Traffic control system using verilog

Abstract

Traffic control is a challenging problem in many cities. This is due to the large number of vehicles and the high dynamics of the traffic system. Poor traffic systems are the big reason for accidents, time losses. In this method of approach, it will reduce the waiting time of the vehicles at traffic signals. The hardware design has been developed using Verilog Hardware Description Language (HDL) programming.

Verilog designing is hardware descriptive language, the name itself suggest that it deals with the hardware designing and simulation. Basically, it becomes very difficult to mount the various electronic components on breadboard or PCB circuit. It also takes too much time for the simulation and sometimes many errors occur because of improper connection of components onto the circuit. And thus, to overcome this factor hardware descriptive language comes into conclusion. we can code the process using Verilog and we can mount it on a circuit or just upload it to the circuit accordingly so that particular circuit will work as according to the code we have written.

HDL language is often used for sequential circuits like shift register, combinational logic circuit like adder, subtractor etc. Basically, it describes the digital systems like microprocessor or a memory. Whatever design that is described in HDL are independent, it has its unique state of work, very much easy to simulate, designing and debugging, and very useful than schematics, especially for large circuits thus, to overcome difficulties or problems to design the circuits manually with breadboard and PCB, use of Verilog designing in this complex world is increasing a way better.

This project deals with a basic design of a T - Shaped Road for traffic light control. The output of system has been tested using Xilinx Vivado 2023.1

Introduction

Traffic light signal controlling is most important and essential thing for any country to protect the people from heavy load of traffic. Before this kind of invention there was much difficult for traffic police to handle the heavy traffic (particular direction given manually). Thus, traffic signal controlling technology made much easier to handle the heavy loads of traffic. Safe movement of vehicles without any type of collision, accidents.

Apart from the traffic it is very necessary for the people to cross the roads at particular time interval. And this is only possible by controlling the traffic by giving some kind of signal. Analysing the traffic, estimating the delays to the areas is crucial part. Population can be predicted using GPS trekking and thus we can easily estimate the amount of time to be taken for delay. A perfect aligning of cars, bikes, cycles, trucks with orderly flow by giving right of way, this makes the process very systematic and even in the presence of heavy traffic accident rate goes down which is one of the biggest advantages.

Timing and the delay of particular signal plays a vital role because it is very necessary for us to keep information about the amount of traffic which present in the local area. This gives us an idea about timing and delay requirement of every signal in the local area. As we know the timing depends on traffic volume and it’s not necessary for us to have same traffic volume at each day so for that we can estimate average volume of traffic around the local area. Average can be made with consideration of 20 days for example we will analyse the traffic of 20 days then we will take an average of it and estimate delays and timings of it. It is very necessary factor for us to have adaptive mechanism.

Apart from that we can estimate the traffic volume using GPS, which can give you volume prediction every day. For this we no need to take an average of particular days. GPS give us more correct prediction of volume of traffic than calculating an average of traffic of particular days. Thus, coordinating signal timing minimizes starting and stopping of vehicles in the traffic to avoid the traffic jam

Literature Survey

Traffic Light Systems:

A traffic light system is an electronic device that assigns right of way at an intersection or crossing or street crossing by means of displaying the standard red, yellow and green coloured indications. In addition, it also works in conjunction with pedestrian displays to assign pedestrian crossing right of way.

A traffic light, also known as traffic signal, stop light, stop-and-go lights, is a signalling device positioned at a road intersection, pedestrian crossing, or other location in order to indicate when it is safe to drive, ride, or walk using a universal colour code.

Nowadays,

- A red light meant traffic in all directions had to stop.
- A yellow light meant cross-town traffic would have to slow and,
- A green light would go or proceed.

The difficulty in understanding this confusing color sequence was compounded by neighbouring towns using another system. The development of an intelligent control structure ensures an optimal solution for all participants in the transportation and road traffic system. There are different ways controlling road intersections. In the simplest cases the right-hand rule or, if the traffic is higher, a round about or the signal of a policeman can help steer the traffic.

However, especially in big cities, in the complicated cases when the roads in the intersection have several lanes, the use of traffic lights cannot be avoided. An additional issue arises when in the intersection not only roads but also railroad tracks take part, what often occurs in suburban traffic situations. The most common way to handle this type of intersection is the conventional cyclic lights control. In more enhanced control, the traffic in different directions is monitored by sensors and the signals thus obtained control the traffic lights. In this method the control is adapting to the traffic. The general problem is the huge number of variables and the need for large computing efforts.

