

Xilinx Design Constraints

Introduction

In this lab you will use the `uart_led` design that was introduced in the previous labs. You will start the project with I/O Planning type, enter pin locations, and export it to the rtl. You will then create the timing constraints and perform the timing analysis.

Objectives

After completing this lab, you will be able to:

- Create a I/O Planning project
- Enter the pin locations and IO standards via Device view, Package Pins tab, and Tcl commands
- Create Period, Input Setup, and Output Setup delays
- Perform timing analysis

Procedure

This lab is broken into steps that consist of general overview statements providing information on the detailed instructions that follow. Follow these detailed instructions to progress through the lab.

Design Description

The design consists of a uart receiver receiving the input typed on a keyboard and displaying the binary equivalent of the typed character on the 8 LEDs. When a push button is pressed, the lower and upper nibbles are swapped. The block diagram is as shown in **Figure 1**.

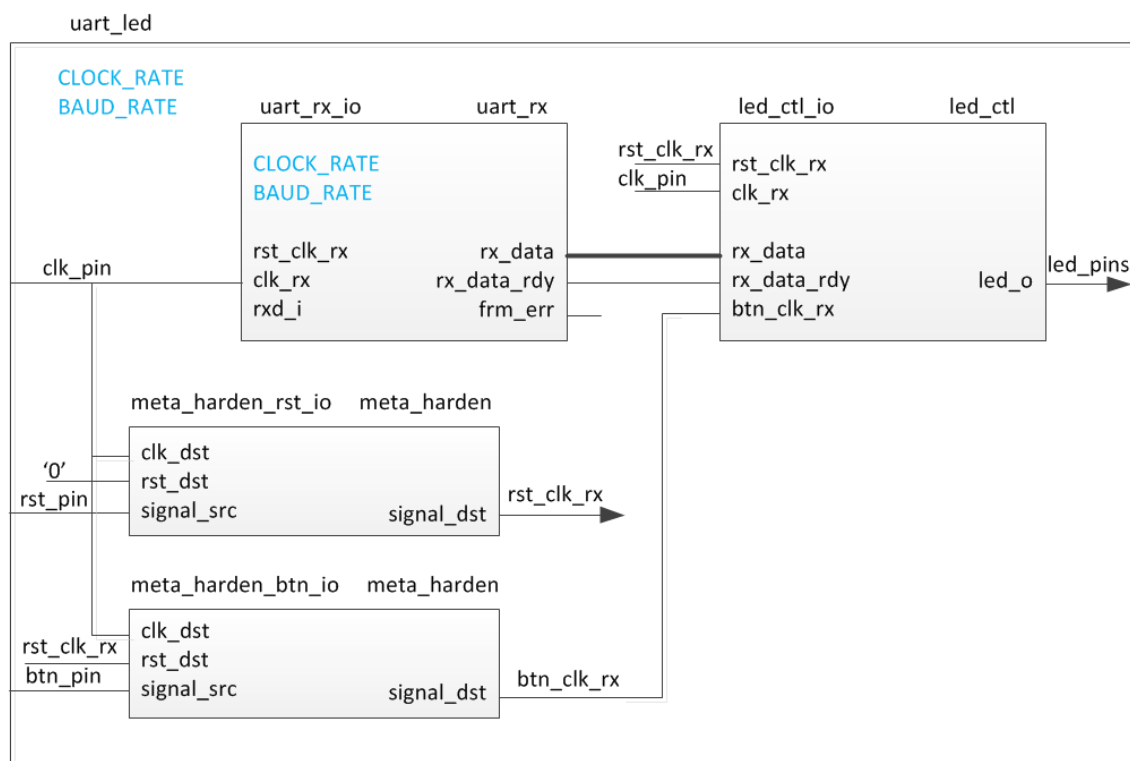
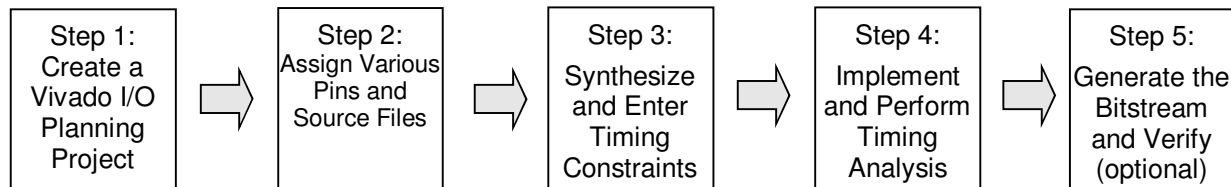


Figure 1. The design

General Flow



Create a Vivado I/O Planning Project

Step 1

- 1-1. Launch Vivado and create an I/O Planning project targeting the XC7A100TCSG324-1 (Nexys4 DDR), the XC7A35TCPG236-1 (Basys3) or the XC7A200TSBG484-1 (Nexys Video).**

References to `<2015_2_artix7_labs>` is a placeholder for the `c:\xup\fpga_flow\2015_2_artix7_labs` directory and `<2015_2_artix7_sources>` is a placeholder for the `c:\xup\fpga_flow\2015_2_artix7_sources` directory.

Reference to `<board>` means either the **Nexys4 DDR** or the **Basys3** or the **Nexys Video**

- 1-1-1.** Open Vivado by selecting **Start > All Programs > Xilinx Design Tools > Vivado 2015.2 > Vivado 2015.2**
- 1-1-2.** Click **Create New Project** to start the wizard. You will see *Create A New Vivado Project* dialog box. Click **Next**.
- 1-1-3.** Click the Browse button of the *Project location* field of the **New Project** form, browse to `<2015_2_artix7_labs>`, and click **Select**.
- 1-1-4.** Enter **lab5** in the *Project name* field. Make sure that the *Create Project Subdirectory* box is checked. Click **Next**.
- 1-1-5.** Select **I/O Planning Project** option in the *Project Type* form, and click **Next**.
- 1-1-6.** Select **Do not import I/O ports at this time**, and click **Next**.
- 1-1-7.** In the *Default Part* form, using the **Parts** option and various drop-down fields of the **Filter** section, select the **XC7A100TCSG324-1** (for the Nexys4 DDR), the **XC7A35TCPG236-1** (for the Basys3), or **XC7A200tsbg484-1** (for the Nexys Video).

Using the **Boards** option, you may also select the **Nexys4 DDR**, the **Basys3**, or the **Nexys Video** depending on your board.
- 1-1-8.** Click **Next**.

1-1-9. Click **Finish** to create the Vivado project.

The device view window and package pins tab will be displayed.

