Lab 4: BCD Counters

Submission Due Dates:

Demo: 2023/10/17 17:20
Source Code: 2023/10/17 18:30
Report: 2023/10/22 23:59

Objective

1. Getting familiar with the 7-segment display and pushbuttons on the FPGA board.
   Note: Signals from pushbuttons should be processed by debouncing and one-pulse converters properly.
2. Getting familiar with the counter designs and finite-state machines in Verilog.

Action Items

1 lab4_1.v (60%)

In this lab, you must design a 3-digit BCD reaction timer. This timer must be control by a finite-state machine (FSM) which controls the LEDs and 7-segment display based on the inputs from the pushbuttons.

a. I/O list

I/O	Connected to	Definition
clk	W5	Clock signal with the frequency of 100MHz
rst	SW0	Asynchronous positive reset signal, reset the counter back to the **INITIAL** state
stop	BTNC	Stop the counter in the **COUNTING** state and then enter the **RESULT** state.
start	BTNU	Changing the **INITIAL** state to the **PREPARE** state.
direction	BTND	Switching the counting direction between counting down and counting up.
LED[9:0]	LD9~LD0	Lighting up the LEDs based on the current counter's hundreds digit.
DISPLAY[6:0]		Controlling the seven LED segments of the 7-segment display.
DIGIT[3:0]		Enabling one of the 7-segment digits.

b. **Finite state machine (FSM)**

The FSM may consist of an **INITIAL** state to initialize the counter and set direction, a **PREPARE** state before entering the COUNTING state, a **COUNTING** state to increase or decrease the counter value based on the current direction (you may store the direction information in a register), and a **RESULT** state for showing the reaction

time. You can design your own variant instead.

✓ INITIAL state

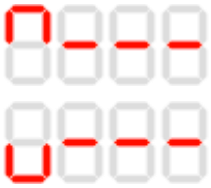
- Pressing the **direction** button can change the counting direction between UP and DOWN. After reset, the direction will be set as **UP**.

  ✧ NOTE: the direction button will only work in the **INITIAL** state.

- First, it initializes the current BCD counter **000 (UP)** or **999 (DOWN)** (it will be 000 after reset); the **LD9~LD0** are all **on**; the current direction will stay the same as the previous setting. Then, the 7-segment display will show the current direction and three dashes as below. The FSM can enter the **PREPARE** state by pressing the **start** button.

LD9 ●●●●●●●●●● LD0

(● : LED on, ◯ : LED off)



The LEDs and 7-segment display in the **INITIAL** state

✓ PREPARE state

- After entering the **PREPARE** state, the counter will wait for **3 seconds**. After this time period, it will enter the **COUNTING** state automatically.
- In this state, all the LEDs will turn off and the 7-segment display will show a single “P” as in the following.

  EX:

LD9 ◯◯◯◯◯◯◯◯◯◯ LD0

(● : LED on, ◯ : LED off)

The LEDs and 7-segment display in the PREPARE state

✓ COUNTING state

- In this state, the counter will start counting up/down from 000/999 (depending on the direction). The 7-segment display will display the current direction and counter value. When the **stop** button is pressed, the counter will stop and enter the **RESULT** state. Also, if the counter counts to 999 (when counting UP) or 000 (when counting DOWN), it will also stop counting and enter the **RESULT** state. That is, the counter will stop at 999 and enter the **RESULT** state eventually when the direction is UP; the counter will stop at 000

and enter the **RESULT** state when the direction is DOWN.

E.g., the counter counts up to 053

E.g., the counter counts down to 855

- The counter value will increase or decrease by one every **0.01 seconds** (that is, exactly 0.01 seconds) based on its current direction, UP or DOWN, respectively.
- The LEDs will light up based on the current counter's hundreds digit.

  EX:

  When the counter counts to 089, the LEDs will light up as follows:

  LD9 ○○○○○○○○○● LD0

  When the counter counts to 199, the LEDs will light up as follows:

  LD9 ○○○○○○○○●○ LD0

  When the counter counts to 200, the LEDs will light up as follows:

  LD9 ○○○○○○○●○○ LD0

  When the counter counts to 876, the LEDs will light up as follows:

  LD9 ○●○○○○○○○○ LD0

  (● : LED on, ○ : LED off)

✓ RESULT state

- When entering this state, the **LD9~LD0** will be flashing for 5 seconds (lighting up first for one second then off). After flashing, the LEDs will be all **on**. Therefore, the on-off sequence will be "on off on off on".
- Pressing the **start** button can go back to the **INITIAL** state with the counter paused.
- In this state, the leftmost digit of the 7-segment display will show the direction; the other three digits will show the counter value.

