



Welcome to The Hardware Design & Lab!

Fall 2023

Lab 5: Keyboard and Audio Modules

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Agenda

- Lab 5 Outline
- Lab 5 Basic Questions
- Lab 5 Advanced Questions



Lab 5 Outline

- Basic questions (1%)
 - Group assignments
 - Due on **11/16/2023 (Thu)**. Demonstration on your FPGA board (**In class**)
 - Only demonstration is necessary. Nothing to submit.

- Advanced questions (6%)
 - Individual and Group assignments
 - eeclass submission due on **11/23/2023 (Thu). 23:59:59.**
 - Demonstration on your FPGA board (**In class**)
 - Assignment submission (**Submit to eeclass**)
 - Source codes and testbenches
 - Lab report in PDF

Lab 5 Rules

- Please note that grading will be based on NCVerilog
- You can use **ANY** modeling techniques
- If not specifically mentioned, we assume the following SPEC
 - **clk** is **positive edge triggered**
 - Synchronously reset the Flip-Flops when **rst_n == 1'b0, if there exists one rst_n signal in the specification**

Lab 5 Submission Requirements

- Source codes and testbenches
 - Please follow the templates **EXACTLY**
 - We will test your codes by TAs' testbenches
- Lab 5 report
 - Please submit your report in a single **PDF** file
 - Please **draw** the **block diagrams** and **state transition diagrams** of your designs
 - Please **explain** your designs in detail
 - Please **list** the contributions of each team member clearly
 - **Please explain how you test your design**
 - What you have **learned** from Lab 5

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- **Lab 5 Basic Questions**
- Lab 5 Advanced Questions



Basic Questions

- Group assignment
- FPGA demonstration (due on 11/16/2023. In class.)
 - Keyboard sample code
 - Audio sample code 1 & 2

Basic FPGA Demonstration 1

- **Keyboard sample code**

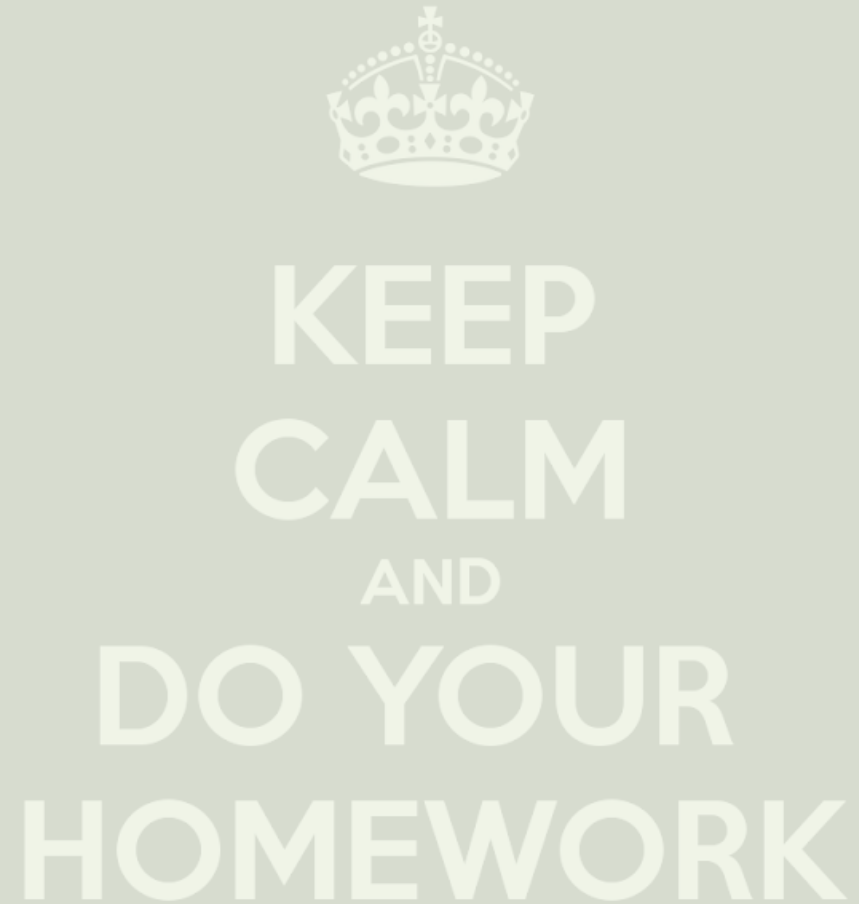
- Please implement the keyboard sample codes released on eeclass

