External Memory Interfaces IP core. The system connects to external pins through the `a10_pcie_ref_design.sv` wrapper.

#### 1.3.1.1. PCI Express IP core

The Arria 10 Hard IP for PCI Express IP core is a Gen3x8, with a 256-bit interface and running at 250 MHz.

The following table provides information on the configuration fields of the PCI Express IP core that the reference design uses that are different from the default settings:

<table>
<thead>
<tr>
<th>Table 3.</th>
<th>PCI Express IP Core Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Setting</strong></td>
<td><strong>Parameter</strong></td>
</tr>
<tr>
<td>System Settings</td>
<td>Application interface type</td>
</tr>
<tr>
<td></td>
<td>Hard IP mode</td>
</tr>
<tr>
<td></td>
<td>Port type</td>
</tr>
<tr>
<td></td>
<td>RX buffer credit allocation for received requests vs completions</td>
</tr>
<tr>
<td>Avalon-MM Settings</td>
<td>Enable control register access (CRA) Avalon-MM slave port</td>
</tr>
<tr>
<td>Base Address Registers - BAR2</td>
<td>Type</td>
</tr>
<tr>
<td>Base Address Registers - BAR4</td>
<td>Type</td>
</tr>
<tr>
<td>Device Identification Registers</td>
<td>Vendor ID</td>
</tr>
<tr>
<td></td>
<td>Device ID</td>
</tr>
<tr>
<td></td>
<td>Revision ID</td>
</tr>
<tr>
<td></td>
<td>Class code</td>
</tr>
<tr>
<td></td>
<td>Subsystem Vendor ID</td>
</tr>
</tbody>
</table>

*continued...*
### Table 4. Arria 10 DDR4 External Memory Interfaces IP Configuration

<table>
<thead>
<tr>
<th>Setting</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory - Topology</td>
<td>DQ width</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>DQ pins per DQS group</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Number of DQS groups</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Alert# pin placement</td>
<td>I/O Lane with Address/Command Pins</td>
</tr>
<tr>
<td></td>
<td>Address/Command I/O lane of ALERT#</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Pin index of ALERT#</td>
<td>0</td>
</tr>
</tbody>
</table>

### 1.3.1.3. Design Top

This component forms the core of the design, and includes the following:

- Reset logic
- PR region
- Partial Reconfiguration IP core
- Clock crossing and pipe-lining for Avalon MM Transactions
- System description ROM
- PLL

### 1.3.1.3.1. Global Reset Logic

The PLL generates the main clock for this design. All logic, excluding the PCIe ip, pr ip, and ddr4 emif run using this 250 MHz clock. The PCIe generates the global reset, along with the PLL reset signal. On power up, a countdown timer, tcd2um counts down using the internal 50 MHz oscillator, to a 830 μs delay. Until the timer
reaches this delay, the PLL is held in reset, deasserting the locked signal. This action freezes the design, and because the PLL locked signal is ORed with the PCIe reset, the design also is held in reset. Once the timer reaches 830 μs, the design functions normally, and enters a known state.

1.3.1.3.2. PR Region Wrapper

The PR region wrapper contains the PR region controller, freeze bridges, and the personas. The region controller interacts with the driver over the Avalon-MM interface to initiate PR, and act as a bridge for communicating to the PR region for freeze and start requests initiation.

1.3.1.3.3. Parent PR Region

The parent PR region contains two sets of PR region controllers and freeze bridges, because of the two child personas within the parent PR region. Each set of PR region controller and freeze bridge is dedicated to one child persona.

1.3.1.3.4. Arria 10 Partial Reconfiguration Region Controller IP Core

Use the Arria 10 Partial Reconfiguration Region Controller IP core to initiate a freeze request to the PR region. The PR region finalizes any actions, on freeze request acknowledgment. The freeze bridges also intercept the Avalon-MM interfaces to the PR region, and correctly responds to any transactions made to the PR region during partial reconfiguration. Finally, on PR completion, the region controller issues a stop request, allowing the region to acknowledge, and act accordingly. The fpga-region-controller program provided with this reference design performs these functions.

