



AN 820: Hierarchical Partial Reconfiguration over PCI Express* Reference Design for Intel® Stratix® 10 Devices

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

The Hierarchical Partial Reconfiguration (HPR) over PCI Express* (PCIe*) reference design demonstrates reconfiguring the FPGA fabric through the PCIe link in Intel® Stratix® 10 devices. This reference design runs on a Linux system with the Intel Stratix 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.

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 Intel Quartus® Prime Pro Edition 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.



- [Hierarchical Partial Reconfiguration Tutorial for Intel Stratix 10 GX FPGA Development Board](#)
For a step-by-step tutorial on creating a hierarchical partial reconfiguration design.
- [Intel Stratix 10 FPGA Development Kit User Guide](#)
For information on Intel Stratix 10 GX FPGA development board overview and setup procedure.

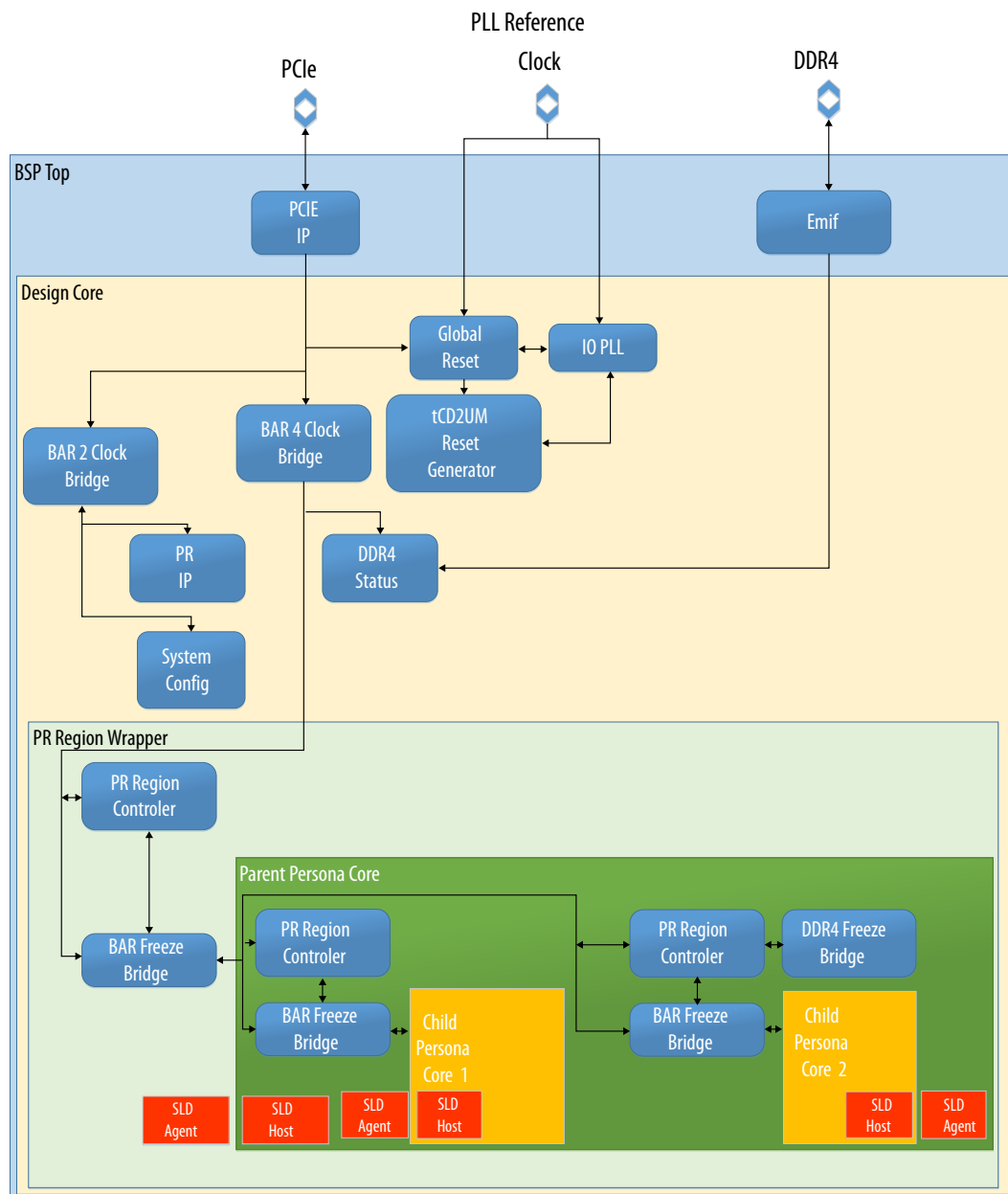
1.1. Reference Design Overview

The reference design consists of the following components:

- `s10_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.



Figure 1. Intel Stratix 10 PCIe Reference Design Block Diagram