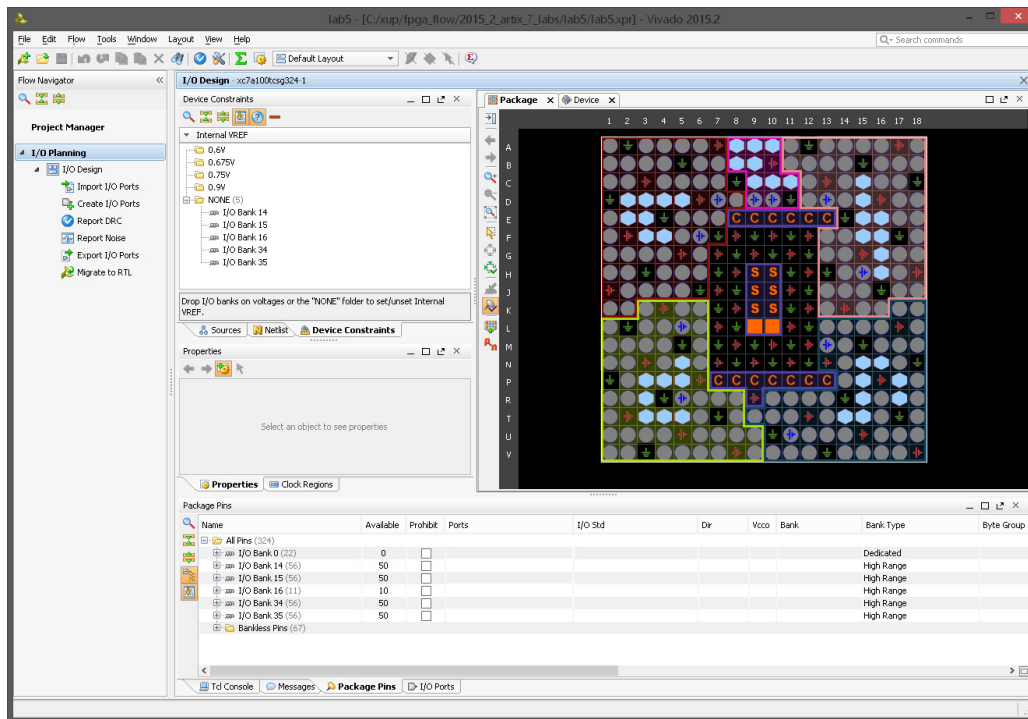


Figure 2. I/O Planning project's default windows and views for the Nexys4 DDR

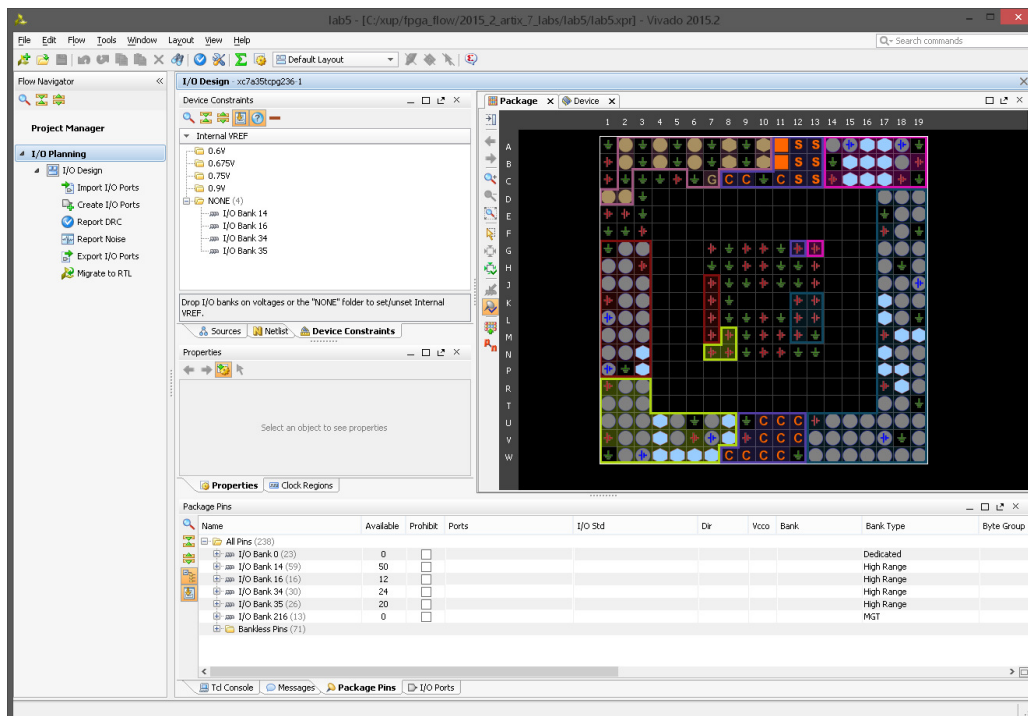


Figure 2. I/O Planning project's default windows and views for the Basys3

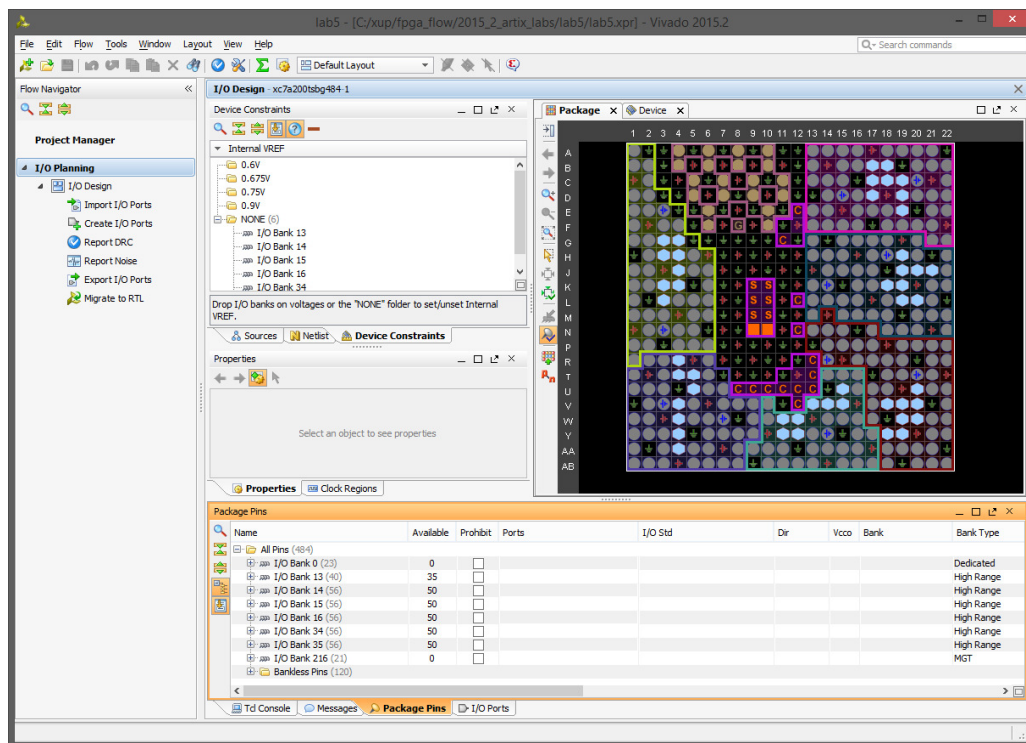


Figure 2. I/O Planning project's default windows and views for the Nexys Video

Create I/O Ports, Assign Various Pins and Add Source Files Step 2

2-1. Create input ports `clk_pin`, `btn_pin`, `rx_d_pin`, and `rst_pin`.

- 2-1-1. Expand the *I/O Design* entry under the *I/O Planning* task of the *Flow Manager* and click on **Create I/O Ports**.

The Create I/O Ports form will be displayed.

- 2-1-2. Type `clk_pin` in the *Name* field, select **Input** for the *Direction* and select **LVC MOS33** as the *I/O Standard*, and click **OK**.

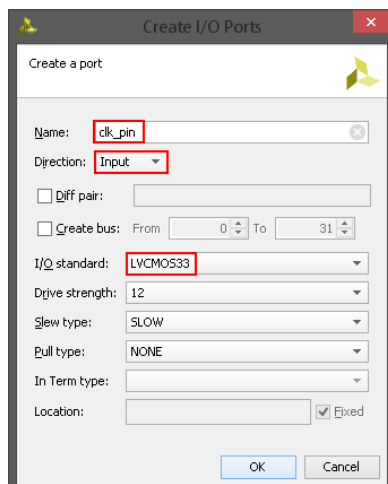


Figure 3. Creating I/O Port for `clk_pin` input

2-1-3. Similarly, create the **btn_pin**, **rxn_pin** and **rst_pin** input ports.

If using the Nexys Video, *btn_pin* must have *I/O STANDARD LVCMOS12*, *rxn_pin* *LVCMOS33*, and *rst_pin* *LVCMOS12*.

2-2. For the Nexys4 DDR, assign input pins **clk_pin**, **btn_pin**, **rxn_pin**, and **rst_pin** to **E3**, **M18**, **C4**, and **N17** locations using the Device view and package pins.

For the Basys3, assign input pins **clk_pin**, **btn_pin**, **rxn_pin**, and **rst_pin** to **W5**, **T18**, **B18**, and **U18** locations using the Device view and package pins.

For the Nexys Video, assign input pins **clk_pin**, **btn_pin**, **rxn_pin**, and **rst_pin** to **R4**, **F15**, **V18**, and **B22** locations using the Device view and package pins.

2-2-1. For the Nexys4 DDR, move the mouse over the Device view window and hover over it on the **E3** location.

For the Basys3, hover the mouse over **W5** in the Device view window.

For the Nexys Video, hover the mouse over **R4** in the Device view window.



Figure 4. Locating E3 pin in the Device view for the Nexys4 DDR

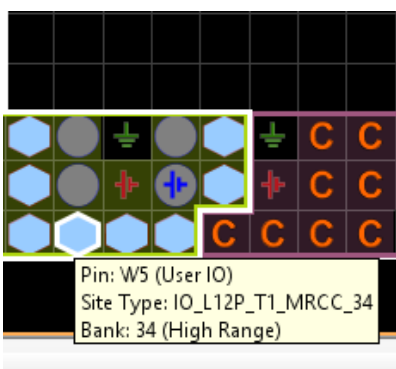


Figure 4. Locating W5 pin in the Device view for the Basys3

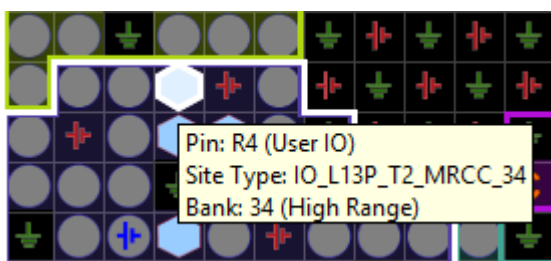


Figure 4. Locating R4 pin in the Device view for the Nexys Video

2-2-2. When located, click on it.

The pin entry will be highlighted and displayed in the Package Pins tab.

2-2-3. In the *Package Pins* pane, click in the Ports column of **E3** (Nexys4 DDR), **W5** (Basys3), or **R4** (Nexys Video) pin's row, and select **clk_pin**.

2-2-4. Similarly, add the **btn_pin** input port at **M18** (Nexys4 DDR), **T18** (Basys3), or **F15** (Nexys Video).