The reference design configures the Partial Reconfiguration Region Controller IP core to operate as an internal host. The design connects this IP core to the PCI Express IP core, via an instance of the Avalon-MM interface. The PR IP core has a clock-to-data ratio of 1. Therefore, the PR IP core is not capable of handling encrypted or compressed PR data.

The following table lists the configuration fields of the Arria 10 Hard IP for PCI Express IP core that are different from the preset settings:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enable JTAG debug mode</td>
<td>Disable</td>
</tr>
<tr>
<td>Enable Avalon-MM slave interface</td>
<td>Enable</td>
</tr>
<tr>
<td>Input data width</td>
<td>32</td>
</tr>
</tbody>
</table>

1.3.1.3.5. Partial Reconfiguration Logic

The reference design provides the following personas:

Table 5. Reference Design Personas

<table>
<thead>
<tr>
<th>Persona</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDR4 access</td>
<td>Performs a sweep across a memory span, first writing, and then reading each address.</td>
</tr>
<tr>
<td>Basic DSP</td>
<td>Provides access to a 27x27 DSP multiplier, and demonstrates hardware acceleration.</td>
</tr>
</tbody>
</table>

continued...
<table>
<thead>
<tr>
<th>Persona</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic arithmetic</td>
<td>Includes a basic 32-bit unsigned adder, and demonstrates hardware acceleration.</td>
</tr>
<tr>
<td>Game of Life</td>
<td>Includes an 8x8 Conway’s Game of Life, and demonstrates hardware acceleration.</td>
</tr>
<tr>
<td>Parent persona</td>
<td>A wrapper that instantiates two child partitions. The parent persona also connects the two child personas to the static region with their own PR region controller, BAR freeze bridge, and DDR4 freeze bridge.</td>
</tr>
</tbody>
</table>

Each persona has an 8-bit `persona_id` field in the `pr_data` register to indicate a unique identification number. A 32-bit control register and 16 I/O registers follow the 8-bit `persona_id`. The 16 I/O registers are 32-bit each, with 8 bits for device inputs, and 8 bits for device outputs. Each persona uses these registers in different ways. For more information, refer to the source code for each of the personas.

Additionally, the reference design provides a template to implement your custom persona. This template persona allows you to modify the RTL, create a wrapper to interface with the register file, compile, and run your design.

### 1.4. Compiling the Reference Design

In order to compile the other personas in the design, you must export the static region from the compiled base revision. Then, the implementation revisions that define these personas import the static region. To compile the HPR child personas, you must export the HPR parent region from the compiled HPR parent revision. Then, the implementation revisions that define these child personas import the HPR parent region.

1. To compile the base revision of the reference design, run the following command from the project directory level:

   ```bash
   quartus_sh --flow compile a10_pcie_devkit_cvp -c a10_pcie_devkit_cvp
   ```

2. To export the `.qdb` file representing the static region, run the following command:

   ```bash
   quartus_cdb -r a10_pcie_devkit_pr -c a10_pcie_devkit_cvp \
   --export_block root_partition --snapshot final --file a10_pcie_devkit_cvp_static.qdb
   ```

   All the implementation revisions, except the base revision contain the following QDB file partition assignment in their respective `.qsf` files:

   ```bash
   set_instance_assignment -name QDB_FILE_PARTITION \
   a10_pcie_devkit_cvp_static.qdb -to |
   ```

   This assignment imports the `.qdb` file representing the reference design static region logic into the subsequent PR persona implementation compile. Each implementation revision also contains one or two `ENTITY_REBINDING` assignment. This assignment links the hierarchy of the static region and the
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Hierarchy of the PR persona. For example, a10_pcie_devkit_cvp_ddr4_access.qsf contains the following entity rebinding assignment:

```qsf
set_instance_assignment -name ENTITY_REBINDING
    parent_persona_top -to
    u_top|design_core|pr_region_wrapper|pr_persona_wrapper|u_pr_logic
```

For more information, please refer to the Partial Reconfiguration Design Flow section in the Partial Reconfiguration User Guide.