Benefit of Traffic Light Controller:

When properly used, traffic control signals are important devices for the control of vehicles in road. They assign the right-of-way to a choice of traffic movements and thereby deeply influence traffic flow.

Traffic control signals that are properly designed, located, operated, and maintained will have one or more of the following advantages:

- Provide orderly movement of traffic.
- Minimize completing movement.
- Coordinated for continuous movement.
- Provide driver confidence by assigning right way traffic control signals are often considered, a cure for all traffic problems at intersections.

This belief has led to traffic control signals being installed at many locations where they are not needed, adversely affecting the safety and efficiency of vehicular, bicycle, and pedestrian traffic. Traffic control signals, even when justified by traffic and roadway conditions, can be ill-designed, ineffectively placed, improperly operated, or poorly maintained. While traffic signals can help in locations where they are justified and installed properly, they also have disadvantages.

There will always be some disadvantages even if the signal is justified. Most traffic signals will have the following components or part:

- Main display with red, yellow and green lights.
- Traffic signal cabinet containing the traffic signal controller and Vehicle Detection systems.
- Inductive loops or sensors.

Traffic jamming is a critical predicament in many of the cities and towns all over the world. Traffic congestion has been causing many setbacks and challenges in the major and most occupied cities all over the globe. This traffic jam directly impacts the productivity of the workers, traders, suppliers and in all affecting the market and raising the prices of the commodities in a way light.

The problem of heavy jam is happened because of never configure the level of jam in each way and set the delay time. Another problem represents when there is no jam, but the waiting still continues. The solution for these problems is to determine the level of jam and set the delay time. This problem need of evaluation of the traffic policeman, and then there is need for manual control of the traffic.

The target of this paper is to propose system provide solution for all above problems with least possible cost. Traffic light controller (TLC) can be implemented using microcontroller, FPGA, and ASIC design. FPGA has many advantages over microcontroller, some of these advantages are; the speed, number of input/output ports and performance which are all very important in TLC design, at the same time ASIC design is more expensive than FPGA.

Nowadays, FPGA becomes one of the most successful of today's technologies for developing the systems which require a real time operation. FPGA is a re-configurable integrated circuit that consists of two dimensional arrays of logic blocks and flip-flops with an electrically programmable interconnection between logic blocks.

The reconfiguration property enables fast prototyping and updates for hardware devices even after market launch. Most of the TLCs implemented on FPGA are simple ones that have been implemented as examples of Finite State Machine (FSM).

The Verilog language has been selected for programming the FPGA to fill two important needs in the design process.

- Firstly, it gives full description of the structure of a design that is how it is decomposed into sub-designs, and how those sub-designs are interconnected.
- Secondly, it allows simulating the design before starting the manufacturing. Accordingly, the designers can quickly compare alternatives and test for correctness without the delay and expense of hardware prototyping.

Benefits of Using Verilog HDL (Hardware Description Language):

Verilog is a widely used Hardware Description Language (HDL) for designing digital circuits. It can also be used for modelling analogue circuits. Verilog is a descriptive language that describes a relationship between signals in a circuit.

A Verilog model describes a unit of digital hardware in terms of:

Interconnections of other hardware unit whose models prescribe their behavior in a simulation.

Behavioural / procedural algorithms that abstractly describe input/output behaviour that could be personified in a hardware unit.

Hardware description language (HDL) is divided by two types, Verilog and VHDL (VHSIC – Very High-Speed Integrated Circuit Hardware Description Language). Both have its advantages and its disadvantage.

In this project, Verilog HDL was chosen because it's used for synthesis of logic circuits (synthesizable code), used for verification purposes of a circuit (can be analogue or digital or mixed signal), can be used by combining synthesis & verification (synthesizable & behavioural code) and it used for netlist representation of a synthesizable circuit (structural code).

The advantages using Verilog HDL are shown below:

- Easy to write.
- Easy to understand as it similar to C program.
- Easier to learn compared with VHDL.