- **Audio sample codes**

- Please implement the audio sample codes 1 & 2 released on eeclass

Agenda

- Lab 5 Outline
- Lab 5 Basic Questions
- **Lab 5 Advanced Questions**



Advanced Questions

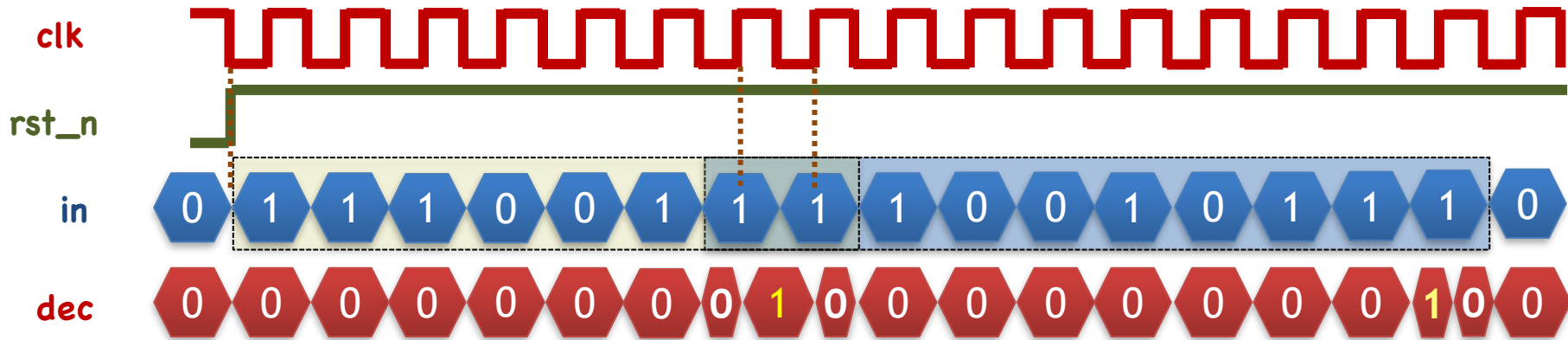
- Individual and Group assignments
- Verilog questions (Individual assignments)
 - Source codes and the report due on 11/23/2023. 23:59:59.
 - **Optional**: Sliding window sequence detector
 - **Optional**: Traffic light controller
 - **Necessary**: Greatest common divisor
 - **Bonus**: Booth multiplier
- FPGA demonstration (group assignments) on 11/23/2023, in class
 - Source codes and the report due on 11/23/2023. 23:59:59.
 - **Necessary**: Mixed keyboard and audio modules together
 - **Necessary**: Vending machine