3. To compile all the non-HPR personas, run the following commands:

```bash
quartus_sh --flow compile a10_pcie_devkit_cvp -c a10_pcie_devkit_cvp_normal_ddr4_access
quartus_sh --flow compile a10_pcie_devkit_cvp -c a10_pcie_devkit_cvp_normal_basic_arithmetic
quartus_sh --flow compile a10_pcie_devkit_cvp -c a10_pcie_devkit_cvp_normal_basic_dsp
quartus_sh --flow compile a10_pcie_devkit_cvp -c a10_pcie_devkit_cvp_normal_gol
```

4. To compile the HPR parent persona, run the following command:

```bash
quartus_sh --flow compile a10_pcie_devkit_cvp -c a10_pcie_devkit_cvp_ddr4_access
```

5. To export the .qdb representing the parent region, run the following command:

```bash
quartus_cdb -r a10_pcie_devkit_cvp -c a10_pcie_devkit_cvp_ddr4_access --export_block pr_partition --snapshot final --file a10_pcie_devkit_cvp_ddr4_access_pr_partition_final.qdb
```

All the HPR child implementation revisions contain an additional QDB FILE PARTITION assignment:

```qsf
set_instance_assignment -name QDB_FILE_PARTITION
    a10_pcie_devkit_cvp_ddr4_access_pr_partition_final.qdb -to
    u_top|design_core|pr_region_wrapper|pr_persona_wrapper|u_pr_logic
```

This assignment imports the .qdb file representing the HPR parent region into the subsequent into the subsequent HPR child region compilation. Because the HPR child revisions comprise of two child regions, they contain two ENTITY REBINDING assignments.

```qsf
set_instance_assignment -name ENTITY_REBINDING
    basic_arithmetic_persona_top -to
    u_top|design_core|pr_region_wrapper|pr_persona_wrapper|u_pr_logic|u0|child_region_0|u_child_pr_logic

set_instance_assignment -name ENTITY_REBINDING
    basic_arithmetic_persona_top -to
    u_top|design_core|pr_region_wrapper|pr_persona_wrapper|u_pr_logic|u0|child_region_1|u_child_pr_logic
```

6. To compile the HPR child personas, run the following commands:

```bash
quartus_sh --flow compile a10_pcie_devkit_cvp -c a10_pcie_devkit_cvp_basic_arithmetic
quartus_sh --flow compile a10_pcie_devkit_cvp -c a10_pcie_devkit_cvp_basic_dsp
```
a10_pcie_devkit_cvp_basic_dsp
quartus_sh --flow compile a10_pcie_devkit_cvp -c \
a10_pcie_devkit_cvp_gol

Related Information

- Partial Reconfiguration Design Flow
- AN 806: Hierarchical Partial Reconfiguration Tutorial for Intel Arria 10 GX FPGA Development Board

1.5. Testing the Reference Design

The reference design provides the following utilities for programming the FPGA board:

- `program-fpga-jtag`
- `program_fpga_pcie`
- `fpga-region-controller`

The design also includes an example_host_uio application to communicate with the device, and demonstrate each of the personas.

1.5.1. `program_fpga_jtag`

Use the `program_fpga_jtag` script to program the entire device (full-chip programming) without any requirement for reboot.

`program_over_jtag` performs the following functions:

- Uses the Intel Quartus Prime Programmer to program the device.
- Accepts an SRAM Object File (.sof) and configures the target device over a JTAG interface.
- Communicates with the driver to perform the following functions:
  - Disable upstream AER (advanced error reporting)
  - Save state
  - Restore AER
  - Restore state

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>-f=, --file=[&lt;filename&gt;]</code></td>
<td>Specifies the .sof file name.</td>
</tr>
<tr>
<td><code>-c=, --cable=[&lt;cable number&gt;]</code></td>
<td>Specifies the programmer cable.</td>
</tr>
<tr>
<td><code>-d=, --device=[&lt;device index&gt;]</code></td>
<td>Specifies the PCIe device number. For example, <code>-d=0000:03:00.0</code></td>
</tr>
<tr>
<td><code>-h, --help</code></td>
<td>Provides help for <code>program_fpga_jtag</code> script.</td>
</tr>
</tbody>
</table>
Note: Use the following command to obtain the device index:

```
/sbin/ispci -d 1172:
```

For example, consider that the command returns the following output:

```
03:00.0 Class ea00: Altera Corporation Device 5052 (rev 01)
```

The first value is the device index. Prepend 0000 to this value. In this case, your device index is 0000.03:00.0.