  EX:

  If you pressed the **stop** button in the **COUNTING** state when the counter counted down to 127, the 7-segment will be as follows in the **RESULT** state:

If you pressed the **stop** button in the **COUNTING** state when the counter counted up to 039, the 7-segment will be as follows in the **RESULT** state:

c. DEMO video

https://youtu.be/Xe-hGBvvEck

d. You have to use the following template for your design:

```
module lab4_1 (
  input wire clk,
  input wire rst,
  input wire stop,
  input wire start,
  input wire direction,
  output reg [3:0] DIGIT,
  output reg [6:0] DISPLAY,
  output reg [9:0] led
);
    /* Note that output ports can be either reg or wire.
     * It depends on how you design your module. */
    // add your design here
endmodule
```

2 lab4_2.v (40%)

In this lab, you need to design a Timing Game with a BCD timer. In this game, the timer value will be hidden and the user needs to press the **stop** button in a certain time interval.

a. I/O list:

I/O	Connected to	Definition
clk	W5	Clock signal with the frequency of 100MHz.
rst	SW0	Asynchronous positive reset signal; reset the machine back to the **INITIAL** state.
Digit_1	SW1	Select the units digit when configuring the counter.
Digit_2	SW2	Select the tens digit when configuring the

		counter.
Digit_3	SW3	Select the hundreds digit when configuring the counter.
stop	BTNC	Stop the counter in the **COUNTING** state.
start	BTNU	Changing the machine's state from the **INITIAL** state to the **COUNTING** state or from the **FAIL/SUCCESS state** to the **INITIAL** state.
increase	BTNR	Increase the chosen digit(s) by 1 in the INITIAL state.
decrease	BTNL	Decrease the chosen digit(s) by 1 in the INITIAL state.
direction	BTND	Switching the counting direction between counting down and counting up.
LED[15:0]	LD15~LD0	Lighting up based on the current state.
DISPLAY[6:0]		Controlling the seven LED segments of the 7-segment display.
DIGIT[3:0]		Enabling one of the 7-segment digits.

b. **Finite state machine (FSM)**

The FSM may consist of an **INITIAL** state to initialize the counter and set direction, a **COUNTING** state to increase or decrease the counter value based on the current direction (you may store the direction information in a register), and a **SUCCESS** state and a **FAIL** state for showing the pressing time. You can design your own variant instead.

✓ INITIAL state

- Pressing the **direction** button can change the counting direction between UP and DOWN. After reset, the direction will be set as **UP,** and the counter will be set as **000.** If the FSM enters the INITIAL state not because of the reset, it initializes the counter to the value that you previously set. The **LD15~LD0** are all on, and the current direction will be the same as the previous setting. The 7-segment display will show the current direction and the value that you previously set, as shown below. The FSM can enter the **COUNTING** state by pressing the **start** button.

LD15 ●●●●●●●●●●●●●●●● LD0

The LEDs in the **INITIAL** state

(● : LED on, ○ : LED off)

The 7-segment display in the **INITIAL** state

- NOTE: the direction button will only work in the **INITIAL** state. When the system is in the INITIAL state, you can use the switch (**Digit_1~Digit_3**) to select one or more desired digits to adjust by increasing or decreasing the selected digit(s) by one when the **increase** button or **decrease** button is pressed, respectively.

  For example, if the **Digit_1** and **Digit_2** are switched to high and the current counter value is 5**23**, pressing the **increase** button will change the counter value to 5**34**. By contrast, pressing the **decrease** button will change the counter from 5**23** to 5**12**.
- When the selected digit's value is 9, pressing the **increase** button will reset its value to 0. For example, if **Digit_1** is selected and the current counter value is 52**9**, pressing the **increase** button will change the value to 52**0**. Similarly, when the selected digit's value is 0, pressing the **decrease** button will set its value to 9. For example, if **Digit_2** is selected and the current counter value is 9**0**2, pressing the **decrease** button will change the value to 9**9**2.

✓ COUNTING state

- In this state, the counter will start counting up/down from 000/999 (depends on the direction). The 7-segment display will show the current direction and counter value, and the LEDs will all light up in the first three seconds (**UP:**000~299, **DOWN:**999~700). After three seconds, the 7-segment display will show the direction and three dashes; the LEDs will all turn **off**. When the **stop** button is pressed, the counter will stop and enter the **SUCCESS** or the **FAIL** state. Also, if the counter counts to 999 (UP) or 000 (DOWN), it will also stop counting and enter the **FAIL** state automatically.