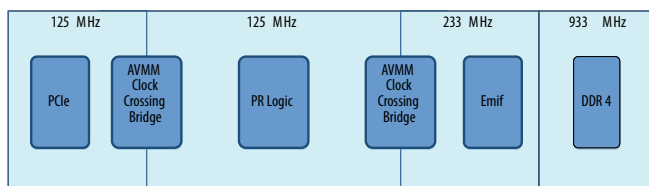


1.1.1. Clocking Scheme

The reference design creates a separate Altera IOPLL IP core-generated clock. This clock creation decouples the PR logic clocking domain from both the PCIe clocking domain that runs at 125 MHz, and the EMIF clocking domain that runs at 233 MHz. The clock for PR Logic is set at 125 MHz. To ensure timing closure, modify the parameterization of the IOPLL IP core to a lower clock frequency.



Figure 2. Timing Closure



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 1. PCIe Memory Address Map

| Domain | Address Map | Base | End |
|--------|-------------------------|-------------|-------------|
| BAR 2 | System Description ROM | 0x0000_0000 | 0x0000_0FFF |
| BAR 2 | PR IP | 0x0000_1000 | 0x0000_103F |
| BAR 4 | PR Region | 0x0000_0000 | 0x0000_FFFF |
| BAR 4 | PR Region Controller | 0x0001_0000 | 0x0001_000F |
| BAR 4 | DDR4 Calibration Export | 0x0001_0010 | 0x0001_001F |

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 2. DDR4 External Memory Interfaces (EMIF) Memory Address Map

| Address Map | Base | End |
|-------------|-------------|-------------|
| DDR | 0x0000_0000 | 0x7fff_ffff |