### 1.5.2. program_fpga_pcie

Use the `program_fpga_pcie` utility to perform partial reconfiguration. The script accepts a `.rbf` file for a given persona. The script performs the following functions:

- Communicates with the driver to remove device sub-drivers, if any
- Communicates with the `fpga-region-controller` script to assert/de-assert freeze
- Writes the `.rbf` to the Partial Reconfiguration Controller IP core
- Re-deploys the sub-drivers, if any, that are required upon successful PR

#### Table 7. program_fpga_pcie Command-Line Options

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>-f=, --file=&lt;filename&gt;</code></td>
<td>Specifies the <code>.rbf</code> file name.</td>
</tr>
<tr>
<td><code>-d=, --device=&lt;device index&gt;</code></td>
<td>Specifies the PCIe device number. For example, <code>-d 0000:03:00.0</code></td>
</tr>
</tbody>
</table>
| `-r=, --region=<region offset>` | Specifies the target FPGA region controller offset, used for freeze bridge enable. This option performs the following operations:  
  - Initiates the freeze request exchange  
  - Asserts/deasserts reset for the PR region, during and after partial reconfiguration  
  For example:  
  ```
  program-fpga-pcie --file=<region.rbf> --device=0000:03:00.0 --region=10000
  ```  
  Note: The region offset value must be a hexadecimal number.  
  The PR region is reset during this operation. |
| `-h, --help`     | Provides help for `program_jtag_pcie` script.                               |

### 1.5.3. example_host_uio

The `example_host_uio` module demonstrates the FPGA device access. This application interacts with each persona, verifying the contents and functionality of the personas.

The program requires a PCIe device number, followed by optional parameters of the seed for generating test data, number of tests performed, and verbosity for displaying extra information.
Table 8. example_host_uio Command-Line Options

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>-s=, --seed [&lt;seed&gt;]</td>
<td>Specifies the seed to use for number generation. Default value is 1.</td>
</tr>
<tr>
<td>-d, --device [&lt;device index&gt;]</td>
<td>Specifies the PCIe device number. For example, -d 0000:03:00.0</td>
</tr>
<tr>
<td>-v, --verbose</td>
<td>Allows you to print additional information during execution.</td>
</tr>
<tr>
<td>-n, --iterations</td>
<td>Allows you to specify the iterations for the test you wish to perform.</td>
</tr>
<tr>
<td>-h, --help</td>
<td>Provides help for example_host application.</td>
</tr>
</tbody>
</table>

Signal Tap

The reference design supports signal tapping the PR regions, through hierarchical hubs. This feature facilitates the on-chip debugging of a specific persona. The static region and the parent PR region contains the SLD agent, that communicates with an SLD host. You must instantiate the SLD host in the persona that you wish to signal tap. You must include the .stp file in the synthesis-only revision of a given persona. Do not include the signal tap file in the base revision, or the .qsf file of other personas, if the .stp file is specific to a persona.

Follow these guidelines when signal tapping the PR logic:
- Use pre-synthesis registers
- An instance cannot cross partition boundaries
- Do not trigger across partition boundaries


Related Information

Debugging Partial Reconfiguration Designs Using Signal Tap Logic Analyzer

1.5.3.1. Compiling the Example Applications

The reference design software applications are available in the software/util directory. Each application has a respective sub-directory structure, with a corresponding Makefile.

