

CMPS 375
Computer Architecture
Lab1: Adder1 (1-bit Adder)
Introduction to the Nexys4 DDR Package (VIVADO 2019.2)

Objectives

The purpose of this lab is to learn the basics of the VIVADO software and the Xilinx Nexys4 DDR FPGA board as shown in Figure 1. After completing this exercise, you will be able to:

- Create a Vivado project sourcing VHDL models and targeting a specific FPGA device located on the Nexys4 DDR board
- Understand the design circuit writing in VHDL hardware description language and its schematic
- Use the provided user constraint file (XDC) to constrain pin locations
- Simulate the design using the XSIM simulator
- Synthesize and implement the design
- Generate the bitstream
- Program and download the design to the FPGA device on the Nexys4 DDR board
- Test and verify the functionality of the designed circuit on the Nexys4 DDR board

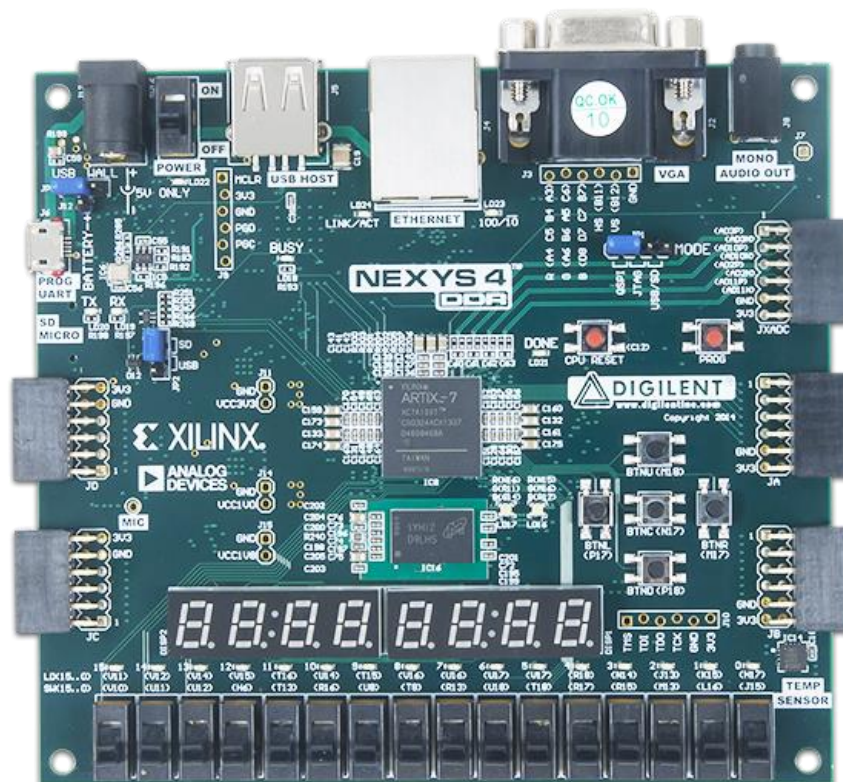


Figure 1. Xilinx Nexys4 DDR Board: Artix-7 FPGA (XC7A100TCSG324-1)

Problem Description

You are required to create a 1-bit adder in in VHDL language. Like Figure 3.21 in textbook, this 1-bit adder can perform a binary addition using switches as inputs and LEDs as outputs on the Nexys4 DDR board.