2-2-5. Select **Edit > Find** or Ctrl-F to open the Find form. Select **Package Pins** in the *Find* drop-down field, type ***C4** (for the Nexys4 DDR), ***B18** (for the Basys3), or ***V18** (for the Nexys Video) in the match criteria field, and click on **OK**.

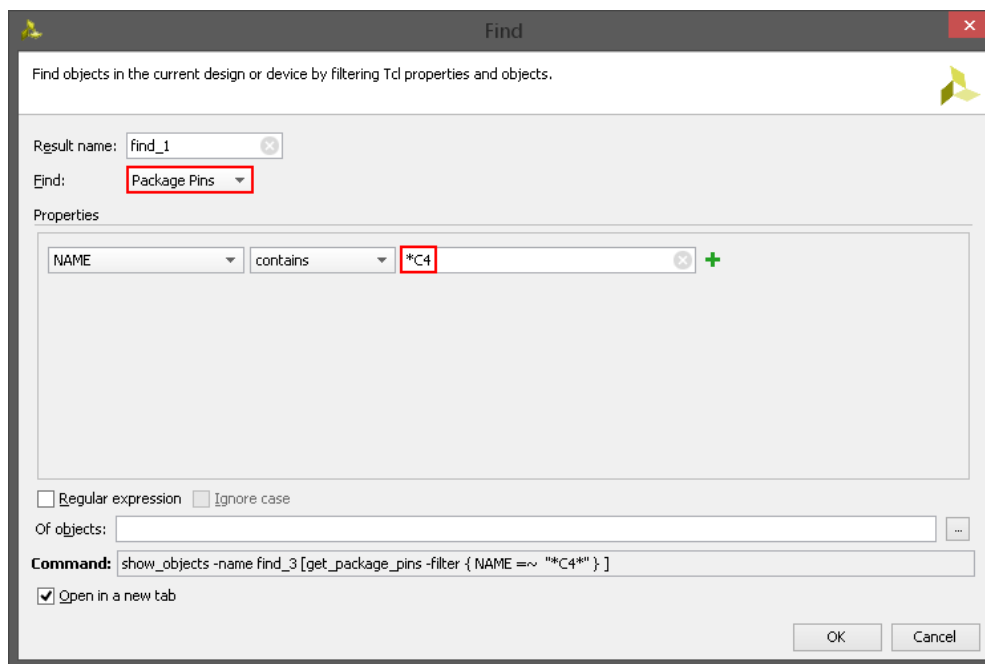


Figure 5. Finding a package pin for the Nexys4 DDR (use B18 for the Basys3 or V18 for the Nexys Video)

Notice that the Find Results tab is opened, and the corresponding entry is shown in the tab.

2-2-6. Assign the **rxn_pin** input to the pin.

2-2-7. Similarly add the **rst_pin** input by assigning it to the **N17** location for the Nexys4 DDR. For the Basys3, assign it to **U18** and **B22** for the Nexys Video.

- 2-3.** For the Nexys4 DDR, assign output pins `led_pins[7]` to `led_pins[0]` to locations U16, U17, V17, R18, N14, J13, K15, and H17. Create them as a vector and assign them using the Tcl command `set_property`. They all will be LVCMOS33.

For the Basys3, assign output pins `led_pins[7]` to `led_pins[0]` to locations V14, U14, U15, W18, V19, U19, E19 and U16. Create them as a vector and assign them using the Tcl command `set_property`. All the pins will be LVCMOS33.

For the Nexys Video, assign output pins `led_pins[7]` to `led_pins[0]` to locations T14, T15, T16, U16, V15, W16, W15, Y13. Create them as a vector and assign them using the Tcl command `set_property`. All the pins will be LVCMOS25.

- 2-3-1.** In the I/O Ports tab, click on the create I/O port button on the left vertical ribbon.

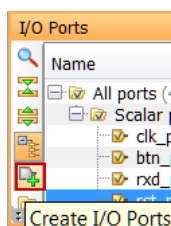


Figure 6. Create I/O Ports button

The Create I/O Ports form will be displayed.

- 2-3-2.** Type `led_pins` in the *Name* field, select *Output* direction, click on the check-box of **Create bus**, set the msb to `7`, and select **LVCMOS33** I/O standard if you are using a Nexys4 DDR or Basys3, or **LVCMOS25** if you are using the Nexys Video and click **OK**.

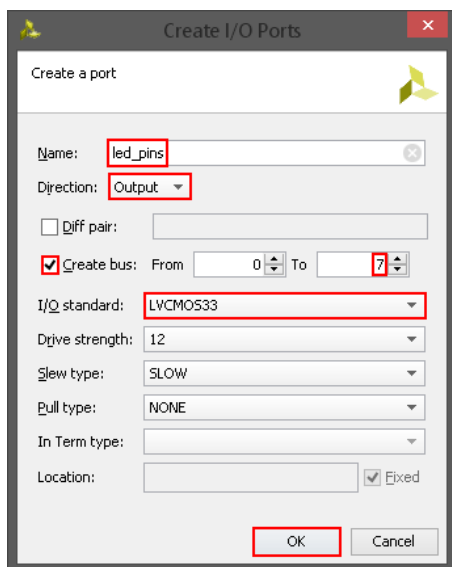


Figure 8. Creating I/O ports for the led_pins output

The `led_pins` entries will be created and displayed in the I/O Ports tab. Notice that the I/O standard and directions are already set, leaving only the pin locations to be assigned.

2-3-3. Type the following commands in the console to assign the pin locations.

For the Nexys4 DDR:

```
set_property PACKAGE_PIN U16 [get_ports led_pins[7]]
set_property PACKAGE_PIN U17 [get_ports led_pins[6]]
set_property PACKAGE_PIN V17 [get_ports led_pins[5]]
set_property PACKAGE_PIN R18 [get_ports led_pins[4]]
set_property PACKAGE_PIN N14 [get_ports led_pins[3]]
set_property PACKAGE_PIN J13 [get_ports led_pins[2]]
set_property PACKAGE_PIN K15 [get_ports led_pins[1]]
set_property PACKAGE_PIN H17 [get_ports led_pins[0]]
```

For the Basys3:

```
set_property PACKAGE_PIN V14 [get_ports led_pins[7]]
set_property PACKAGE_PIN U14 [get_ports led_pins[6]]
set_property PACKAGE_PIN U15 [get_ports led_pins[5]]
set_property PACKAGE_PIN W18 [get_ports led_pins[4]]
set_property PACKAGE_PIN V19 [get_ports led_pins[3]]
set_property PACKAGE_PIN U19 [get_ports led_pins[2]]
set_property PACKAGE_PIN E19 [get_ports led_pins[1]]
set_property PACKAGE_PIN U16 [get_ports led_pins[0]]
```

For the Nexys Video:

```
set_property PACKAGE_PIN T14 [get_ports led_pins[7]]
set_property PACKAGE_PIN T15 [get_ports led_pins[6]]
set_property PACKAGE_PIN U15 [get_ports led_pins[5]]
set_property PACKAGE_PIN T16 [get_ports led_pins[4]]
set_property PACKAGE_PIN V15 [get_ports led_pins[3]]
set_property PACKAGE_PIN W16 [get_ports led_pins[2]]
set_property PACKAGE_PIN W15 [get_ports led_pins[1]]
set_property PACKAGE_PIN Y13 [get_ports led_pins[0]]
```

2-3-4. Select **File > Save Constraints**.

The Save Constraints form will be displayed.

2-3-5. Enter **uart_led** in the *File name* field, and click **OK**.

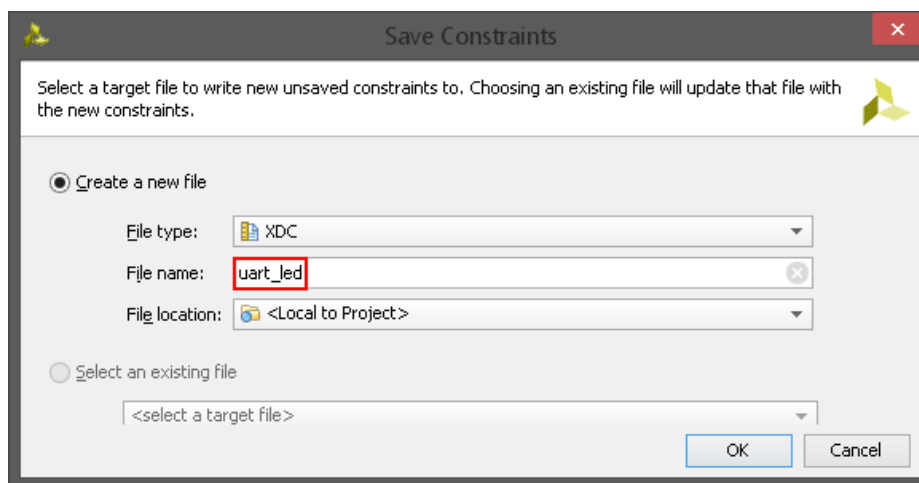


Figure 8. Saving constraints

The `uart_led.xdc` file will be created and added to the Sources tab.