To build the example application:
1. To compile the example_host module, type the following from the Linux shell:

   ```
   cd source/util
   make
   ```

   This command generates the executable within the sub-directory. For example:

   ```
   ./example_host_uio -d 0000:03:00.0 -s 1 -n 100 -v
   ```

   This command uses the device 0000:03:00.0, seed the input generation with a value of 1, perform 100 iterations, and print more information on the current status.
1.5.3.2. Programming the Design Using Example Applications

Assume that the device is 0000:03:00.0 and the cable number is 1.

The following steps describe programming your design using the provided scripts:

1. To program the DDR access persona’s .sof file after design compilation, type the following from the Linux shell:
   
   ```bash
   program-fpga-jtag -f=a10_PCIE_devkit_cvp_ddr4_access.sof -c=1 -d=0000:03:00.0
   ```

2. To verify the functionality of the design, type the following from the Linux shell:
   
   ```bash
   source/util/example_host/example_host_uio -d 0000:03:00.0
   ```

3. To program the register file child PR persona’s .rbf file after design compilation, type the following from the Linux shell:

   ```bash
   program-fpga-pcie -f=a10_PCIE_devkit_cvp_basic_dsp.pr_partition.pr_child_partition_1.rbf -d=0000:03:00.0 -r=10000
   ```

4. To verify the functionality of the design, type the following from the Linux shell:

   ```bash
   software/util/example_host/example_host_uio -d 0000:03:00.0
   ```

5. To program the basic arithmetic persona’s .rbf file after design compilation, type the following from the Linux shell:

   ```bash
   program-fpga-pcie -f=a10_PCIE_devkit_cvp_basic_arithmetic.pr_partition.pr_child_partition_1.rbf -d=0000:03:00.0 -r=10000
   ```

6. To verify the functionality of the design, type the following from the Linux shell:

   ```bash
   software/util/example_host/example_host_uio 0000:03:00.0
   ```

1.6. Extending the Reference Design with Custom Persona

This reference design provides an example template to create your own personas for PR over PCIe. To extend the reference design with your custom persona:

1. Navigate to the a10_PCIE_devkit_cvp_hpr folder:

   ```bash
   cd a10_PCIE_devkit_cvp_hpr
   ```

2. Create a copy of the pr_logic_impl_template.qsf.template implementation revision file:

   ```bash
   cp pr_logic_impl_template.qsf.template <persona_impl_revision_name>.qsf
   ```

3. Create a folder and copy your persona-specific RTL to this folder:

   ```bash
   mkdir <persona_name>
   cp <custom_persona>.sv <persona_name>/
   ```
4. Your custom top-level entity must match the ports for the `custom_persona` module, defined in the `source/templates/pr_logic_template.sv` file. The following example shows interfacing your design with the Avalon-MM interface, controlled over PCIe register file:

```verilog
module custom_persona #(parameter REG_FILE_IO_SIZE = 8 )
    (input wire clk,
     input wire rst_n,
     output wire [31:0] persona_id,
     input wire [31:0] host_cntrl_register,
     input wire [31:0] host_pr [0:REG_FILE_IO_SIZE-1],
     output wire [31:0] pr_host [0:REG_FILE_IO_SIZE-1]);

Utilize any of the parallel I/O port (PIO) register files for customization. The `host_pr` register sends the data from the persona to the host machine. The `pr_host` register sends the data from the host machine to the persona.

5. In your top-level entity file, specify the persona ID as any 32-bit value:

```verilog
assign persona_id = 32'h0000_aeed;

Note: The example template uses only 8 bits, but you can specify any value, up to 32 bits.

6. Set the unused output ports of the `pr_host` register to 0:

```verilog
generate
    genvar i;
    //Tying unused output ports to zero.
    for (i = 2; i < REG_FILE_IO_SIZE; i = i + 1) begin
        assign pr_host [i] = 32'b0;
    end
endgenerate
```

7. Modify your `persona_impl_revision_name.qsf` to include the following assignments:

```bash
set_global_assignment -name TOP_LEVEL_ENTITY a10_pcie_ref_design
set_global_assignment -name SYSTEMVERILOG_FILE \<persona_name>/<custom_persona>.sv
set_global_assignment -name QSYS_FILE <persona_specific_qsys_file>
set_global_assignment -name IP_FILE <persona_specific_ip_file>
set_instance_assignment -name QDB_FILE_PARTITION \a10_pcie_devkit_cvp_static.qdb -to | \set_instance_assignment -name ENTITY_REBINDING \<custom_persona_top_level_entity> -to u_top|design_core|pr_region_wrapper|pr_persona_wrapper|u_pr_logic
```

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8. Update the partial reconfiguration flow script to define your new PR implementation.