Verilog Advanced Question 1

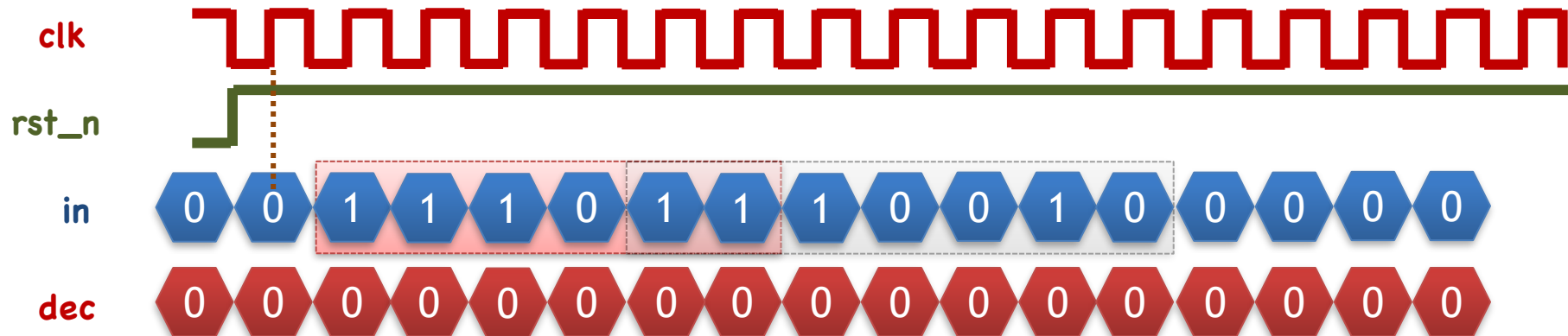
- **Sliding Window** sequence detector (**mealy machine**)
 - Detect the sequence **1110(01)+11** (in regular expression)
 - The pattern **01** in the middle have to appear at least once and can be repeated.
 - For example, **11100111** is a match, **1110010111** is also a match. On the other hand, **111011** is a mismatch.
- **Continuous detection**
 - Detect the sequences whenever they occur, and set **dec** to **1'b1**
 - Please draw a state transition diagram in your report
 - A sample waveform is provided in the next page
- **I/O port definition**
 - Input: **clk, rst_n, in**
 - Output: **dec**

Verilog Advanced Question 1 (Con't)