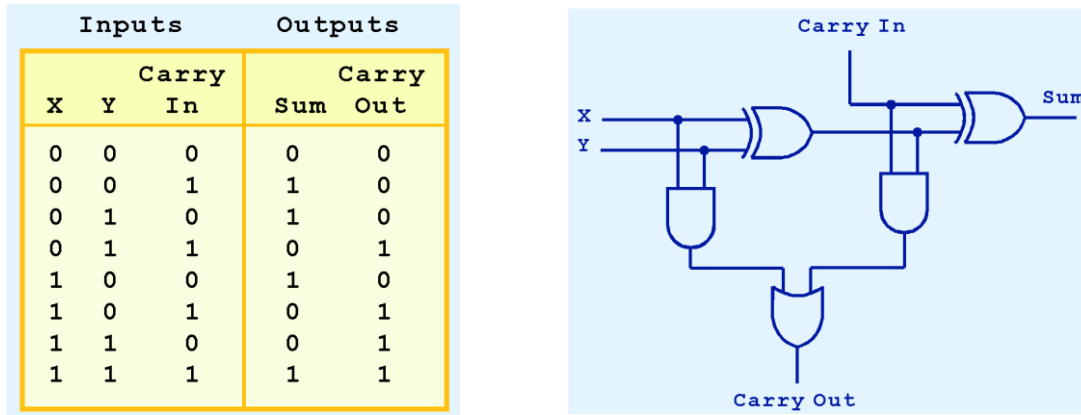


FIGURE 3.21 The Truth Table and The Logic Diagram for a Full-Adder

Note that this full-adder is composed of two half-adder;
 $\text{CarryOut} = XY + (X \text{ xor } Y) \text{ CarryIn};$ $\text{Sum} = X \text{ xor } Y \text{ xor } \text{CarryIn};$

Lab Attachment

- CMPS375Lab1.zip consists of 4 files:
 1. Current document (CMPS375Lab1.pdf)
 2. VHDL design file (Adder1.vhd)
 3. VHDL Test Bench simulation file (Adder1_tb.vhd)
 4. I/O Constraints (Adder1.xdc)

Lab Submission

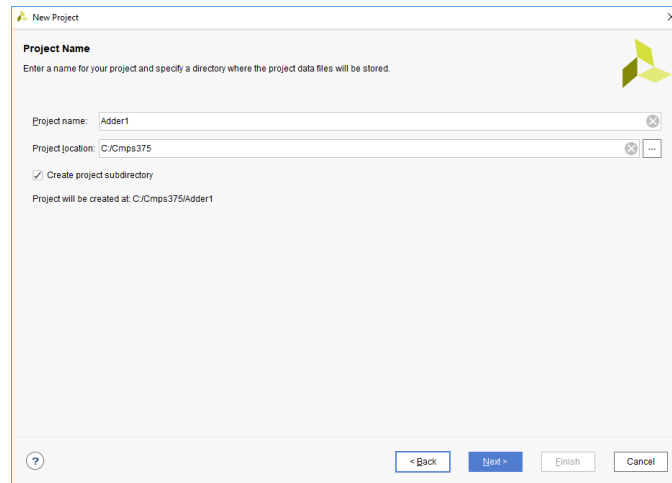
- Zip the **entire** Adder1 project folder including its sub-folders into a single file name Adder1.zip
- Check the following 3 files under Adder1 sub-folders before your submission
 1. **Adder1.vhd** under Adder1/Adder1.srscs/sources_1/imports/CMPS375Lab1 folder
 2. **Adder1_tb.vhd** under Adder1/Adder1.srscs/sim_1/imports/CMPS375Lab1 folder
 3. **Adder1.xdc** under Adder1/Adder1.srscs/constrs_1/imports/CMPS375Lab1 folder
- Submit **Adder1.zip** to Moodle as your lab1.

Note: Perform binary addition using toggle switches as the inputs and LEDs as the outputs on the Nexys4 DDR board.

<i>Scalar Ports</i>	<i>Direction</i>	<i>Package Pin</i>	<i>Name</i>
a	IN	M13	SW[2]
b	IN	L16	SW[1]
cIn	IN	J15	SW[0]
cOut	OUT	K15	LED[1]
sum	OUT	H17	LED[0]

A 1-bit Adder in VHDL Language

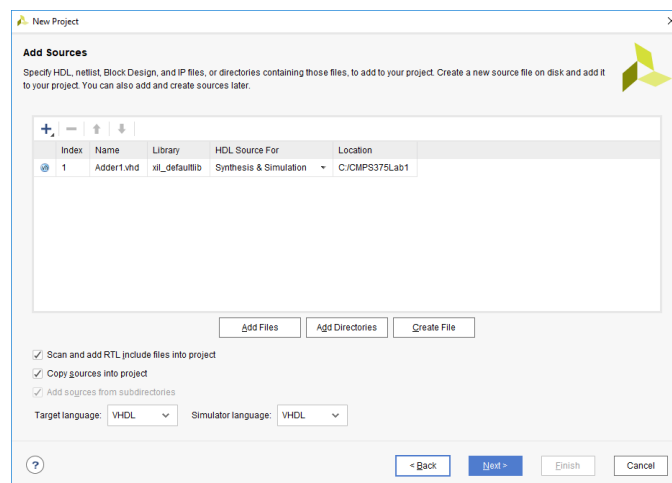
1. Create a Vivado project: Adder1
 - a. Click the *File* menu and then the *New Project* item to start the wizard.
 - b. In the *New Project* form as shown in Figure 3, enter **Adder1** in the *Project name* field and select **C:/Cmps375** in the *Project location*.
 - c. Make sure the *Create Project Subdirectory* box is checked. Click *Next*.