9. Update the `a10_pcie_devkit_cvp.qpf` project file to include your implementation revisions:
   
   ```
   PROJECT_REVISION = "<persona_impl_revision_name>"
   ```

10. Compile the revision.

    For complete information on adding a custom persona to a PR design, refer to the *Adding a New Persona to the Design* section in the *Partially Reconfiguring a Design on Arria 10 GX FPGA Development Board* application note.

Related Information

*Adding a New Persona to the Design*

### 1.7. Document Revision History for AN 813: Hierarchical Partial Reconfiguration over PCI Express Reference Design for Arria 10 Devices

<table>
<thead>
<tr>
<th>Document Version</th>
<th>Intel Quartus Prime Version</th>
<th>Changes</th>
</tr>
</thead>
</table>
| 2018.05.07       | 18.0.0                      | • Compilation flow change  
|                  |                            | • Other minor text edits   |
| 2017.11.06       | 17.1.0                      | • Updated the *Hardware and Software Requirements* section with additional reference design requirements  
|                  |                            | • Updated the *Installing the Linux Driver* section with detailed instructions on installing the open source Linux driver  
|                  |                            | • Version update  
|                  |                            | • Minor text edits |
| 2017.05.22       | 17.0.0                      | Initial Release           |
### A. Reference Design Files

#### Table 9. Reference Design Files List

<table>
<thead>
<tr>
<th>Type</th>
<th>File/Folder</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP files</td>
<td>source</td>
<td>Contains the IP files for the Intel Arria 10 External Memory Interfaces IP core, Intel Arria 10 Hard IP for PCI Express IP core, and devkit pins.</td>
</tr>
<tr>
<td></td>
<td>static_region</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ip</td>
<td></td>
</tr>
<tr>
<td></td>
<td>bsp_top</td>
<td></td>
</tr>
<tr>
<td>source</td>
<td>static_region</td>
<td>Contains the IP file for the Intel Arria 10 Partial Reconfiguration Controller IP core, system description ROM, calibration I/O, and all the interface components.</td>
</tr>
<tr>
<td></td>
<td>ip</td>
<td></td>
</tr>
<tr>
<td></td>
<td>design_top</td>
<td></td>
</tr>
<tr>
<td>source</td>
<td>static_region</td>
<td>Contains the freeze bridges, the region controller, and the JTAG SLD agent.</td>
</tr>
<tr>
<td></td>
<td>ip</td>
<td></td>
</tr>
<tr>
<td></td>
<td>pr_subsystem</td>
<td></td>
</tr>
<tr>
<td>common</td>
<td>reg_file</td>
<td>Contains all the IP files for the register file system, that is common across all personas.</td>
</tr>
<tr>
<td></td>
<td>ip</td>
<td></td>
</tr>
<tr>
<td></td>
<td>reg_file</td>
<td></td>
</tr>
<tr>
<td>common</td>
<td>sld_jtag_host</td>
<td>Contains the JTAG SLD host for the PR region signal tapping. These files are applicable to all the personas.</td>
</tr>
<tr>
<td></td>
<td>ip</td>
<td></td>
</tr>
</tbody>
</table>

*continued...*
### Type

<table>
<thead>
<tr>
<th>File/Folder</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>common</td>
<td>Contains the JTAG SLD agent for the PR region signal tapping. These files are applicable to the static region.</td>
</tr>
<tr>
<td>source</td>
<td>Contains the IP files for the EMIF logic inside the PR persona.</td>
</tr>
</tbody>
</table>