A match case

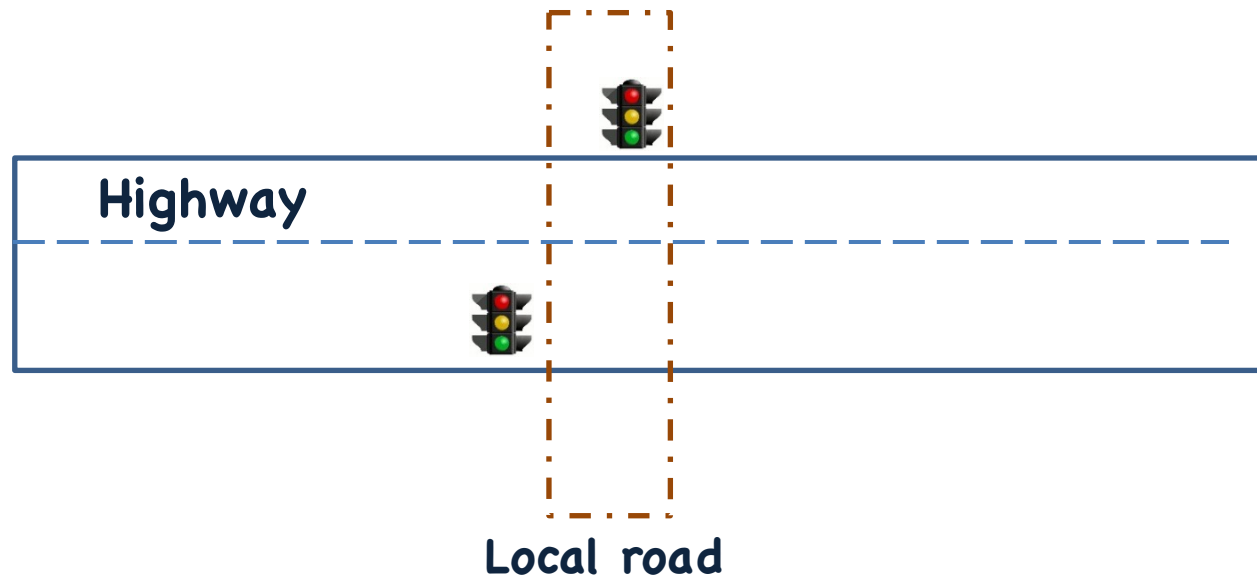


A mismatch case



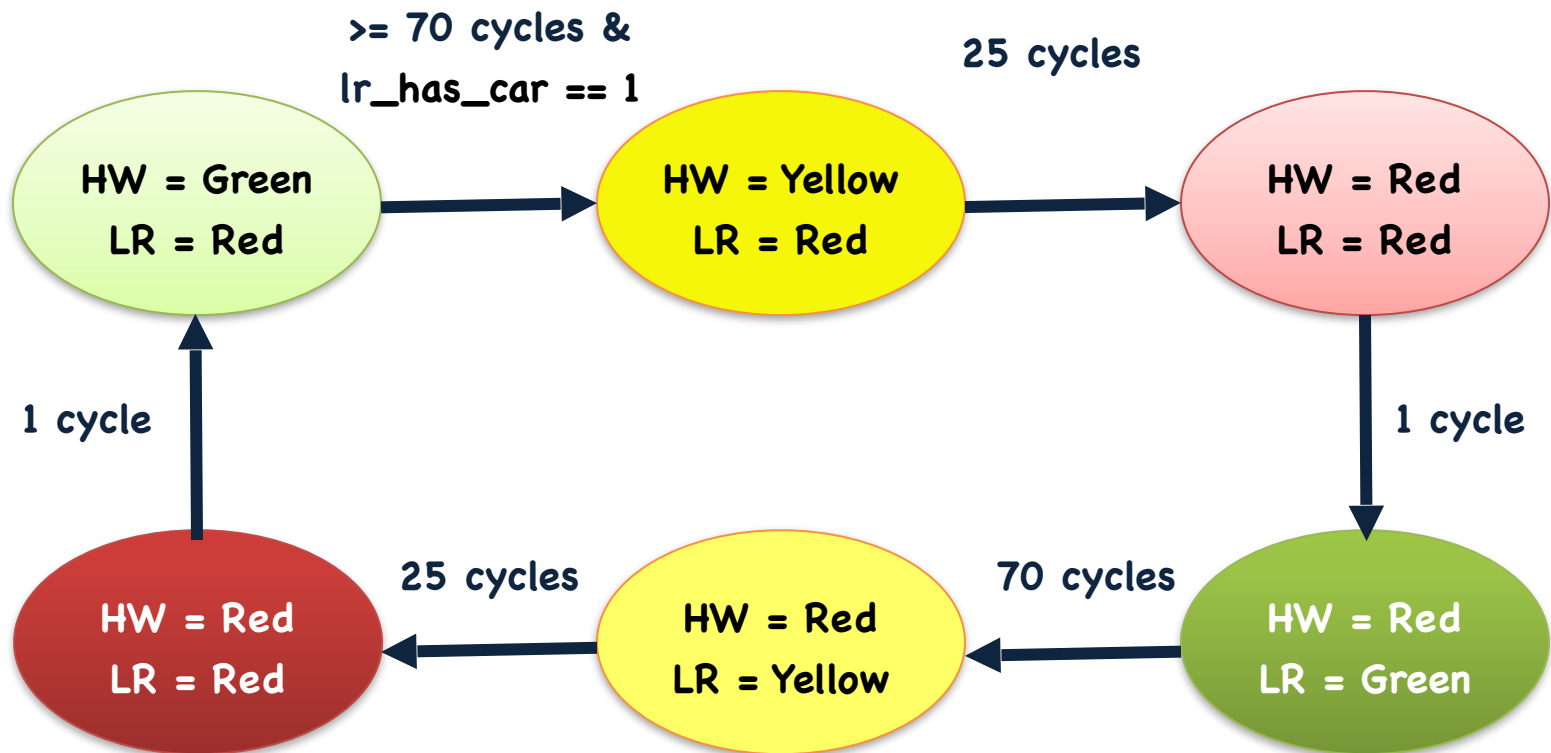
Verilog Advanced Question 2

- **Traffic light controller** for a highway (**HW**) and local road (**LR**) intersection
- **HW** has higher priority and should be green as long as possible
- **LR** has a sensor to detect cars on it. When a car is sensed, LR turns green shortly
- Green light is **at least 70** clock cycles and yellow light is **25** clock cycles
- Input: **clk**, **rst_n**, **lr_has_car**; Output: **hw_light[2:0]**, **lr_light[2:0]**
- **hw_light** & **lr_light**: bits [2:0] represent **Green**, **Yellow**, and **Red**, respectively