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

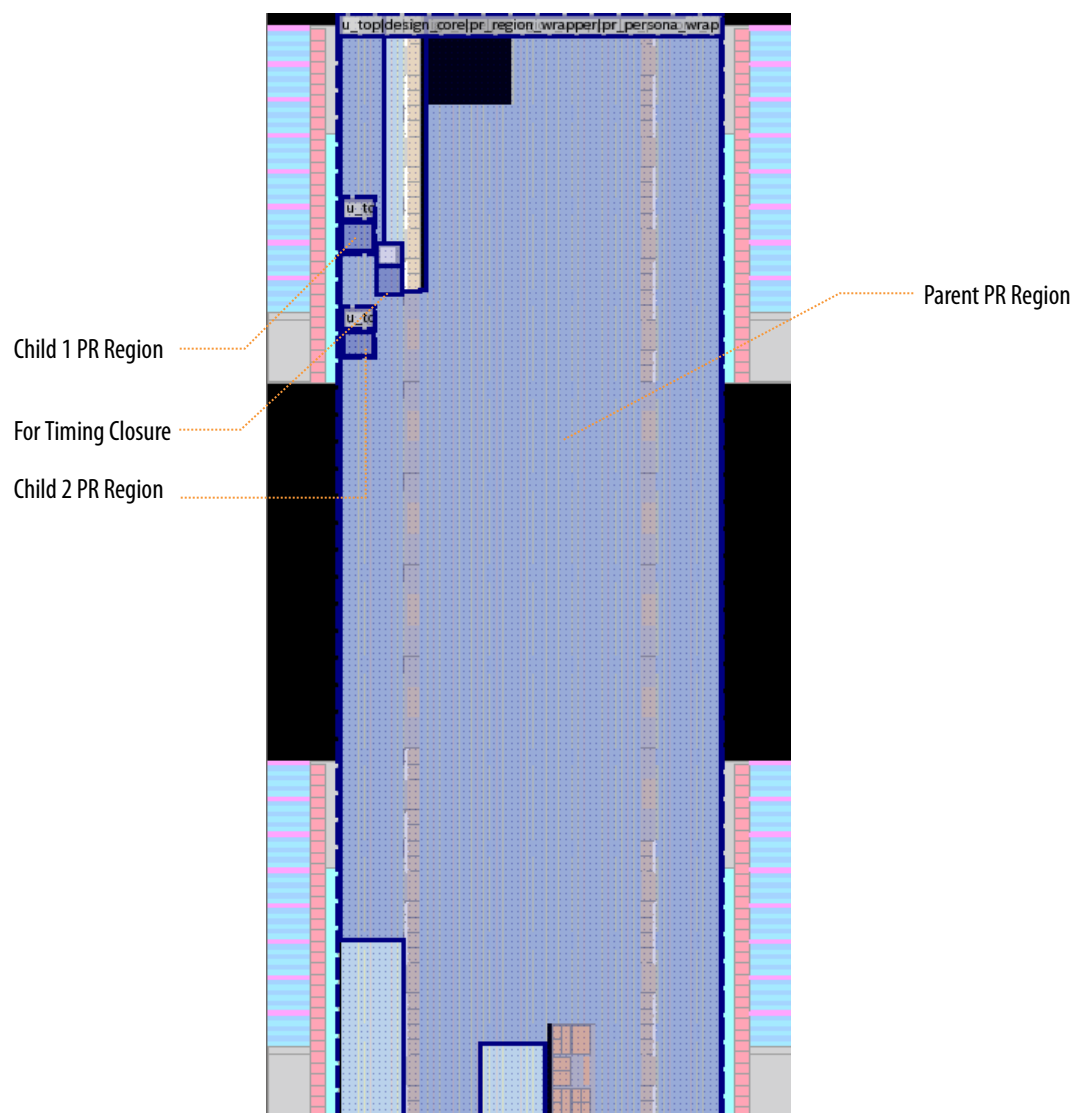
1.1.3. Floorplanning

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:

- Intel Stratix 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
- PCIe slot to plug-in the Intel Stratix 10 GX FPGA development board
- Open source driver for this PR over PCIe reference design
- Intel Quartus Prime Pro Edition software v.18.0
- Intel FPGA Download Cable driver

Important:

- The Linux driver accompanying this reference design is not a production driver. You must adapt this driver to your design's strategy to handle backpressure from the Intel Stratix 10 Partial Reconfiguration IP core.
- This reference design works under the assumption that the PCIe link does not require a 100 ms initialization time.

Note: The open source driver developed for this PR over PCIe reference design is tested using CentOS 7.

1.2.2. Installing the Intel Stratix 10 GX FPGA Development Kit

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

Important:

- When bringing up the design for the first time, ensure that you configure the DIP switch 1 (SW1) with both jumpers in the UP position. The switches are reverted to the standard (UP, DOWN) position after flashing the device.
- 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

- [Intel Stratix 10 FPGA Development Kit User Guide](#)
- [Bringing Up the Reference Design](#) on page 10

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.

Important: This Linux driver does not monitor the backpressure signal from the Intel Stratix 10 Partial Reconfiguration IP core, but instead uses a delay between 4KB blocks. This strategy may not work on your design. Adapt this driver to your design's strategy to handle backpressure from the Intel Stratix 10 Partial Reconfiguration IP core.