#### Platform Designer System Files

<table>
<thead>
<tr>
<th>File/Folder</th>
<th>Description</th>
</tr>
</thead>
</table>
| source      | Contains the following three Platform Designer (Standard) subsystems:  
* bsp_top.qsys—top-level subsystem, containing the PCIe IP core and the External Memory Interfaces IP core.  
* design_top.qsys—static region, encompassing all the Avalon-MM interface logic, reset logic, and PR Region Controller IP core.  
* pr_subsystem.qsys—contains all the logic to communicate and interact with the PR region. |

#### SystemVerilog design files

<table>
<thead>
<tr>
<th>File/Folder</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>source</td>
<td>Contains the top-level wrapper. Also contains the SystemVerilog description for generic components in the three subsystems, and the PR region wrapper.</td>
</tr>
<tr>
<td>basic_dsp_persona</td>
<td>Contains all the source files for the basic DSP persona.</td>
</tr>
<tr>
<td>basic_arithmetic_persona</td>
<td>Contains all the source files for the basic arithmetic persona.</td>
</tr>
<tr>
<td>ddr4_access_persona</td>
<td>Contains all the source files for the DDR4 access persona.</td>
</tr>
<tr>
<td>gol_persona</td>
<td>Contains all the source files for the Game of Life persona.</td>
</tr>
<tr>
<td>parent_persona</td>
<td>Contains all the source files for the parent persona.</td>
</tr>
</tbody>
</table>

---

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### A. Reference Design Files

<table>
<thead>
<tr>
<th>Type</th>
<th>File/Folder</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>source</td>
<td>Example personas that use the template for persona configuration. These examples demonstrate integrating a custom persona RTL into the reference design.</td>
</tr>
<tr>
<td>Memory files</td>
<td>avalon_config.hex</td>
<td>Used for system description ROM.</td>
</tr>
<tr>
<td>Synopsys Design Constraints Files</td>
<td>a10_pcie_devkit_cvp.sdc</td>
<td>Synthesis constraints for the design.</td>
</tr>
<tr>
<td></td>
<td>auxiliary.sdc</td>
<td>Provides exceptions.</td>
</tr>
<tr>
<td></td>
<td>jtag.sdc</td>
<td>Auto-generated constraints from pcie_subsystem_alt_pr.ip file.</td>
</tr>
<tr>
<td>Intel Quartus Prime Project File</td>
<td>a10_pcie_devkit_cvp.qpf</td>
<td>Contains all the revisions.</td>
</tr>
<tr>
<td>Intel Quartus Prime Settings Files</td>
<td>a10_pcie_devkit_cvp.qsf</td>
<td>Base revision settings file for single DDR4 access persona.</td>
</tr>
<tr>
<td></td>
<td>a10_pcie_devkit_cvp_ddr4_access.qsf</td>
<td>Implementation revision settings file for the parent persona with two DDR4 access personas.</td>
</tr>
<tr>
<td></td>
<td>a10_pcie_devkit_cvp_basic dsp.qsf</td>
<td>Implementation revision settings file for the parent persona with two basic DSP personas.</td>
</tr>
<tr>
<td></td>
<td>a10_pcie_devkit_cvp_basic arithmetic.qsf</td>
<td>Implementation revision settings file for the parent persona with two basic arithmetic personas.</td>
</tr>
<tr>
<td></td>
<td>a10_pcie_devkit_cvp_gol.qsf</td>
<td>Implementation revision settings file for the parent persona with two Game of Life personas.</td>
</tr>
<tr>
<td></td>
<td>a10_pcie_devkit_cvp_normal_ddr4_access.qsf</td>
<td>Implementation revision settings file for a single DDR4 access persona without the parent persona.</td>
</tr>
<tr>
<td></td>
<td>a10_pcie_devkit_cvp_normal_basic arithmetic.qsf</td>
<td>Implementation revision settings file for a single basic arithmetic persona without the parent persona.</td>
</tr>
<tr>
<td></td>
<td>a10_pcie_devkit_cvp_normal_gol.qsf</td>
<td>Implementation revision settings file for a single Game of Life persona without the parent persona.</td>
</tr>
</tbody>
</table>