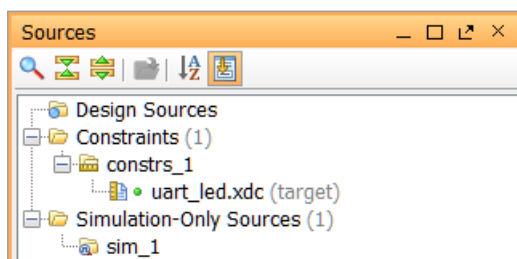


Figure 9. The `uart_led.xdc` file added to the source tree

- 2-3-6. Expand the **I/O Planning > I/O Design** in the *Flow Navigator* pane.
- 2-3-7. Click on **Report DRC** and click **OK**. Notice the design rules checker is run and one warning is reported. Ignore the warning.
- 2-3-8. Click on **Report Noise** and click **OK**. Notice the noise analysis is done on the output pins only (led_pins) and the results are displayed.
- 2-3-9. Click on **Migrate to RTL**.

The Migrate to RTL form will be displayed with Top RTL file field showing `c:/xup/fpga_flow/2015_2_artix7_labs/lab5/io_1.v` entry.

- 2-3-10. Change `io_1.v` to `uart_led.v`, and click **OK**

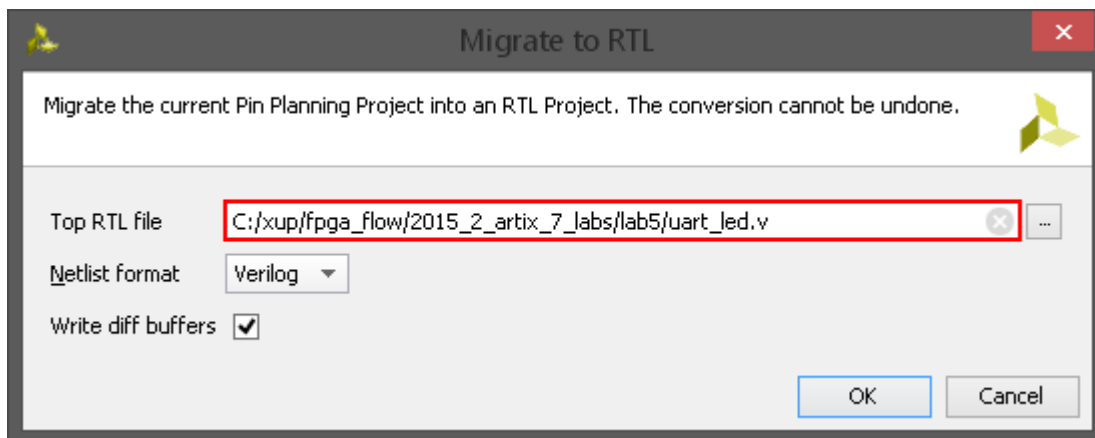


Figure 10. Assigning top-level file name

- 2-3-11. Select the **Hierarchy** tab and notice that the `uart_led.v` file has been added to the project with top-level module name as **ios**. If you double-click the entry, you will see the module name with the ports listing.

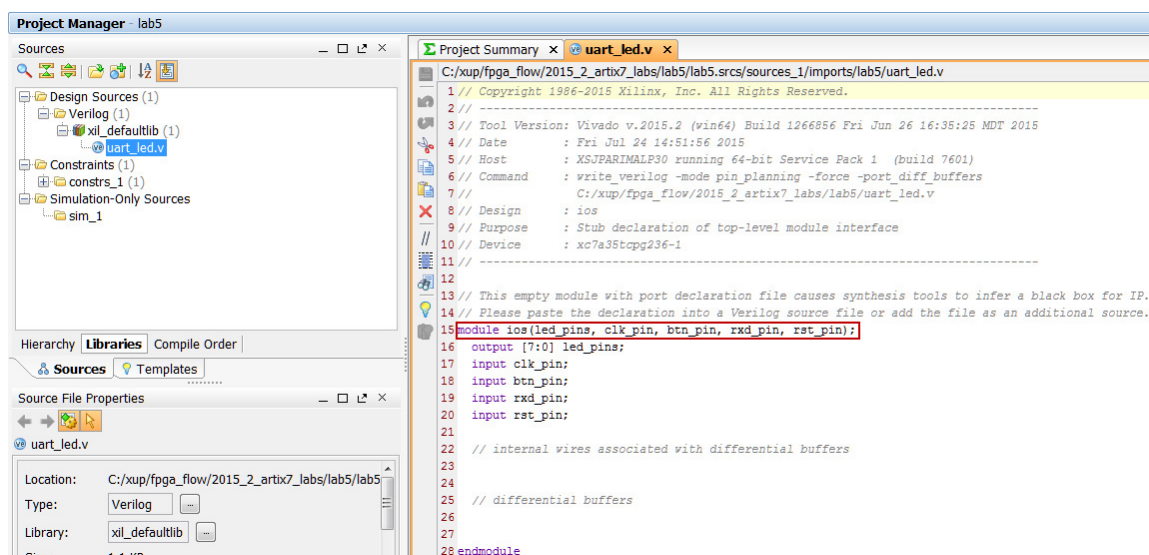


Figure 11. The top-level module content and the design hierarchy after migrating to RTL

2-4. Add the provided source files (from <2015_2_artix7_sources>\lab5) to the project. Copy the uart_led.txt (located in the <2015_2_artix7_sources>\lab5) content into the top-level source file.

2-4-1. Click on **Add Sources** in the *Flow Navigator*.

2-4-2. In the *Add Sources* form, select *Add or Create Design Sources*, and click **Next**.

2-4-3. Click on the **Green Plus** button, then the **Add Files...**

2-4-4. Browse to <2015_2_artix7_sources>\lab5 and select all .v files (led_ctrl, uart_rx, meta_harden, uart_baud_gen, uart_rx_ctl), and click **OK**.

2-4-5. Click **Finish**.

2-4-6. Using Windows Explorer, browse to <2015_2_artix7_sources>\lab5 and open uart_led.txt using any text editor. Copy the content of it and paste it in uart_led.v (around line 22) in the Vivado project.

Synthesize and Enter Timing Constraints


Step 3

3-1. Synthesize the design. Use the Constraints Wizard to specify a clock frequency, and input and output delay constraints.

3-1-1. Click on the **Run Synthesis** in the *Flow Navigator* pane.

When synthesis is completed a form with three options will be displayed.

3-1-2. Select *Open Synthesized Design* and click **OK**.

- 3-1-3.** In the *Flow Navigator* pane (under Synthesized Design), click on the **Constraints Wizard**  button. This will open up the Constraints Wizard.
- 3-1-4.** Read the *Identify and Recommend Missing Timing Constraints* screen of the wizard to understand what the wizard does and click **Next**.
- 3-1-5.** Specify the frequency of the object “clk_pin” to be **100 MHz**, notice the Period, Rise At and Fall At are automatically populated. Also notice the Tcl command that can be previewed at the bottom of the wizard. Click **Next** to proceed.

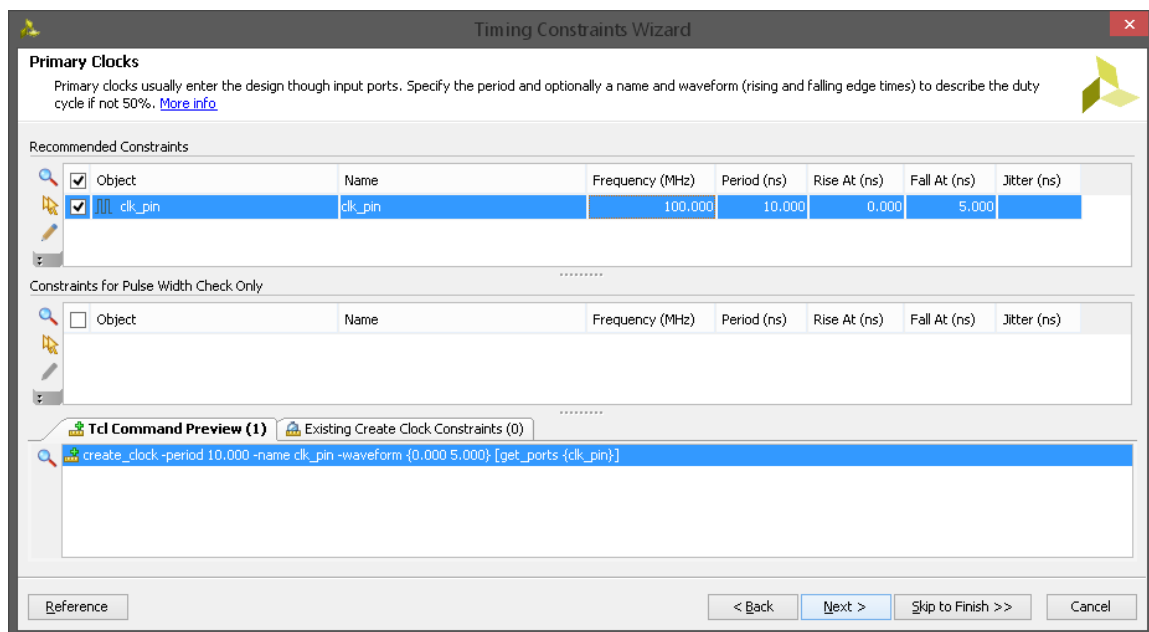


Figure 12. Constraints Wizard *clk_pin* parameters and Tcl command

- 3-1-6.** There are no missing Generated Clocks, click **Next** to proceed.
- 3-1-7.** There are no missing Forwarded Clocks, click **Next** to proceed.
- 3-1-8.** There are no missing External Feedback Delays, click **Next** to proceed.
- 3-1-9.** The wizard identifies Input Delays needed for the pins: btn_pin, rst_pin and rxd_pin. Do the following:
- (1) Press Ctrl and select all three rows.
 - (2) Enter the **tco_min** value to be **-0.5 ns** and everything else as **0 ns**. Click **Apply**.
 - (3) Notice that under the Tcl Command Preview tab, 6 Tcl commands have been generated.
 - (4) Click **Next**.