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

```
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 prerequisite packages before installing this driver. To install the per-requisite packages, run the following commands:

```
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 DEVICE=s10
```

Ensure that the following two kernel object files are present in the driver source directory after running this command:

- fpga-mgr-mod.ko
- fpga-pcie-mod.ko



Note: By default, the driver introduces a 5 ms delay with each 4KB chunk of the PR bitstream sent. To change this default value, run the following command:

```
make DEVICE=s10 WAIT_TIME=x
```

where x is the delay in milliseconds.

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 /sbin/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.

Related Information

[Red Hat Documentation](#)

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 `s10_pcie_devkit_hpr` folder to the home directory in your Linux system.

Before you begin: You must at least compile the base revision of the design.

To bring up the reference design on the board:

1. Plug-in the Intel Stratix 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 `s10_pcie_devkit_hpr/software/installation` folder in your system.
6. This reference design uses a lower frequency memory reference clock than the default configuration on the device. To configure the memory reference clock to the correct frequency:



- a. Open the Intel Quartus Prime software and click **Tools ► Programmer**.
- b. Use the `max5_116.pof` file in the `s10_pcie_devkit_hpr/software/installation` directory to flash the MAX® V device on the Intel Stratix 10 GX FPGA Development Kit.
7. Ensure that the DIP switch 1 is configured with both jumpers in the UP position.
Important: Perform the above step only if you are bringing up the design for the first time. Otherwise, you can skip this step.
8. To overwrite the existing factory image on the board with the reference design, execute the `flash.pl` script.
9. 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 `s10_pcie_devkit_hpr.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.
10. Turn-off the machine, reset DIP switch 1 to move the jumpers to the default position (UP, DOWN), and then turn-on the machine.
Important: Perform the above step only if you are bringing up the design for the first time. Otherwise, you can simply 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 `s10_pcie_ref_design.sv` wrapper.

1.3.1.1. PCI Express IP core

The Intel Stratix 10 Hard IP for PCI Express IP core is a Gen2x8, with a 256-bit interface and running at 125 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 3. PCI Express IP Core Configuration

| Setting | Parameter | Value |
|---------------------------|--|--------------------------------------|
| System Settings | Application interface type | Avalon-MM with DMA |
| | Hard IP mode | Gen2:x8, Interface: 256-bit, 125 MHz |
| | Port type | Native endpoint |
| Avalon-MM Settings | Enable control register access (CRA) Avalon-MM slave port | Disable |
| <i>continued...</i> | | |



| Setting | Parameter | Value |
|---------------------------------------|--|--------------------------------|
| Base Address Registers - BAR2 | Type | 32-bit non-prefetchable memory |
| Base Address Registers - BAR4 | Type | 32-bit non-prefetchable memory |
| Device Identification Registers | Vendor ID | 0x00001172 |
| | Device ID | 0x00005052 |
| | Revision ID | 0x00000001 |
| | Class code | 0x00ea0001 |
| | Subsystem Vendor ID | 0x00001172 |
| | Subsystem Device ID | 0x00000001 |
| PCI Express/PCI Capabilities - Device | Maximum payload size | 256 Bytes |
| PHY Characteristics | Requested equalization far-end TX preset | Preset 9 |

Note: Instantiate the PCI Express IP core as part of a Platform Designer system.

1.3.1.2. Intel Stratix 10 DDR4 External Memory Interfaces IP Core

The ddr4_emif logic includes the Intel Stratix 10 External Memory Interfaces IP core. This IP core interfaces to the DDR4 external memory, with a 64-bit interface that runs at 933 MHz. Also, the IP core provides 2 GB of DDR4 SDRAM memory space. The EMIF Avalon-MM slave runs at 233 MHz clock.

The following table lists the configuration fields of the Intel Stratix 10 External Memory Interfaces IP core that are different from the Intel Stratix 10 GX FPGA Development Kit with DDR4 HILO preset settings:

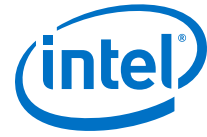
Table 4. Intel Stratix 10 DDR4 External Memory Interfaces IP Configuration

| Setting | Parameter | Value |
|-------------------|-----------------------|-------------------------|
| Memory - Topology | DQ width | 8 |
| | DQ pins per DQS group | 8 |
| | Number of DQS groups | 2 |
| | Alert# pin placement | I/O Lane with DQS Group |
| | DQS Group of ALERT# | 0 |

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 125 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 μ s 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 μ s, 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. Intel Stratix 10 Partial Reconfiguration Region Controller IP Core

Use the Intel Stratix 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.

1.3.1.3.4. Intel Stratix 10 Partial Reconfiguration Controller IP Core

The reference design configures the Partial Reconfiguration Region 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. During partial reconfiguration, the Linux driver included with this reference design sends the PR bitstream directly to the PR IP core, through the Avalon-MM interface.

Important: This Linux driver does not monitor the backpressure signal from the Intel Stratix 10 Partial Reconfiguration IP core, but instead uses a delay between 4KB blocks. This strategy may not work on your design. Adapt this driver to your design's strategy to handle backpressure from the Intel Stratix 10 Partial Reconfiguration IP core. You can achieve this backpressure handling by reading the `avst_sink_ready` or the `avmm_slave_waitrequest` signals. For more information, refer to the *Intel Stratix 10 Partial Reconfiguration Controller Ports* section in the *Partial Reconfiguration Solutions IP User Guide*.



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

Table 5. Intel Stratix 10 Hard IP for PCI Express IP Core Configuration

| Parameters | Value |
|--|-----------|
| Enable Avalon-ST sink or Avalon-MM interface | Avalon-MM |
| Input data width | 32 |
| Enable interrupt interface | No |

Related Information

[Intel Stratix 10 Partial Reconfiguration Controller Ports](#)

1.3.1.3.5. Partial Reconfiguration Logic

The reference design provides the following personas:

Table 6. Reference Design Personas

| Persona | Description |
|------------------|--|
| DDR4 access | Performs a sweep across a memory span, first writing, and then reading each address. |
| Basic DSP | Provides access to a 27x27 DSP multiplier, and demonstrates hardware acceleration. |
| Basic arithmetic | Includes a basic 32-bit unsigned adder, and demonstrates hardware acceleration. |
| Game of Life | Includes an 8x8 Conway's Game of Life, and demonstrates hardware acceleration. |
| Parent persona | 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. |

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 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:

```
quartus_sh --flow compile s10_pcie_devkit_hpr -c s10_pcie_devkit_hpr
```

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

```
quartus_cdb -r s10_pcie_devkit_hpr -c s10_pcie_devkit_hpr \
--export_block root_partition --snapshot final \
--file s10_pcie_devkit_hpr_static.qdb --
include_sdc_entity_in_partition
```

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

```
set_instance_assignment -name QDB_FILE_PARTITION \
s10_pcie_devkit_hpr_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 hierarchy of the PR persona. For example, s10_pcie_devkit_hpr_ddr4_access.qsf contains the following entity rebinding assignment:

```
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:

```
quartus_sh --flow compile s10_pcie_devkit_hpr \
-c s10_pcie_devkit_hpr_normal_ddr4_access
quartus_sh --flow compile s10_pcie_devkit_hpr \
-c s10_pcie_devkit_hpr_normal_basic_arithmetic
quartus_sh --flow compile s10_pcie_devkit_hpr \
-c s10_pcie_devkit_hpr_normal_basic_dsp
quartus_sh --flow compile s10_pcie_devkit_hpr \
-c s10_pcie_devkit_hpr_normal_gol.qsf
```

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

```
quartus_sh --flow compile s10_pcie_devkit_hpr \
-c s10_pcie_devkit_hpr_ddr4_access
```

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

```
quartus_cdb -r s10_pcie_devkit_hpr -c s10_pcie_devkit_hpr_ddr4_access \
--export_block pr_partition --snapshot final \
--file s10_pcie_devkit_hpr_ddr4_access_pr_partition_final.qdb \
--include_sdc_entity_in_partition
```

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

```
set_instance_assignment -name QDB_FILE_PARTITION \
s10_pcie_devkit_hpr_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.