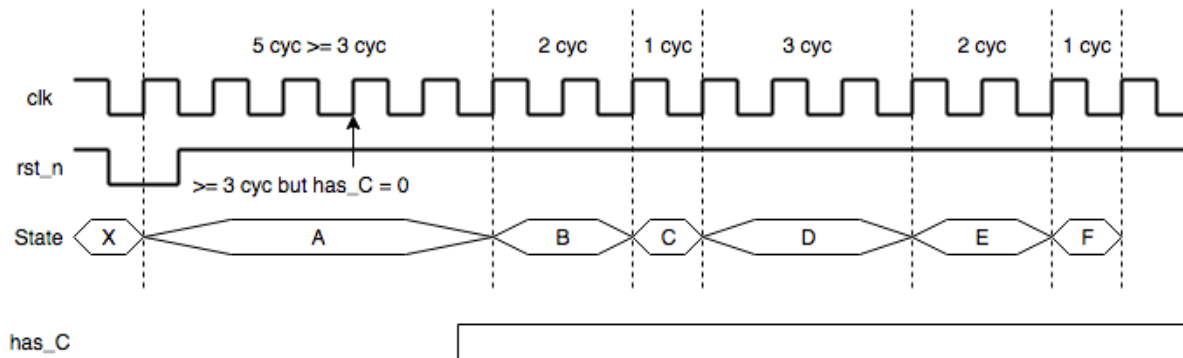
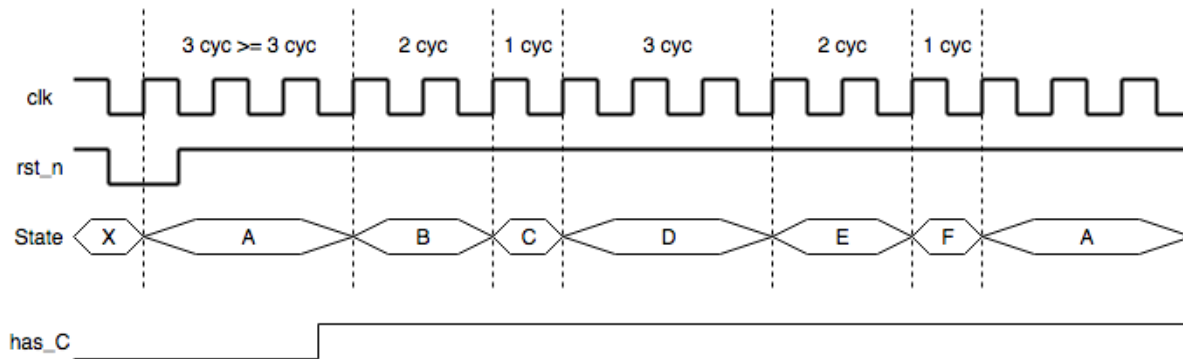
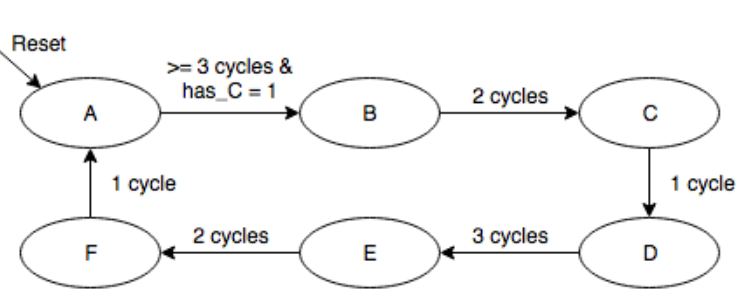


Verilog Advanced Question 2 (Con't)

- Traffic light controller Finite State Machine
- Please complete the FSM in your report (some arrows are removed intentionally)