The 'New Project' dialog box in Vivado. It has a title bar 'New Project' with a close button. Below the title bar is the 'Project Name' section with the instruction 'Enter a name for your project and specify a directory where the project data files will be stored.' There are two input fields: 'Project name' with the text 'Adder1' and 'Project location' with the text 'C:/Cmps375'. Below these fields is a checkbox labeled 'Create project subdirectory' which is checked. Underneath the checkbox, it says 'Project will be created at: C:/Cmps375/Adder1'. At the bottom right, there are four buttons: '< Back', 'Next >', 'Finish', and 'Cancel'.

Figure 3. Project Name and Location

- d. In the *Project Type* form, select the *RTL Project* option, and click *Next*.
 - e. In the *Add Sources* form as shown in Figure 4, click the *Add File* button, then browse directory, select **Adder1.vhd**.
 - f. Verify the *Copy Constraints files into projects* box is checked. Select **VHDL** as the *Target Language* and as the *Simulator language*. Then, click *Next*.



The 'Add Sources' dialog box in Vivado. It has a title bar 'New Project' with a close button. Below the title bar is the 'Add Sources' section with the instruction 'Specify HDL, netlist, Block Design, and IP files, or directories containing those files, to add to your project. Create a new source file on disk and add it to your project. You can also add and create sources later.' There is a table with the following columns: Index, Name, Library, HDL Source For, and Location. The table contains one row: Index 1, Name 'Adder1.vhd', Library 'xilinx_defaultlib', HDL Source For 'Synthesis & Simulation', and Location 'C:/CMPS375Lab1'. Below the table are three buttons: 'Add Files', 'Add Directories', and 'Create File'. Below these buttons are three checkboxes: 'Scan and add RTL include files into project' (checked), 'Copy sources into project' (checked), and 'Add sources from subdirectories' (checked). At the bottom, there are two dropdown menus: 'Target language' set to 'VHDL' and 'Simulator language' set to 'VHDL'. At the bottom right, there are four buttons: '< Back', 'Next >', 'Finish', and 'Cancel'.

Figure 4. Add Source Form

- g. In the *Add Constraints* form as shown in Figure 5, click the *Add File* button, then browse directory, select **Adder1.xdc**.
- h. Verify the *Copy Constraints files into projects* box is checked. Then, click *Next*.

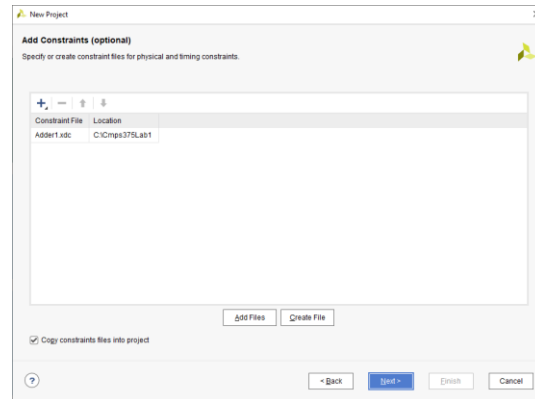


Figure 5. Add Constraints Form

- i. In the *Default Part* form as shown in Figure 6, select device Artix-7 FPGA **XC7A100TCSG324-1**. Then click *Next*.

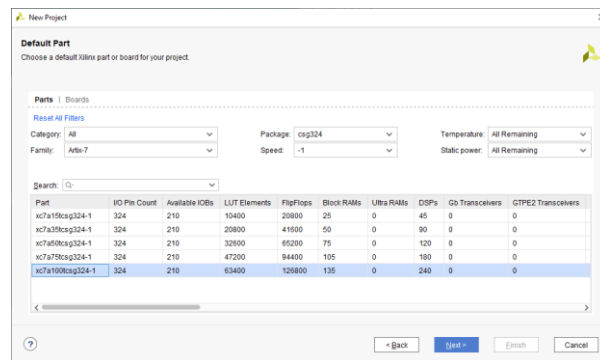


Figure 6. Default Part Form

- j. In the *New Project Summary* as shown in Figure 7, click *Finish* to create the project.