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

```
quartus_sh --flow compile s10_pcie_devkit_hpr \  
-c s10_pcie_devkit_hpr_basic_arithmetic  
quartus_sh --flow compile s10_pcie_devkit_hpr \  
-c s10_pcie_devkit_hpr_basic_dsp  
quartus_sh --flow compile s10_pcie_devkit_hpr \  
-c s10_pcie_devkit_hpr_gol
```

Related Information

[Partial Reconfiguration Design Flow](#)

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_fpga_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 7. program_fpga_jtag Command-Line Options

| Option | Description |
|-------------------------------|---------------------------------|
| -f=, --file=[<filename>] | Specifies the .sof file name. |
| -c=, --cable=[<cable number>] | Specifies the programmer cable. |
| continued... | |



| Option | Description |
|-------------------------------|--|
| -d, --device=[<device index>] | Specifies the PCIe device number. For example, -d=0000:03:00.0 |
| -i, --index=[<jtag index>] | Provides the JTAG chain index for the FPGA device. |
| -h, --help | Provides help for program_fpga_jtag script. |

Note: Use the following command to obtain the device index:

```
/sbin/lspci -d1172:
```

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 8. program_fpga_pcie Command-Line Options

| Option | Description |
|--------------------------------|--|
| -f, --file=[<filename>] | Specifies the .rbf file name. |
| -d, --device=[<device index>] | Specifies the PCIe device number. For example, -d 0000:03:00.0 |
| -r, --region=[<region offset>] | <p>Specifies the target FPGA region controller offset, used for freeze bridge enable. This option performs the following operations:</p> <ul style="list-style-type: none"> • Initiates the freeze request exchange • Asserts/deasserts reset for the PR region, during and after partial reconfiguration <p>For example:</p> <pre>program-fpga-pcie --file=<region.rbf> --device=0000:03:00.0 --region=10000</pre> <p>Note: The region offset value must be a hexadecimal number.</p> <p>The PR region is reset during this operation.</p> |
| -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 9. `example_host_uio` Command-Line Options

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

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

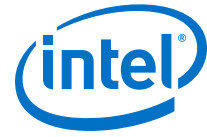
For complete information on the debug infrastructure using hierarchical hubs, refer to *Debugging Partial Reconfiguration Designs Using Signal Tap Logic Analyzer* section in Volume 3 of the Intel Quartus Prime Pro Edition handbook.

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`, the cable number is 1, and the JTAG chain index is 2.

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

1. To program the DDR4 access persona's (HPR parent persona) `.sof` file after design compilation, type the following from the Linux shell:

```
program-fpga-jtag -f=s10_pcie_devkit_hpr_ddr4_access.sof -c=1 -
d=0000:03:00.0 -i=2
```

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

```
source/util/example_host/example_host_uio -d 0000:03:00.0
```

3. To program the basic DSP child PR persona's `.rbf` file after design compilation, type the following from the Linux shell:

```
program-fpga-pcie -
f=s10_pcie_devkit_hpr_basic_dsp.pr_partition.pr_child_partition_1.rbf -
d=0000:03:00.0 -r=20
```

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

```
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:

```
program-fpga-pcie -
f=s10_pcie_devkit_hpr_basic_arithmetic.pr_partition.pr_child_partition_1
.rbf -d=0000:03:00.0 -r=20
```

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

```
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 `s10_pcie_devkit_hpr` folder:

```
cd s10_pcie_devkit_hpr
```

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

```
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:

```
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:

```
module custom_persona #(  
    parameter REG_FILE_IO_SIZE = 8  
)(  
    //clock  
    input wire clk,  
  
    //active low reset, defined by hardware  
    input wire rst_n,  
  
    //Persona identification register, used by host in host program  
    output wire [31:0] persona_id,  
  
    //Host control register, used for control signals.  
    input wire [31:0] host_cntrl_register,  
  
    // 8 registers for host -> PR logic communication  
    input wire [31:0] host_pr [0:REG_FILE_IO_SIZE-1],  
  
    // 8 Registers for PR logic -> host communication  
    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:

```
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:

```
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:

```
set_global_assignment -name TOP_LEVEL_ENTITY \
    <custom_persona> s10_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>
```

8. Update the `s10_pcie_devkit_hpr.qpf` project file to include your implementation revisions:

```
PROJECT_REVISION = "<persona_impl_revision_name>"
```

9. Compile the revision.

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

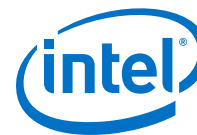
Related Information

[Adding a New Persona to the Design](#)

1.7. Document Revision History for AN 820: Hierarchical Partial Reconfiguration over PCI Express Reference Design for Intel Stratix 10 Devices

This document has the following revision history.

| Document Version | Intel Quartus Prime Version | Changes |
|------------------|-----------------------------|--|
| 2018.05.10 | 2018.05.10 | Corrected an issue with the driver installation instructions. |
| 2018.05.07 | 18.0.0 | <ul style="list-style-type: none"> Compilation flow change Other minor text edits |
| 2018.02.15 | 17.1.1 | <ul style="list-style-type: none"> Added additional notes about the Linux driver shipped with the design Minor text edits and content reorganization |
| 2018.01.17 | 17.1.1 | Initial Release |



A. Reference Design Files

Table 10. Reference Design Files List

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

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












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| Type | File/Folder | Description |
|--------------------------------|-------------|---|
| | | Contains the JTAG SLD agent for the PR region signal tapping. These files are applicable to all the personas. |
| | | Contains all the IP files for EMIF interface in the PR personas. |
| Platform Designer System Files | | Contains the following three Platform Designer (Standard) subsystems: <ul style="list-style-type: none"> • <code>bsp_top.qsys</code>—top-level subsystem, containing the PCIe IP core and the External Memory Interfaces IP core. • <code>design_top.qsys</code>—static region, encompassing all the Avalon-MM interface logic, reset logic, and PR Region Controller IP core. • <code>pr_subsystem.qsys</code>—contains all the logic to communicate and interact with the PR region. |
| | | Contains the PR persona EMIF interface. |
| SystemVerilog design files | | Contains the top-level wrapper. Also contains the SystemVerilog description for generic components in the three subsystems, and the PR region wrapper. |
| | | Contains all the source files for the basic DSP persona. |
| | | Contains all the source files for the basic arithmetic persona. |
| | | Contains all the source files for the Game of Life persona. |
| continued... | | |



| Type | File/Folder | Description |
|------------------------------------|---|--|
| |  source  ddr4_access_persona | Contains all the source files for the DDR4 access persona. |
| |  source  templates | Example personas that use the template for persona configuration. These examples demonstrate integrating a custom persona RTL into the reference design. |
| Memory files |  avalon_config.hex | Used for system description ROM. |
| Synopsys Design Constraints Files |  s10_pcie_devkit_hpr.sdc | Synthesis constraints for the design. |
| |  auxiliary.sdc | Provides exceptions. |
| |  jtag.sdc | JTAG timing constraints file. |
| Signal Tap File |  basic_dsp_persona.stp | Signal Tap file for the basic DSP persona. |
| Software utilities |  software | Contains software utilities for flashing the development board, and communicating with the reference design. |
| Intel Quartus Prime Project File |  s10_pcie_devkit_hpr.qpf | Contains all the revisions. |
| Intel Quartus Prime Settings Files |  s10_pcie_devkit_hpr.qsf | Base revision settings file for the DDR4 access persona. |
| |  s10_pcie_devkit_hpr_ddr4_access.qsf | Implementation revision settings file for the DDR4 access persona. |
| |  s10_pcie_devkit_hpr_basic_dsp.qsf | Implementation revision settings file for basic DSP persona. |
| |  s10_pcie_devkit_hpr_basic_arithmetic.qsf | Implementation revision settings file for basic arithmetic persona. |
| |  s10_pcie_devkit_hpr_gol.qsf | Implementation revision settings file for Game of Life persona. |
| |  s10_pcie_devkit_hpr_normal_ddr4_access.qsf | Implementation revision settings file for non-HPR parent DDR4 access persona. |
| |  s10_pcie_devkit_hpr_normal_basic_arithmetic.qsf | Implementation revision settings file for non-HPR child basic arithmetic persona. |
| |  s10_pcie_devkit_hpr_normal_basic_dsp.qsf | Implementation revision settings file for non-HPR child basic DSP persona. |
| continued... | | |



| Type | File/Folder | Description |
|--------------|--|--|
| |  s10_pcie_devkit_hpr_normal_gol.qsf | Implementation revision settings file for non-HPR child GOL persona. |
| |  pr_logic_impl_template.qsf.template | Template implementation revision settings file. |
| Verification |  verif | Contains testbench files for the design. |