LD15 ●●●●●●●●●●●●●●●● LD0

The LEDs in the first three seconds

LD15 ○○○○○○○○○○○○○○○○ LD0

The LEDs after three seconds

(● : LED on, ○ : LED off)

The counter counts to 053 with the up direction

The counter counts to 300~999 with the up direction

The counter counts to 855 with the down direction

The counter counts to 699~000 with the direction

- The counter value will be increased or decreased by one every **0.01 seconds** (that is, exactly 0.01 seconds) based on its current direction, UP or DOWN, respectively.
- If the user presses the **stop** button between **"the number you set in the INITIAL state"** $\pm$ **100**, the counter will stop and enter the **SUCCESS** state. Otherwise it will enter the **FAIL** state.

✓ FAIL state

- When entering this state, the **LD15~LD0** will be flashing for 5 seconds (lighting up first for one second then off for another second). After flashing, the LEDs will be all **off**. Therefore, the on-off sequence will be "on off on off on off".
- Pressing the **start** button can go back to the **INITIAL** state.
- In this state, the leftmost digit of the 7-segment display will show "F", and the three other digits will show the current counter value.

  EX:

  If you pushed the **stop** button in the **COUNTING** state when the counter counted to 127 and 127 is not in the time period that you set in the **INITIAL** state, the 7-segment will be as follows in the **FAIL** state:

  If you pushed the **stop** button in the **COUNTING** state when the counter counted to 039 and 039 is not in the time period that you set in the **INITIAL** state, the 7-segment will be as follows in the **FAIL** state:

✓ SUCCESS state

- When entering this state, the **LD15~LD0** will be flashing for 5 seconds. (lighting up first for one second then off). After flashing, the LEDs will be all

on. Therefore, the on-off sequence will be "on off on off on".

- Pressing the **start** button can go back to the **INITIAL** state with the counter paused.
- In this state, the leftmost digit of the 7-segment display will show "S", and the three other digits will show the current counter value.

  EX:

  If you pushed the **stop** button in the **COUNTING** state when the counter counted to 177 and 177 is in the time period that you set in the **INITIAL** state, the 7-segment will be as follows in the **SUCCESS** state:

  If you pushed the **stop** button in the **COUNTING** state when the counter counted to 839 and 839 is in the time period that you set in the **INITIAL** state, the 7-segment will be as follows in the **SUCCESS** state:

c. DEMO video

https://youtu.be/1KL1Dq_5KHg

d. You have to use the following template for your design:

```
module lab4_2 (
  input wire clk,
  input wire rst,
  input wire Digit_1,
  input wire Digit_2,
  input wire Digit_3,
  input wire stop,
  input wire start,
  input wire increase,
  input wire decrease,
  input wire direction,
  output reg [3:0] DIGIT,
  output reg [6:0] DISPLAY,
  output reg [15:0] led
 );
   /* Note that output ports can be either reg or wire.
    * It depends on how you design your module. */
```

```
    // add your design here
endmodule
```

3 Questions and Discussion

Please answer the following questions in your report.

A. Why do we need the debounce and one-pulse modules? What is the relation between the FSM's clock rate and the one-pulse module's clock rate? Explain your reason. And what will happen when we implement with a wrong clock rate? (Please draw waveforms to explain)

B. Please propose two different design methods to manipulate two or more clocks in one module.

4 Guidelines for the report

Refer to the guidelines in the report template (or in the previous lab assignments).
Grading policy (subject to change): Part (A): **35%**; Part (B): **50%**; Part (C): **10%**; (D): **5%**

Attention

- ✓ DO NOT copy-and-paste code segments from the PDF materials. It may also paste invisible non-ASCII characters, leading to hard-to-debug syntax errors.
- ✓ In this lab, we provide you **onepulse.v**, **debounce.v** and **clock_divider.v**. Do not include them in your submissions. We will take care of them when verifying your source code.
- ✓ If you have two or more modules used for any specific lab, merge them into one Verilog file before the submission.
- ✓ You should submit two source files, including **lab4_1.v and lab4_2.v**. Upload each source file individually. DO NOT hand in any compressed ZIP files, which will be considered an incorrect format.
- ✓ You should also hand in your report as **lab4_report_StudentID.pdf** (i.e., lab4_report_111456789.pdf).
- ✓ You should be able to answer questions about this lab from TA during the demo.
- ✓ You need to prepare the bitstream files before the lab demo to make the demo process smooth.
- ✓ Feel free to ask any questions about the specification on the EECLASS forum.