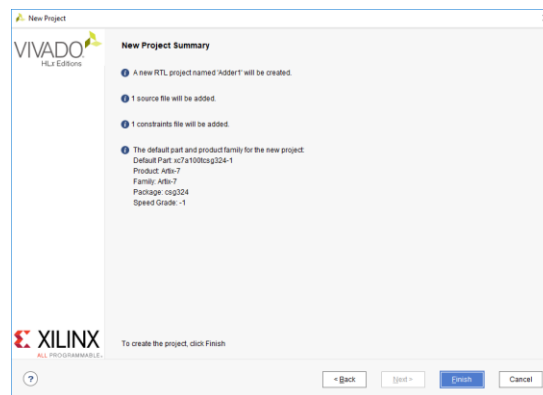


Figure 7. New Project Summary Form

2. Write VHDL code for the design circuit and view its schematic entry
 - a. In the *Sources* pane as shown in Figure 8, double-click the Adder1.vhd entry to open the file in the text mode. The file contents of **Adder1.vhd** are shown in Figure 9.

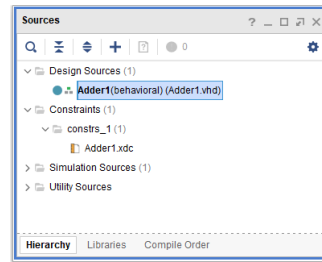


Figure 8. Sources Pane

- b. **Add** your team's and members' names as Authors.
- c. **Insert** two lines (one for cOut and the other for sum) of VHDL code.

```

-----
-- Description:    1-bit Adder
-- Project:        Adder1
-- Program-ID:     Adder1.vhd
-- Authors:        -- Add your team's and members' names as Authors Here
-- Package:        Xilinx Nexys4 DDR Board
-- Device:         Artix-7 FPGA (XC7A100TCSG324-1)
-- Software:       Vivado Design Suite
-----

LIBRARY IEEE;
USE IEEE.STD_LOGIC_1164.ALL;

ENTITY Adder1 IS
    PORT (
        a, b, cIn : IN std_logic;
        cOut, sum : OUT std_logic);
END Adder1;

ARCHITECTURE behavioral OF Adder1 IS
BEGIN

    -- Insert two lines (one for cOut and the other for sum) of VHDL code Here

END behavioral;
  
```

Figure 9. VHDL code for Adder1 Design Circuit: Adder1.vhd

- d. In the *Flow Navigator* pane, click the *Open Elaborated Design* entry under the *RTL ANALYSIS* to perform RTL (Register-Transfer Level) analysis on the source file. Click the *Schematic* to see a logic view of the design as shown in Figure 10.

