Laboratory Exercise 4

Counters

The purpose of this exercise is to build and use counters. The designed circuits are to be implemented on an Intel® FPGA DE10-Lite, DE0-CV, DE1-SoC, or DE2-115 Board.

Students are expected to have a basic understanding of counters and sufficient familiarity with the Verilog hardware description language to implement various types of latches and flip-flops.

Part I

Consider the circuit in Figure 1. It is a 4-bit synchronous counter which uses four T-type flip-flops. The counter increments its value on each positive edge of the clock signal if the *Enable* signal is high. The counter is reset to 0 on the next positive clock edge if the synchronous *Clear* input is low. You are to implement an 8-bit counter of this type.

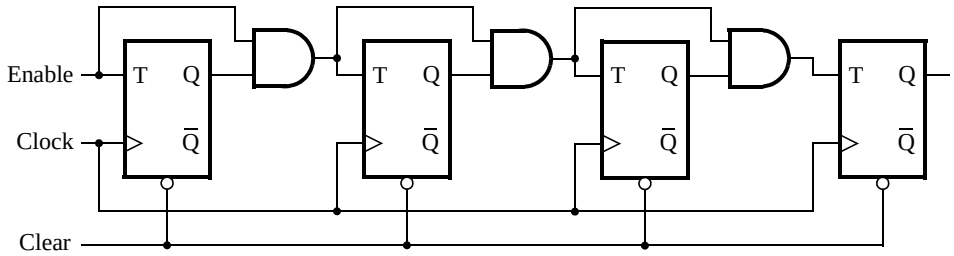

Figure 1: A 4-bit counter.

1. Write a Verilog file that defines an 8-bit counter by using the structure depicted in Figure 1. Your code should include a T flip-flop module that is instantiated eight times to create the counter. Compile the circuit. How many logic elements (LEs) are used to implement your circuit?
2. Simulate your circuit to verify its correctness.
3. Augment your Verilog file to use the pushbutton KEY_0 as the *Clock* input and switches SW_1 and SW_0 as *Enable* and *Clear* inputs, and 7-segment displays *HEX1-0* to display the hexadecimal count as your circuit operates. Make the necessary pin assignments needed to implement the circuit on your DE-series board, and compile the circuit.
4. Download your circuit into the FPGA chip and test its functionality by operating the switches.
5. Implement a four-bit version of your circuit and use the Quartus® RTL Viewer to see how the Quartus software synthesized the circuit. What are the differences in comparison with Figure 1?

Part II

Another way to specify a counter is by using a register and adding 1 to its value. This can be accomplished using the following Verilog statement:

$$Q <= Q + 1;$$

Compile a 16-bit version of this counter and determine the number of LEs needed. Use the RTL Viewer to see the structure of this implementation and comment on the differences with the design from Part I. Implement the counter on your DE-series board, using the displays *HEX3-0* to show the counter value.

Part III

Design and implement a circuit that successively flashes digits 0 through 9 on the 7-segment display *HEX0*. Each digit should be displayed for about one second. Use a counter to determine the one-second intervals. The counter should be incremented by the 50-MHz clock signal provided on the DE-series boards. Do not derive any other clock signals in your design–make sure that all flip-flops in your circuit are clocked directly by the 50-MHz clock signal. A partial design of the required circuit is shown in Figure 2. The figure shows how a large bit-width counter can be used to produce an enable signal for a smaller counter. The rate at which the smaller counter increments can be controlled by choosing an appropriate number of bits in the larger counter.

Para testar diferentes quantidades de bits para o contar mais lento, utilize a construção "parameter" para definir a constante com a quantidade de bits.
Ex:
parameter m = 10;
logic [m-1:0] slow_count;

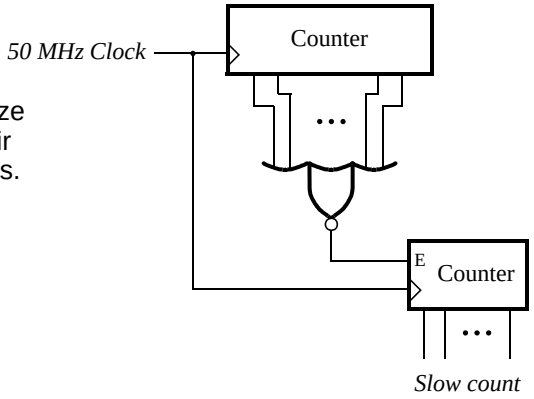

Figure 2: Making a slow counter.

Part IV

Design and implement a circuit that displays a word on four 7-segment displays $HEX3 - 0$. The word to be displayed for your DE-series board is given in Table 1. Make the letters rotate from right to left in intervals of about one second. The rotating pattern for the DE10-Lite is given in Table 2. If you are using the DE0-CV, DE1-SoC, or DE2-115, use the word given in Table 1. There are many ways to design the required circuit. One solution is to re-use the Verilog code designed in Laboratory Exercise 1, Part V. Using that code, the main change needed is to replace the two switches that are used to select the characters being rotated on the displays with a 2-bit counter that increments at one-second intervals.

Board	Word
DE10-Lite	dE10
DE0-CV	dE0
DE1-SoC	dE1
DE2-115	dE2

Table 1: DE-series boards and corresponding word to display

Count	Characters			
00	d	E	1	0
01	E	1	0	d
10	1	0	d	E
11	0	d	E	1

Table 2: Rotating the word dE10 on four displays.

Part V

Augment your circuit from Part IV so that it can rotate the word over all of the 7-segment displays on your DE-series board. The shifting pattern for the DE10-Lite is shown in Table 3.

Count	Character pattern					
000			d	E	1	0
001		d	E	1	0	
010	d	E	1	0		
011	E	1	0			d
100	1	0			d	E
101	0			d	E	1

Table 3: Rotating the word dE10 on six displays.