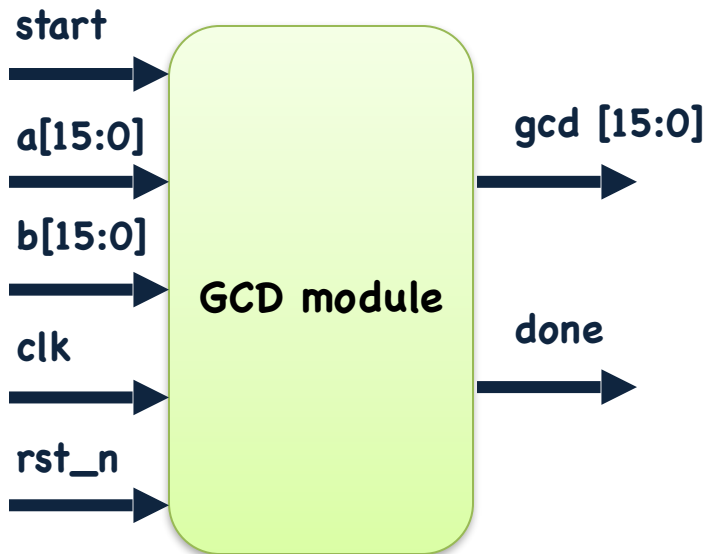
Verilog Advanced Question 2 (Con't)



- A Traffic light controller **"example"** timing diagram is illustrated on the left
- Please make sure that your state transitions follows the timing diagram correctly

Verilog Advanced Question 3

- Greatest common divisor
- Calculate the greatest common divisor of two numbers **a** and **b**
- Top level block diagram and pseudo code are as follows
 - You **shall not** use **loop statements and modulus (%)** in your Verilog codes



Function gcd (a, b)

begin

if (a == 0)
return b;

while (b != 0)

// Do the following operation once per clock cycle

begin

if (a > b)
a = a - b;

else
b = b - a;

end

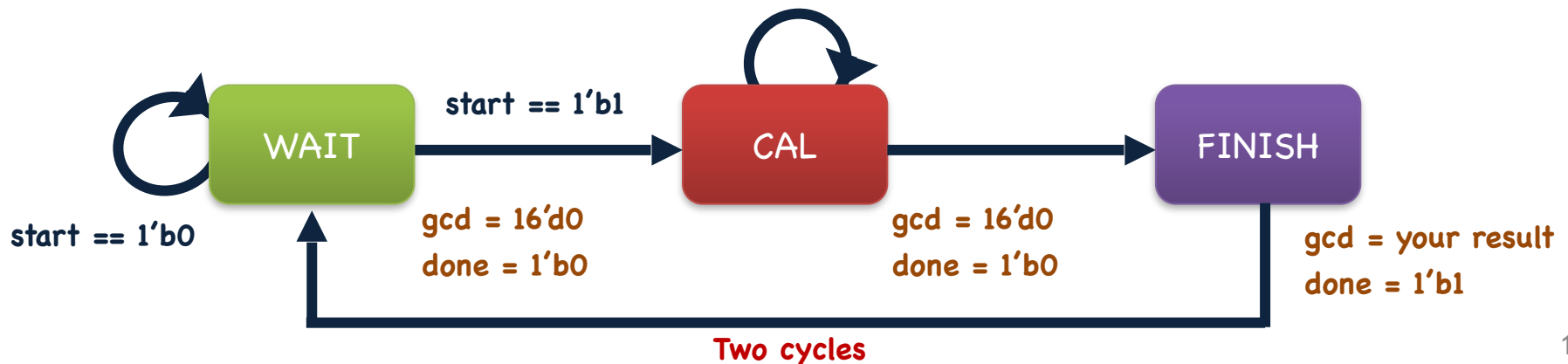
return a;

end

**GCD pseudo
code**

Verilog Advanced Question 3 (Cont'd)

- Three states are used: **WAIT**, **CAL**, and **FINISH**
- **WAIT state**
 - Wait for **start == 1'b1** (**one cycle**) to begin the operation (**and fetch the inputs**)
 - The values of **a** and **b** may change during operation. Be sure to fetch and buffer them when the state changes from **WAIT** to **CAL**
 - When **rst_n == 1'b0**, reset the module to the **WAIT state**
- **CAL state**
 - Perform the **subtraction operations once per cycle**
- **FINISH state**
 - Output the **gcd** result for **two cycles**
 - **done == 1'b1** for **two cycles**