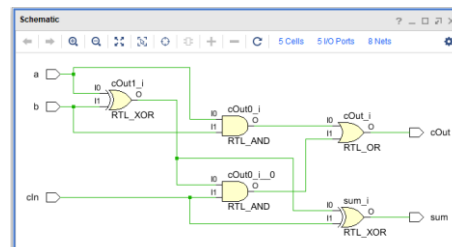


Figure 10. Schematic of Adder1: 1-bit Adder

3. Use the provided user constraint file (XDC) to constrain pin locations
 - a. In the *Sources* pane, double-click **Adder1.xdc** entry under *Constraints* to open the file in the text mode. The file contents of **Adder1.xdc** shown in Figure 11.
 - b. **Edit** the port names for the designed model, **Adder1.vhd**.

```

11: ##Switches
12:
13: #set_property -dict { PACKAGE_PIN 115 IOSTANDARD LVCMOS33 } [get_ports { SW[0] }]; #10_L24M_T3_R20_15 Schew[0]
14: #set_property -dict { PACKAGE_PIN 116 IOSTANDARD LVCMOS33 } [get_ports { SW[1] }]; #10_L3N_T0_D05_BWCCLK_14 Schew[1]
15: #set_property -dict { PACKAGE_PIN M13 IOSTANDARD LVCMOS33 } [get_ports { SW[2] }]; #10_L6N_T0_D05_YREF_14 Schew[2]
16: #set_property -dict { PACKAGE_PIN R15 IOSTANDARD LVCMOS33 } [get_ports { SW[3] }]; #10_L13N_T2_M00C_14 Schew[3]
17: #set_property -dict { PACKAGE_PIN R17 IOSTANDARD LVCMOS33 } [get_ports { SW[4] }]; #10_L12N_T1_M00C_14 Schew[4]
18: #set_property -dict { PACKAGE_PIN T10 IOSTANDARD LVCMOS33 } [get_ports { SW[5] }]; #10_L17N_T1_D10_14 Schew[5]
19: #set_property -dict { PACKAGE_PIN U10 IOSTANDARD LVCMOS33 } [get_ports { SW[6] }]; #10_L17N_T2_A13_D09_14 Schew[6]
20: #set_property -dict { PACKAGE_PIN R13 IOSTANDARD LVCMOS33 } [get_ports { SW[7] }]; #10_L5N_T0_D07_14 Schew[7]
21: #set_property -dict { PACKAGE_PIN T0 IOSTANDARD LVCMOS33 } [get_ports { SW[8] }]; #10_L24M_T3_34 Schew[8]
22: #set_property -dict { PACKAGE_PIN T0 IOSTANDARD LVCMOS33 } [get_ports { SW[9] }]; #10_25_34 Schew[9]
23: #set_property -dict { PACKAGE_PIN R16 IOSTANDARD LVCMOS33 } [get_ports { SW[10] }]; #10_L15P_T2_D05_K0W_14 Schew[10]
24: #set_property -dict { PACKAGE_PIN T13 IOSTANDARD LVCMOS33 } [get_ports { SW[11] }]; #10_L21P_T3_A03_D19_14 Schew[11]
25: #set_property -dict { PACKAGE_PIN H6 IOSTANDARD LVCMOS33 } [get_ports { SW[12] }]; #10_L24P_T3_35 Schew[12]
26: #set_property -dict { PACKAGE_PIN U12 IOSTANDARD LVCMOS33 } [get_ports { SW[13] }]; #10_L20P_T3_A08_D24_14 Schew[13]
27: #set_property -dict { PACKAGE_PIN U11 IOSTANDARD LVCMOS33 } [get_ports { SW[14] }]; #10_L19N_T2_A09_D25_YREF_14 Schew[14]
28: #set_property -dict { PACKAGE_PIN V10 IOSTANDARD LVCMOS33 } [get_ports { SW[15] }]; #10_L21P_T3_D05_14 Schew[15]
29:
30:
31: ## LEDs
32:
33: #set_property -dict { PACKAGE_PIN H17 IOSTANDARD LVCMOS33 } [get_ports { LED[0] }]; #10_L10P_T2_A24_15 Sch-led[0]
34: #set_property -dict { PACKAGE_PIN R25 IOSTANDARD LVCMOS33 } [get_ports { LED[1] }]; #10_L24P_T3_R21_15 Sch-led[1]
35: #set_property -dict { PACKAGE_PIN T13 IOSTANDARD LVCMOS33 } [get_ports { LED[2] }]; #10_L17M_T2_A25_15 Sch-led[2]
36: #set_property -dict { PACKAGE_PIN N14 IOSTANDARD LVCMOS33 } [get_ports { LED[3] }]; #10_L8P_T1_D11_14 Sch-led[3]
37: #set_property -dict { PACKAGE_PIN R10 IOSTANDARD LVCMOS33 } [get_ports { LED[4] }]; #10_L7P_T1_D09_14 Sch-led[4]
38: #set_property -dict { PACKAGE_PIN V17 IOSTANDARD LVCMOS33 } [get_ports { LED[5] }]; #10_L18N_T2_A11_D27_14 Sch-led[5]
39: #set_property -dict { PACKAGE_PIN U17 IOSTANDARD LVCMOS33 } [get_ports { LED[6] }]; #10_L17P_T2_A14_D30_14 Sch-led[6]
40: #set_property -dict { PACKAGE_PIN U16 IOSTANDARD LVCMOS33 } [get_ports { LED[7] }]; #10_L18P_T2_A12_D28_14 Sch-led[7]
41: #set_property -dict { PACKAGE_PIN V16 IOSTANDARD LVCMOS33 } [get_ports { LED[8] }]; #10_L16N_T2_A15_D31_14 Sch-led[8]
42: #set_property -dict { PACKAGE_PIN T15 IOSTANDARD LVCMOS33 } [get_ports { LED[9] }]; #10_L14N_T2_S00C_14 Sch-led[9]
43: #set_property -dict { PACKAGE_PIN U14 IOSTANDARD LVCMOS33 } [get_ports { LED[10] }]; #10_L22P_T3_A05_D21_14 Sch-led[10]
44: #set_property -dict { PACKAGE_PIN T16 IOSTANDARD LVCMOS33 } [get_ports { LED[11] }]; #10_L15N_T2_D05_D07F_C30_D_14 Sch-led[11]
45: #set_property -dict { PACKAGE_PIN V15 IOSTANDARD LVCMOS33 } [get_ports { LED[12] }]; #10_L16P_T3_C31_B_14 Sch-led[12]
46: #set_property -dict { PACKAGE_PIN V14 IOSTANDARD LVCMOS33 } [get_ports { LED[13] }]; #10_L22N_T3_A04_D20_14 Sch-led[13]
47: #set_property -dict { PACKAGE_PIN V12 IOSTANDARD LVCMOS33 } [get_ports { LED[14] }]; #10_L20N_T3_A07_D23_14 Sch-led[14]
48: #set_property -dict { PACKAGE_PIN V11 IOSTANDARD LVCMOS33 } [get_ports { LED[15] }]; #10_L21N_T3_D05_D22_14 Sch-led[15]
49:
50:

```

Figure 11. Editing I/O Constraints: **Adder1.xdc**

- c. Click the *I/O Panning* under the *Layout* menu. Notice that once RTL analysis is performed, I/O Planning layout is available. In Figure 12, the design ports (a, b, cIn, cOut, and sum) are listed in the *I/O Ports* tab of the *Console View* area.

Name	Direction	Neg Diff Pair	Package Pin	Fixed	Bank	I/O Std	Vcc	Vr
All ports (5)								
Scalar ports (5)								
a	IN		M13	✓	14	LVCMOS33*	3.300	
b	IN		L16	✓	14	LVCMOS33*	3.300	
cIn	IN		J15	✓	15	LVCMOS33*	3.300	
cOut	OUT		K15	✓	15	LVCMOS33*	3.300	
sum	OUT		H17	✓	15	LVCMOS33*	3.300	

Figure 12. I/O Ports in Console View: a, b, cIn, cOut, and sum

4. Simulate the design using the XSim Simulator
 - a. In the *PROJECT MANAGER* tasks of the *Flow Navigator* pane, click the *Add Sources*, select the *Add or Create Simulation Sources* option as shown in Figure 13, and click *Next*.

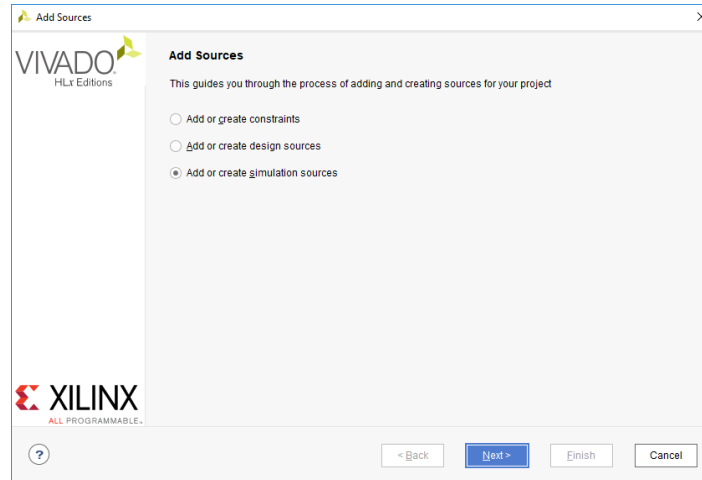


Figure 13. Selecting Simulation Sources option

- b. In the *Add or Create Simulation Sources* form as shown in Figure 14, click the *Add File* button, then browse directory, select **Adder1_tb.vhd**. Then, click *Finish*.