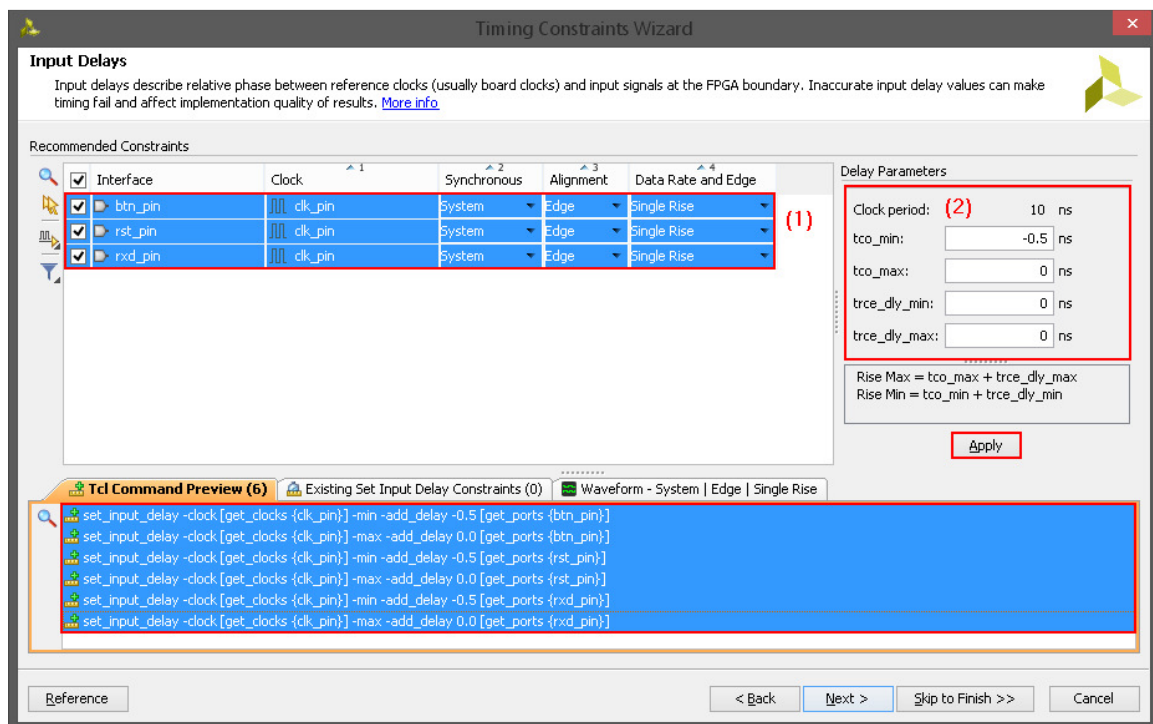


Figure 13. Specifying Input Delays for btn_pin, rst_pin and rxt_pin

- 3-1-10.** For Output Delays, specify all values (tsu, trce_dly_max, thd, trce_dly_min) to be **0 ns**. Click **Apply** and then click **Next**.
- 3-1-11.** There are no Combinatorial Delays identified, click **Next** to proceed.
- 3-1-12.** Click **Skip to Finish** to skip to the final Constraints Summary page. Read the description of each page.
- 3-1-13.** Check **On Finish – View Timing Constraints** and click **Finish** to close the wizard. The option will open the Timing Constraints Editor to show you the generated timing constraint.

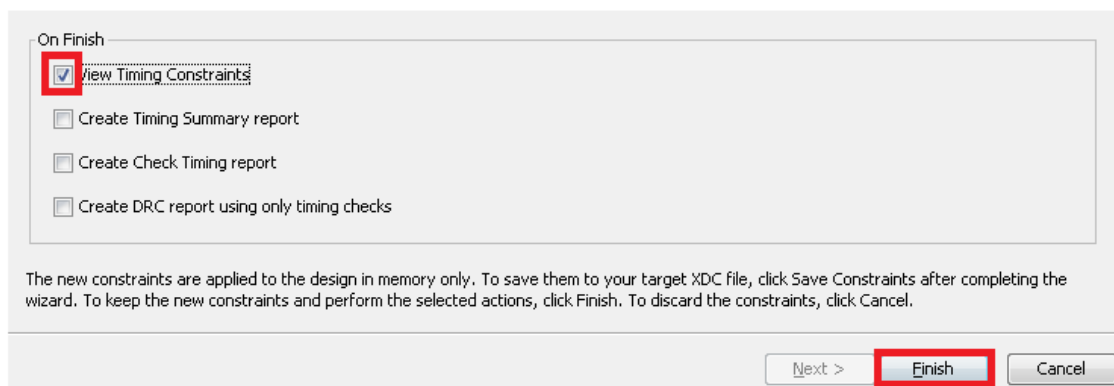


Figure 14. Selecting View Timing constraints

- 3-1-14.** Note the wizard generated the clk_pin constraint for a 10 ns period (or 100 MHz). Notice in the All Constraints window, 9 constraints will be created.

There is no need to click Apply since the constraints have already been applied in the Constraints Wizard.

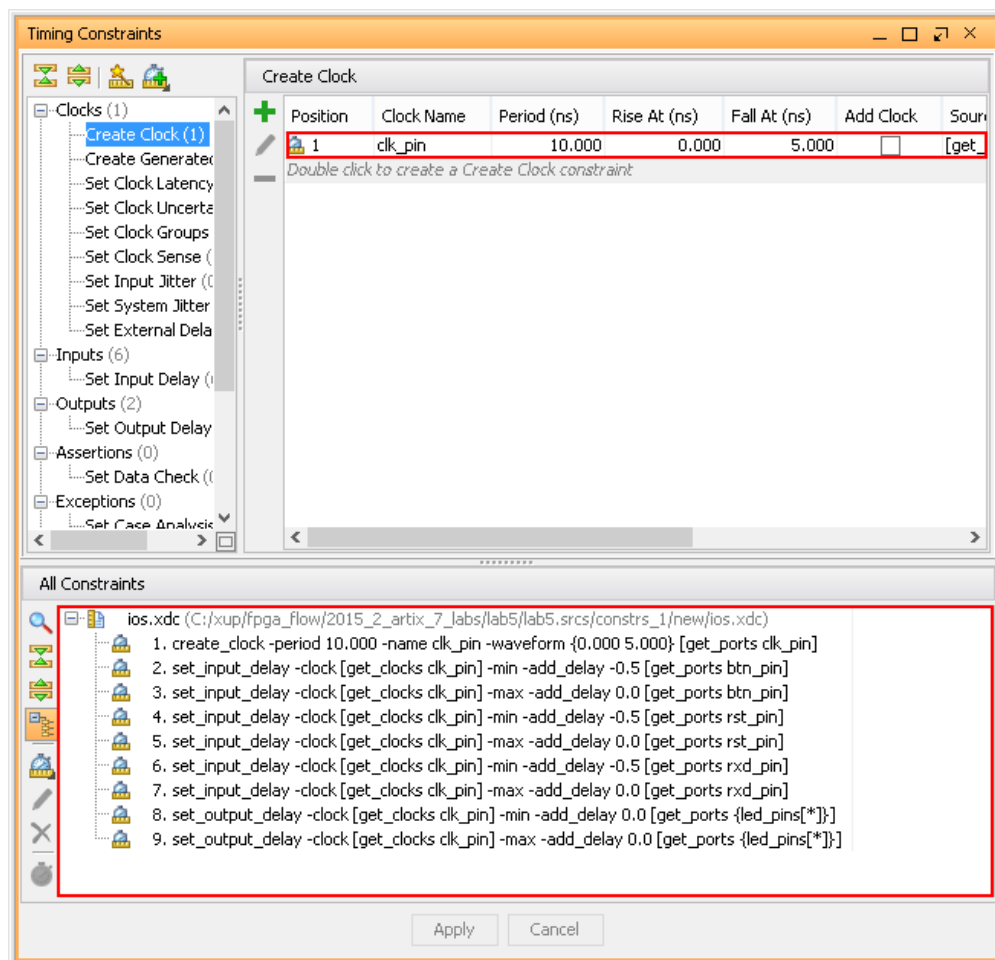


Figure 15. The constraints added after using the Constraints Wizard

3-1-15. Open uart_led.xdc (if it was already opened, click Reload in the yellow status bar) and notice additional constraints were added to the last line of the file.