Bonus: Verilog Advanced Question 4

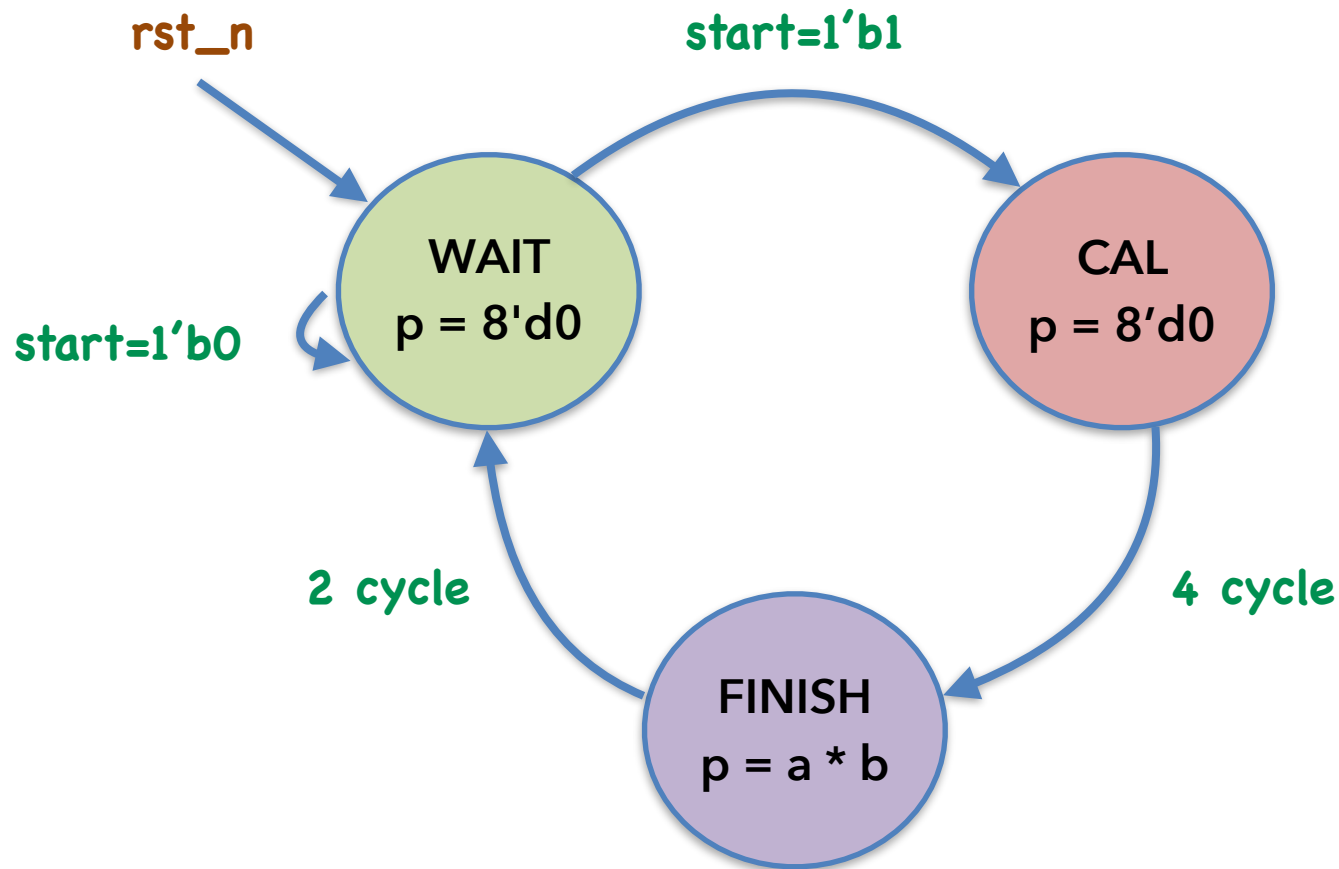
- **Booth Multiplier**
- Please design a **booth multiplier** to compute the product of two signed input (the product is also signed).
- Your design should follow the mechanism of the booth multiplication. Otherwise, no bonus credit will be granted
- For more information about the **booth multiplier**, please refer to the following references:
 - <https://tinyurl.com/kvsyspuj>
 - <https://tinyurl.com/4bzyayf8>
- **I/O port definition**
 - Input: **clk**, **rst_n**, **start**, **a[3:0]** (signed), **b[3:0]** (signed)
 - Output: **p[7:0]** (signed)