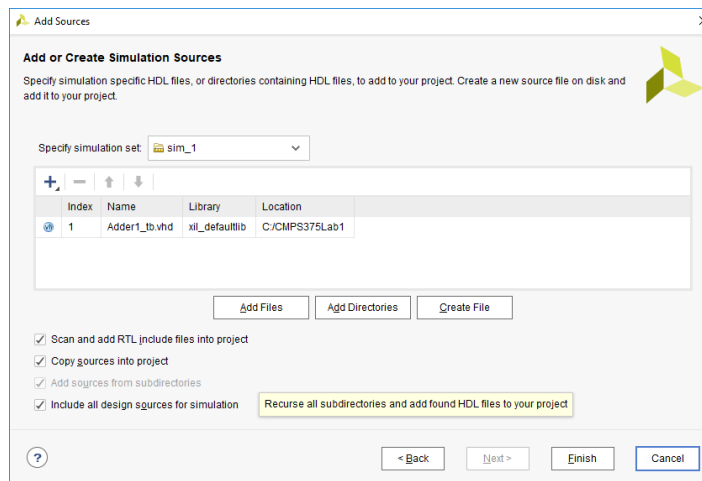


Figure 14. Add Simulation Sources: Adder1_tb.vhd

- c. In the *Sources* pane, double-click the Adder1_tb.vhd entry to open the file in the text mode. The file contents of **Adder1_tb.vhd** are shown in Figure 15.
- d. Do **not** change this simulation file!

```

-----
-- Description:    1-bit Adder (Test Bench)
-- Project:       Adder1
-- Program-ID:    Adder1_tb.vhd
-- Author:       Kuo-pao Yang
-- Package:      Xilinx Nexys4 DDR Board
-- Device:       Artix-7 FPGA (XC7A100TCSG324-1)
-- Software:     Vivado Design Suite
-- Notes:        1. ENTITY: No code (empty)
--               2. ARCHITECTURE: Put simulation code under PROCESS
-----

```

```

LIBRARY IEEE;
USE IEEE.STD_LOGIC_1164.ALL;

ENTITY Adder1_tb IS
END Adder1_tb;

ARCHITECTURE simulate OF Adder1_tb IS
    COMPONENT Adder1
        PORT (
            a, b, cIn : IN std_logic;
            cOut, sum : OUT std_logic);
        END COMPONENT;
    SIGNAL a, b, cIn: STD_LOGIC;
    SIGNAL cOut, sum: STD_LOGIC;
BEGIN
    uut: Adder1 PORT MAP (a, b, cIn, cOut, sum);

    stimulus: PROCESS
    BEGIN
        -- test bench stimulus code
        a    <= '0';    b    <= '0';    cIn <= '0';
        WAIT FOR 100 ns;
        a    <= '0';    b    <= '0';    cIn <= '1';
        WAIT FOR 100 ns;
        a    <= '0';    b    <= '1';    cIn <= '0';
        WAIT FOR 100 ns;
        a    <= '0';    b    <= '1';    cIn <= '1';
        WAIT FOR 100 ns;
        a    <= '1';    b    <= '0';    cIn <= '0';
        WAIT FOR 100 ns;
        a    <= '1';    b    <= '0';    cIn <= '1';
        WAIT FOR 100 ns;
        a    <= '1';    b    <= '1';    cIn <= '0';
        WAIT FOR 100 ns;
        a    <= '1';    b    <= '1';    cIn <= '1';
        WAIT FOR 100 ns;
        a    <= '0';    b    <= '0';    cIn <= '0';

        WAIT;
    END PROCESS;
END simulate;

```

Figure 15. VHDL code for Adder1 Test Bench Simulation File: [Adder1_tb.vhd](#)

- e. Simulate the design for 1000 ns using the XSIM simulator. Click the *Settings* entry under the *PROJECT MANAGER* tasks of the *Flow Navigator* pane, select the *Simulation* tab, and change the simulation time to **1000 ns** as shown in Figure 16.

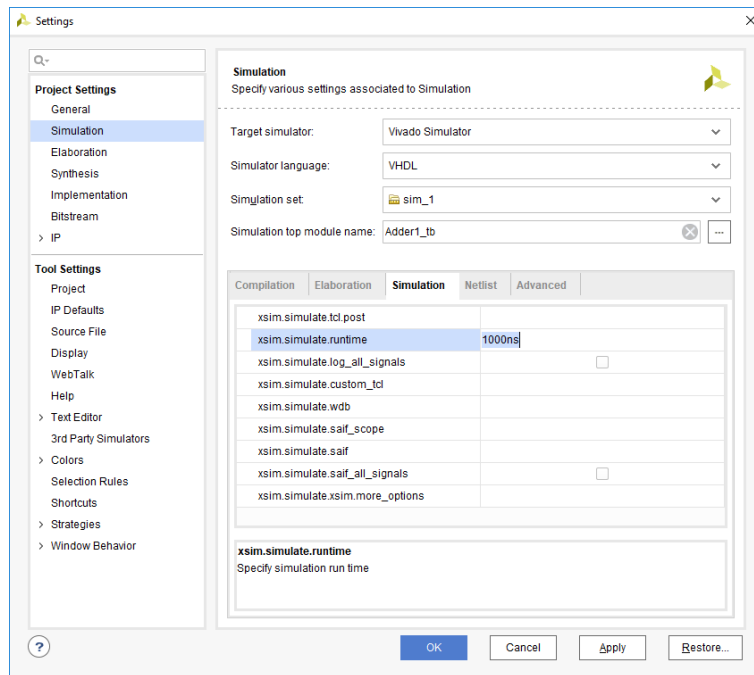


Figure 16. Simulate the Design for 1000 ns

- f. Click the *Run Simulation* under the *SIMULATION* task of the *Flow Navigator* pane. Select the **Run Behavioral Simulation** option. The simulation results are shown in Figure 17.