3-2. Generate an estimated Timing Report showing both the setup and hold paths in the design.

3-2-1. In the Flow Navigator, select **Synthesized Design** > **Report Timing Summary**.

3-2-2. In the Options tab, select **min_max** from the Path delay type drop-down list.

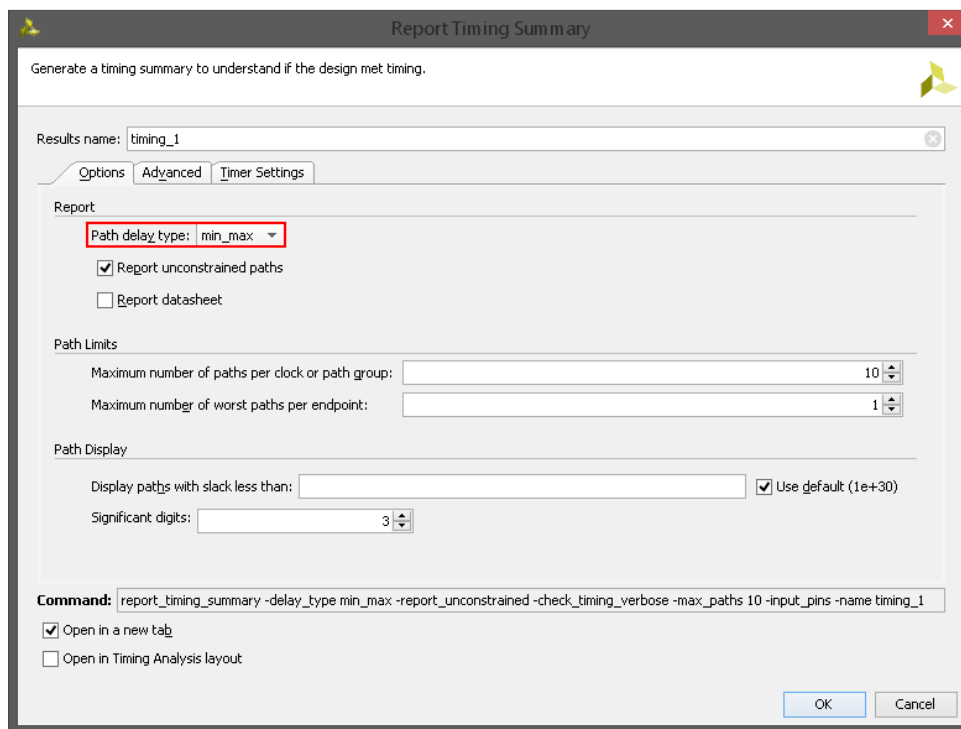


Figure 16. Performing timing analysis

3-2-3. Click **OK** to run the analysis.

The Timing Results view opens at the bottom of the Vivado IDE.

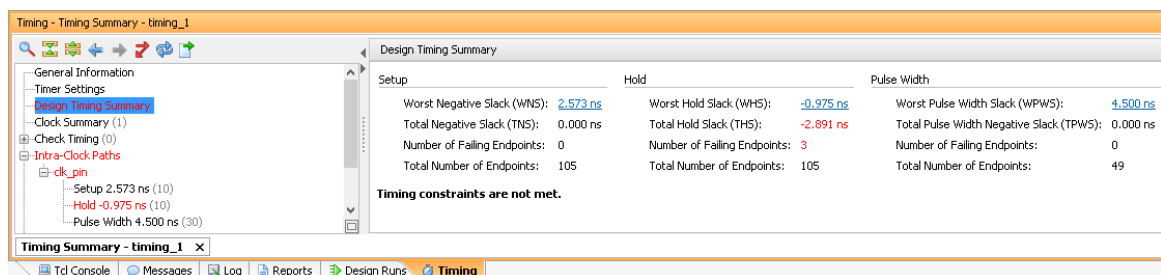


Figure 17. Timing summary for the Nexys4 DDR

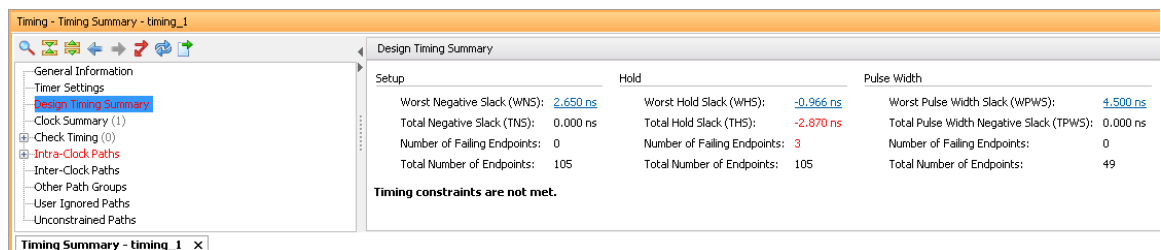


Figure 17. Timing summary for the Basys3

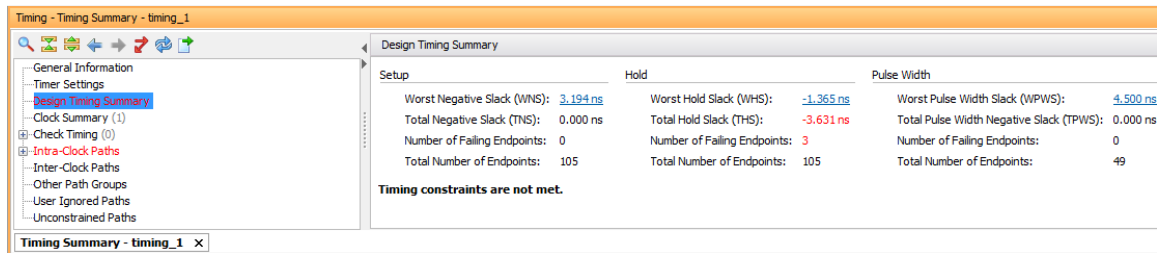


Figure 17. Timing summary for the Nexys Video

The *Design Timing Summary* report provides a brief worst Setup and Hold slack information and Number of failing endpoints to indicate whether the design has met timing or not.

Note that there are three timing failures under the hold check.

3-2-4. Click on the link next to *Worst Hold Slack (WHS)* to see the list of failing paths.

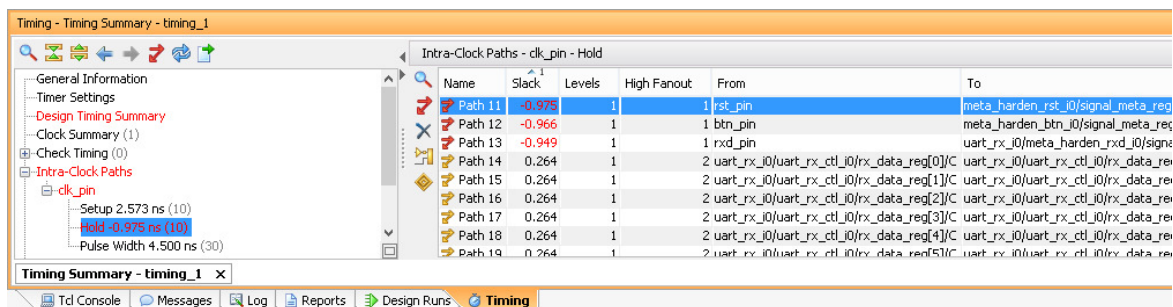


Figure 18. The list of paths showing hold violations for the Nexys4 DDR

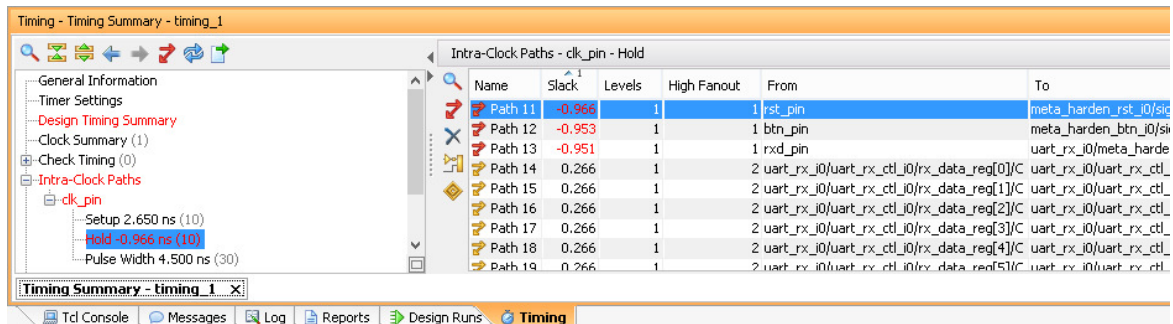


Figure 18. The list of paths showing hold violations for the Basys3

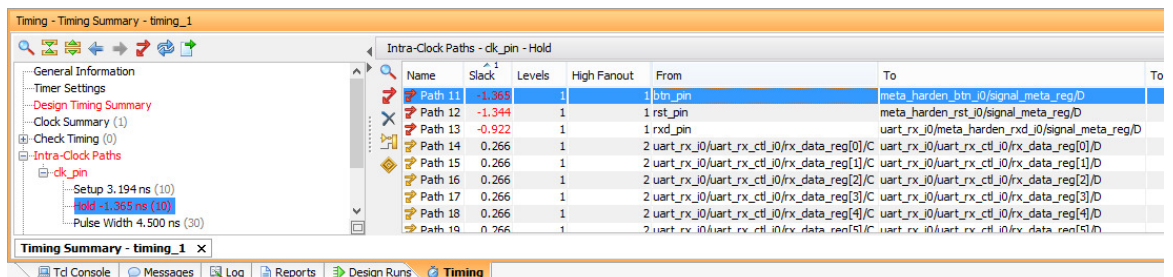


Figure 18. The list of paths showing hold violations for the Nexys Video

3-2-5. Double-click on the Path 11 to see the actual path detail.