Bonus: Verilog Advanced Question 4

- Three states are used: **WAIT**, **CAL**, and **FINISH**
- **WAIT state**
 - Wait for **start == 1'b1** (**one cycle**) to begin the operation (**and fetch the inputs**)
 - The value of **a** and **b** may change during operation. Be sure to fetch and buffer them when the state changes from **WAIT** to **CAL**
 - When **rst_n == 1'b0**, reset the module to the **WAIT state**
- **CAL state**
 - Perform the **booth multiplication operations once per cycle**
 - Transition to **FINISH** state after 4 cycles of calculation.
- **FINISH state**
 - Output the result **p** for **two cycles**

Bonus: Verilog Advanced Question 4

- The state transition diagram of the booth multiplier


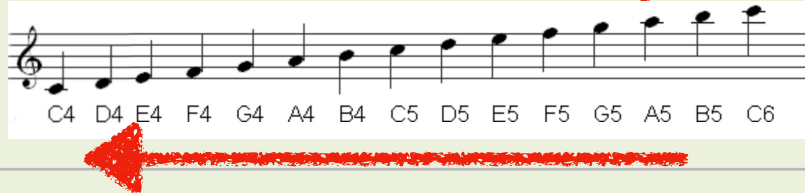


Advanced Questions

- Individual and Group assignments
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 - Source codes and the report due on **11/23/2023. 23:59:59.**
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FPGA Demonstration 1

- Use the numbers ("w" and "s") on the keyboard to control the scale to ascend or descend, ranging from **C4** to high **C8**.
- Change a note every **1 second**. If "r" is pressed, change to a note every **0.5 second**. If "r" is pressed again, go back to **1 second** per note.
- When it reaches **C4** or **C8**, stay on the note until the direction changes (keyboard pressed).

Button	Direction Reset: Set back to C4 and ascend (1sec/note) (Use Enter as rst_n)
w	
s	
r	0.5 sec per note or 1 sec per note

FPGA Demonstration 2

- Four options available: **Coffee, Coke, Oolong, and Water**
 - Prices are: **Coffee (NT\$ 80), Coke (NT\$ 30), Oolong (NT\$ 25), Water (NT\$ 20)**
- The **rightmost three 7-segment displays** show the money inserted into the machine
 - When **rst_n == 1'b1**, please display "0"
 - The maximum value is **NT\$ 100**
 - **Do not prepend '0' when you only have one or two digits to display**
- Use **five buttons** to implement your design:
 - Left: **NT\$ 5**
 - Center: **NT\$ 10**
 - Right: **NT\$ 50**
 - Top: **rst_n**
 - Bottom: **Cancel**



FPGA Demonstration 2

- Use **four LEDs** to indicate which drinks you can buy
 - **LED[3:0]** corresponds to Coffee, Coke, Oolong, and Water, respectively
- Use the **keyboard** to select which drinks you buy
 - **'a', 's', 'd', 'f'** corresponds to **Coffee**, **Coke**, **Oolong**, and **Water**, respectively
 - Assume that the machine allows you to buy **ONLY ONE DRINK** at a time
- Use the **rightmost three 7-segment display** to **show the rest of the money** after buying a drink
 - E.g., if you inserted **NT\$ 40** and bought a can of **Oolong (NT\$ 25)**, the 7-segment display will show **NT\$ 15**

FPGA Demonstration 2

- Remember to add debounce and one-pulse circuits to your buttons
- Decrement the **7-segment display** by **NT\$ 5** every second to mimic the process of returning changes
 - Return the changes until it becomes zero
- If the buyer does not want to buy a drink, he/she can use a **Cancel Button** to cancel it
 - The inserted money will be returned the same way (**NT\$ 5** per second)

The layout of the
buttons used in this
question



Insert
NT\$ 5



RESET



Insert
NT\$ 10



Insert
NT\$ 50



Cancel

Thank you for your attention!



*Lake Helen at Lassen Volcanic National Park, Shasta County, California, USA
This picture is taken by Chun-Yi Lee himself, who is also a fan of photography