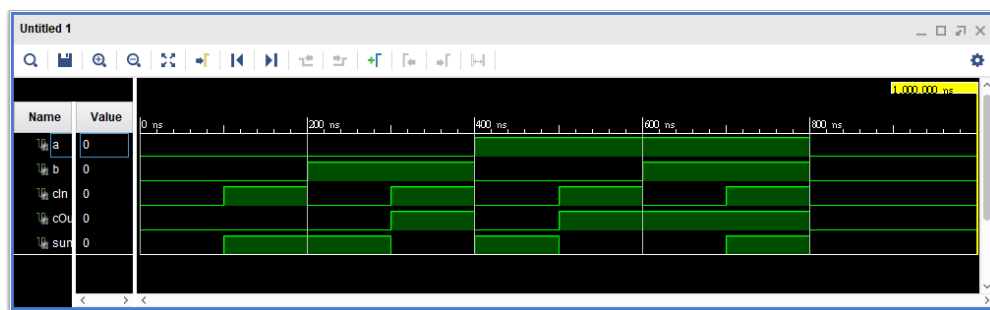


Figure 17. Simulation Results: Adder1_tb.vhd

5. Synthesize and implement the design
 - a. Click the *Run Synthesis* under the *SYNTHESIS* tasks of the *Flow Navigator* pane. Note that: Vivado synthesis is the process of transforming an RTL-specified design into a gate-level representation. This synthesis is **timing-driven** and optimized for memory usage and performance.
 - b. Click the *Run Implementation* under the *IMPLEMENTATION* tasks of the *Flow Navigator* pane. Note that: Vivado implementation includes all steps necessary to place and route the netlist onto **device** resources, within the logical, physical, and timing constraints of the design.
6. Generate the bitstream
 - a. Click the *Generate Bitstream* entry under the *PROGRAM AND DEBUG* tasks of the *Flow Navigator* pane.
7. Program and download the design to the FPGA device
 - a. Make sure the Micro-USB cable is connected between the board and the PC. Power *ON* the switch on the board. Note that it does **not** need to connect the power jack and the board.
 - b. Click the *Open Target* of the *Hardware Manager* entry under the *PROGRAM AND DEBUG* tasks of the *Flow Navigator* pane, and then select the *Auto Connect*.
 - c. Click the *Program Device* of the *Hardware Manager* entry under the *PROGRAM AND DEBUG* tasks of the *Flow Navigator* pane, and then select **xc7a100t_0**.
 - d. Make sure the *Bitstream file* of *Program Device* form is **Adder1.bit** as shown in Figure 18. Then, click the **Program** to program the FPGA. Note that: the *DONE* light on the board will light when the device is programmed.

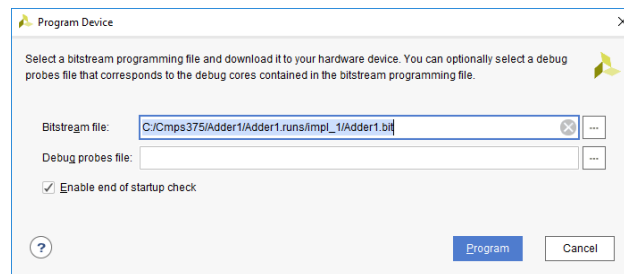


Figure 18. Bitstream for Nexys4 DDR: Adder1.bit

8. Test and verify functionality of the designed circuit
 - a. Verify the functionality by flipping switches and observing the output on the LEDs.

<i>Scalar Ports</i>	<i>Direction</i>	<i>Package Pin</i>	<i>Name</i>
a	IN	M13	SW[2]
b	IN	L16	SW[1]
cIn	IN	J15	SW[0]
cOut	OUT	K15	LED[1]
sum	OUT	H17	LED[0]