Summary

Name	Path 11
Slack (Hold)	-0.975ns
Source	rst_pin (input port clocked by clk_pin {rise@0.000ns fall@5.000ns period=10.000ns})
Destination	meta_harden_rst_i0/signal_meta_reg/D (rising edge-triggered cell FDRE clocked by clk)
Path Group	clk_pin
Path Type	Hold (Min at Slow Process Corner)
Requirement	0.000ns (clk_pin rise@0.000ns - clk_pin rise@0.000ns)
Data Path Delay	2.169ns (logic 1.406ns (64.828%) route 0.763ns (35.172%))
Logic Levels	1 (IBUF=1)
Input Delay	-0.500ns
Clock Path Skew	2.381ns
Clock Uncertainty	0.035ns

Data Path

Delay Type	Incr (ns)	Path (ns)	Location	Netlist Resource(s)
(clock clk_pin rise edge)	(r) 0.000	0.000		
input delay	-0.500	-0.500		
net (fo=0)	(r) 0.000	-0.500	Site: N17	rst_pin
	0.000	-0.500		rst_pin
			Site: N17	rst_pin_IBUF_inst/I
IBUF (Prop_ibuf_I_O)	(r) 1.406	0.906	Site: N17	rst_pin_IBUF_inst/O
net (fo=1, unplaced)	0.763	1.669		meta_harden_rst_i0/rst_pin_IBUF
FDRE				meta_harden_rst_i0/signal_meta_reg/D
Arrival Time		1.669		

Destination Clock Path

Delay Type	Incr (ns)	Path (ns)	Location	Netlist Resource(s)
(clock clk_pin rise edge)	(r) 0.000	0.000		
	(r) 0.000	0.000	Site: E3	clk_pin
net (fo=0)	0.000	0.000		clk_pin
IBUF			Site: E3	clk_pin_IBUF_inst/I
IBUF (Prop_ibuf_I_O)	(r) 1.482	1.482	Site: E3	clk_pin_IBUF_inst/O
net (fo=1, unplaced)	0.000	1.482		clk_pin_IBUF
BUFG				clk_pin_IBUF_BUFG_inst/I
BUFG (Prop_bufg_I_O)	(r) 0.096	1.578		clk_pin_IBUF_BUFG_inst/O
net (fo=48, unplaced)	0.803	2.381		meta_harden_rst_i0/CLK
FDRE				meta_harden_rst_i0/signal_meta_reg/C
clock pessimism	0.000	2.381		
clock uncertainty	0.035	2.416		
EDRE (Hold_fdre_C_D)	0.228	2.644		meta_harden_rst_i0/signal_meta_reg
Required Time		2.644		

Figure 19. Failing hold path for the Nexys4 DDR

Summary

Name	Path 11
Slack (Hold)	-0.966ns
Source	rst_pin (input port clocked by clk_pin {rise@0.000ns fall@5.000ns period=10.000ns})
Destination	meta_harden_rst_i0/signal_meta_reg/D (rising edge-triggered cell FDRE clocked by clk)
Path Group	clk_pin
Path Type	Hold (Min at Slow Process Corner)
Requirement	0.000ns (clk_pin rise@0.000ns - clk_pin rise@0.000ns)
Data Path Delay	2.131ns (logic 1.371ns (64.342%) route 0.760ns (35.658%))
Logic Levels	1 (IBUF=1)
Input Delay	-0.500ns
Clock Path Skew	2.354ns
Clock Uncertainty	0.035ns

Data Path

Delay Type	Incr (ns)	Path (ns)	Location	Netlist Resource(s)
(clock clk_pin rise edge)	(r) 0.000	0.000		
input delay	-0.500	-0.500		
	(r) 0.000	-0.500	Site: U18	rst_pin
net (fo=0)	0.000	-0.500		rst_pin
			Site: U18	rst_pin_IBUF_inst/I
IBUF (Prop_ibuf_I_O)	(r) 1.371	0.871	Site: U18	rst_pin_IBUF_inst/O
net (fo=1, unplaced)	0.760	1.631		meta_harden_rst_i0/rst_pin_IBUF
FDRE				meta_harden_rst_i0/signal_meta_reg/D
Arrival Time		1.631		

Destination Clock Path

Delay Type	Incr (ns)	Path (ns)	Location	Netlist Resource(s)
(clock clk_pin rise edge)	(r) 0.000	0.000		
	(r) 0.000	0.000	Site: W5	clk_pin
net (fo=0)	0.000	0.000		clk_pin
IBUF			Site: W5	clk_pin_IBUF_inst/I
IBUF (Prop_ibuf_I_O)	(r) 1.458	1.458	Site: W5	clk_pin_IBUF_inst/O
net (fo=1, unplaced)	0.000	1.458		clk_pin_IBUF
BUFG				clk_pin_IBUF_BUFG_inst/I
BUFG (Prop_bufg_I_O)	(r) 0.096	1.554		clk_pin_IBUF_BUFG_inst/O
net (fo=48, unplaced)	0.800	2.354		meta_harden_rst_i0/CLK
FDRE				meta_harden_rst_i0/signal_meta_reg/C
clock pessimism	0.000	2.354		
clock uncertainty	0.035	2.390		
EDRE (Hold_fdre_C_D)	0.207	2.597		meta_harden_rst_i0/signal_meta_reg
Required Time		2.597		

Figure 19. Failing hold path for the Basys3

Summary

Name	Path 11
Slack (Hold)	-1.365ns
Source	btn_pin (input port clocked by clk_pin {rise@0.000ns fall@5.000ns period=10.000ns})
Destination	meta_harden_btn_i0/signal_meta_reg/D (rising edge-triggered cell FDRE clocked by clk_pin)
Path Group	clk_pin
Path Type	Hold (Min at Slow Process Corner)
Requirement	0.000ns (clk_pin rise@0.000ns - clk_pin rise@0.000ns)
Data Path Delay	1.748ns (logic 0.988ns (56.528%) route 0.760ns (43.472%))
Logic Levels	1 (IBUF=1)
Input Delay	-0.500ns
Clock Path Skew	2.371ns
Clock Uncertainty	0.035ns

Data Path

Delay Type	Incr (ns)	Path (ns)	Location	Netlist Resource(s)
(clock clk_pin rise edge)	(r) 0.000	0.000		
input delay	-0.500	-0.500		
net (fo=0)	(r) 0.000	-0.500	Site: F15	btn_pin
	0.000	-0.500		btn_pin
			Site: F15	btn_pin_IBUF_inst/I
IBUF (Prop_ibuf_I_O)	(r) 0.988	0.488	Site: F15	btn_pin_IBUF_inst/O
net (fo=1, unplaced)	0.760	1.248		meta_harden_btn_i0/btn_pin_IBUF
FDRE				meta_harden_btn_i0/signal_meta_reg/D
Arrival Time		1.248		

Destination Clock Path

Delay Type	Incr (ns)	Path (ns)	Location	Netlist Resource(s)
(clock clk_pin rise edge)	(r) 0.000	0.000		
	(r) 0.000	0.000	Site: R4	clk_pin
net (fo=0)	0.000	0.000		clk_pin
IBUF			Site: R4	clk_pin_IBUF_inst/I
IBUF (Prop_ibuf_I_O)	(r) 1.475	1.475	Site: R4	clk_pin_IBUF_inst/O
net (fo=1, unplaced)	0.000	1.475		clk_pin_IBUF
BUFG				clk_pin_IBUF_BUFG_inst/I
BUFG (Prop_bufg_I_O)	(r) 0.096	1.571		clk_pin_IBUF_BUFG_inst/O
net (fo=48, unplaced)	0.800	2.371		meta_harden_btn_i0/CLK
FDRE				meta_harden_btn_i0/signal_meta_reg/C
clock pessimism	0.000	2.371		
clock uncertainty	0.035	2.406		
FDRE (Hold_fdre_C_D)	0.207	2.613		meta_harden_btn_i0/signal_meta_reg
Required Time		2.613		

Figure 19. Failing hold path for the Nexys Video

3-2-6. Select Path11, right-click and select Schematic.

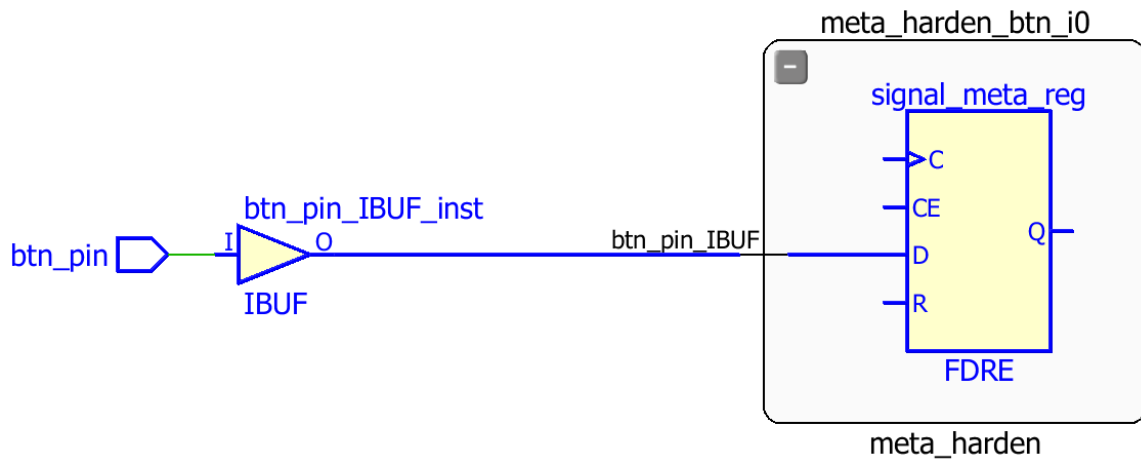


Figure 20. The schematic of the failing path

The three failing paths are of the btn_pin, rxd_pin and rst_pin.

Implement and Analyze Timing Summary

Step 4

4-1. Implement the design.

4-1-1. Click on the **Run Implementation** in the *Flow Navigator* pane.

4-1-2. Click **Yes** to run the synthesis first before running the implementation process.

When the implementation is completed, a dialog box will appear with three options.

4-1-3. Select the *Open Implemented Design* option and click **OK**.

4-1-4. Click **Yes** if you are prompted to close the synthesized design.

4-2. Generate a timing summary report.

4-2-1. In the Flow Navigator, under Implementation > Implemented Design, click **Report Timing Summary**.

4-2-2. Click **OK** to generate the report using the default settings.

The Design Timing Summary window opens at the bottom in the Timing tab.

Note that failing timing paths are indicated in red.

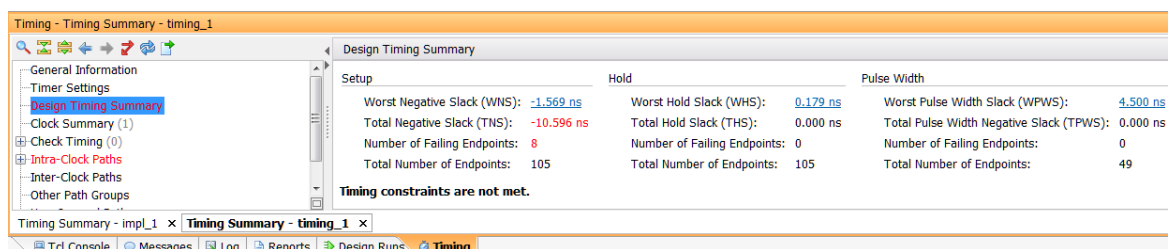


Figure 21. Failing setup paths for the Nexys4 DDR

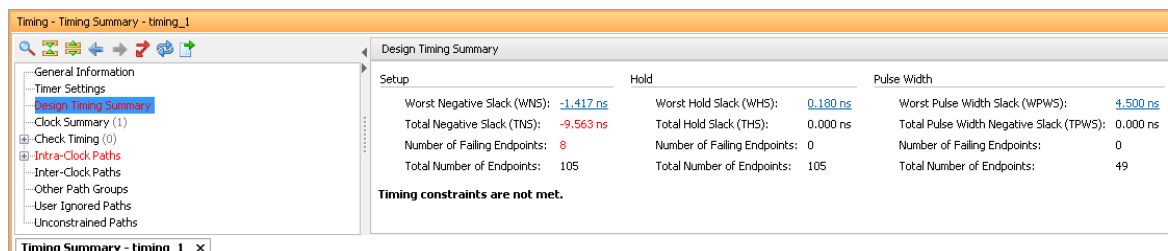


Figure 21. Failing setup paths for the Basys3

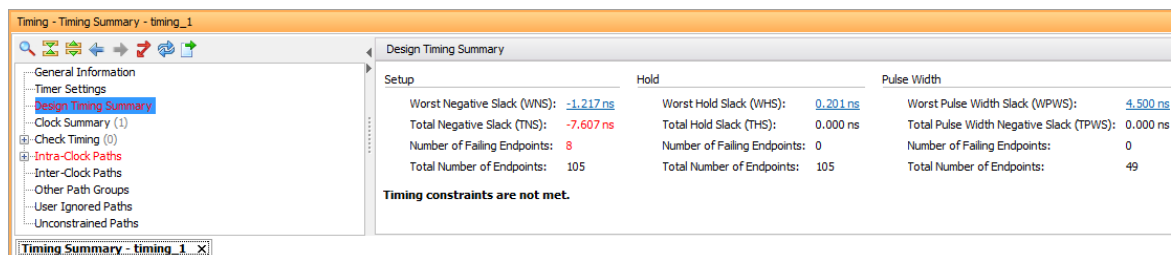


Figure 21. Failing setup paths for the Nexys Video

- 4-2-3. Click on the WNS to see the failing paths.
- 4-2-4. Double-click on the first failing path from the top and see the detailed analysis.
The output path delay can be reduced by placing the register in IOB.
- 4-2-5. Apply the constraint by typing the following command in the Tcl console.

```
set_property IOB TRUE [get_ports led_pins[*]]
```
- 4-2-6. Select **File > Save Constraints**. Click **OK** at the warning message. Click **Yes** to save the project.
- 4-2-7. Click on **Run Implementation**.
- 4-2-8. Click **Yes** to reset the synthesis run, perform the synthesis, and run implementation.
- 4-2-9. Open the implemented design and observe that the number of failing paths in the Design Runs tab reported is 0.
- 4-2-10. Click **Report Timing Summary**, and observe that there are no failing paths.

Generate the Bitstream and Verify the Functionality (Optional) Step 5

5-1. Generate the bitstream.

- 5-1-1. In the Flow Navigator, under *Program and Debug*, click **Generate Bitstream**.
- 5-1-2. The `write_bitstream` command will be executed (you can verify it by looking in the Tcl console).
- 5-1-3. Click **Cancel** when the bitstream generation is completed.

5-2. Connect the board and power it ON. Open a hardware session, and program the FPGA.

- 5-2-1. Make sure that the Micro-USB cable is connected to the JTAG PROG connector (next to the power supply connector). Make sure that the board is set to select USB power (JP3 on the Nexys4 DDR and JP2 on the Basys3).
- 5-2-2. Turn ON the power.
- 5-2-3. Select the *Open Hardware Manager* option.
The Hardware Manager window will open indicating “unconnected” status.
- 5-2-4. Click on the **Open target** link, then **Auto Connect** from the dropdown menu.
You can also click on the **Open recent target** link if the board was already targeted before.
- 5-2-5. The Hardware Manager status changes from Unconnected to the server name and the device is highlighted. Also notice that the Status indicates that it is not programmed.
- 5-2-6. Select the device and verify that the `uart_led.bit` is selected as the programming file in the General tab.

5-3. Start a terminal emulator program such as TeraTerm or HyperTerminal. Select an appropriate COM port (you can find the correct COM number using the Control Panel). Set the COM port for 115200 baud rate communication. Program the FPGA and verify the functionality.

- 5-3-1. Start a terminal emulator program such as TeraTerm or HyperTerminal.
- 5-3-2. Select an appropriate COM port (you can find the correct COM number using the Control Panel).
- 5-3-3. Set the COM port for 115200 baud rate communication.
- 5-3-4. Right-click on the FPGA entry in the Hardware window and select Programming Device...
- 5-3-5. Click on the **Program** button.

The programming bit file be downloaded and the DONE light will be turned ON indicating the FPGA has been programmed.

- 5-3-6.** Verify the functionality as you did in the previous lab, by typing some characters into the terminal, and watching the corresponding values appear on the LEDs.
- 5-3-7.** When satisfied, close the terminal emulator program and power OFF the board.
- 5-3-8.** Select **File > Close Hardware Manager**. Click **OK** to close it.
- 5-3-9.** When done, close the **Vivado** program by selecting **File > Exit** and click **OK**.

Conclusion

In this lab, you learned how to create an I/O Planning project and assign the pins via the Device view, Package Pins tab, and the Tcl commands. You then exported to the rtl project where you added the provided source files. Next you created timing constraints and performed post-synthesis and post-implementation timing analysis.