Implementation

Verilog is a hardware descriptive language (HDL) which is generally used to model electronic system, that is, we can design a circuit, and the function of circuit can be control by Verilog coding. Thus, design and verification can be done using Verilog designing. Similarly, traffic light signal controlling can be done using Verilog (hardware descriptive language). so now we have design the traffic light signal system with Verilog using sequence detector method.

We have considered a T - shaped road as shown in figure 1 and heavy load of traffic is present over this road where we have to control it using traffic signal.

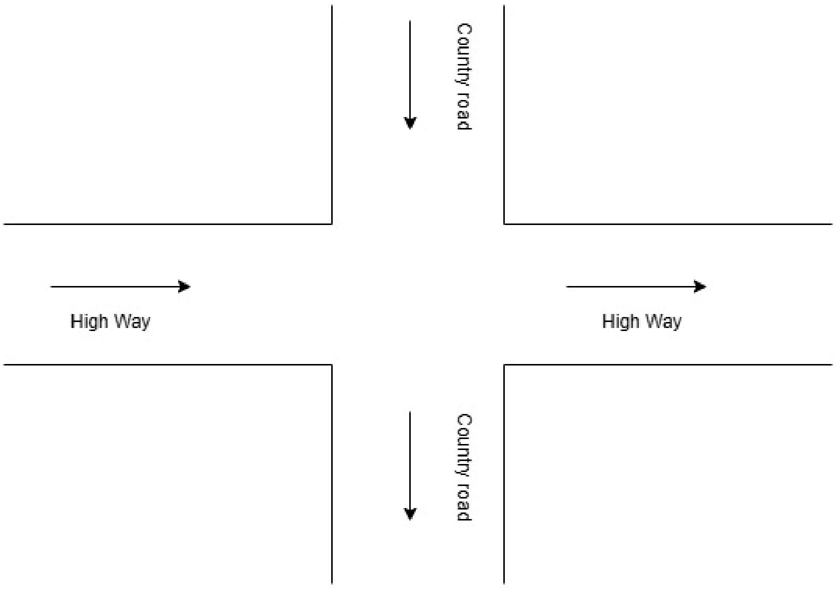

Figure 1 proposed road architecture

In Figure 1, we assume there is less traffic on the countryside road and more traffic on the highway road. As mentioned above, we are prioritizing the highway over the countryside road. The traffic signal on the highway turns red whenever a vehicle is detected on the countryside road. Once there are no vehicles on the countryside road, the highway signal changes back to yellow and then to green.

To detect vehicles, we use a sensor. As soon as the sensor detects a vehicle, it sends a signal to the traffic controller.

There is a structured pattern in the signal color transition to enhance safety and reduce driver confusion. The signal does not switch immediately from green to red or from red to green; instead, it follows a phased approach. During a red-to-green transition, the signal first turns yellow, allowing drivers to prepare for movement, before finally changing to green to indicate they can proceed. Similarly, in a green-to-red transition, the signal first changes from green to yellow, alerting drivers to slow down and prepare to stop, before eventually turning red.

This gradual color transition serves as an additional safety measure, reducing abrupt stops and preventing potential accidents that could occur if drivers had insufficient time to react to an immediate color change. Such phased signaling is especially beneficial in high-traffic areas where maintaining predictable traffic flow is essential. This approach, illustrated in Figure 2, ensures that drivers are given clear visual cues, allowing for a smooth and safe driving experience.

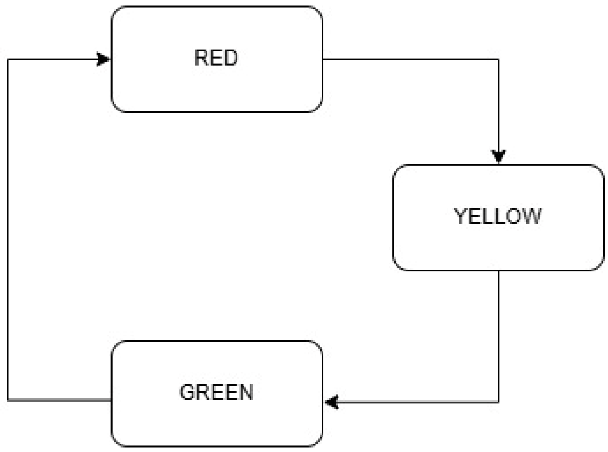

Figure 2 signal transition

- Green light indicates that there is no traffic and there is easy flow of vehicles in that route/direction.
- Red light indicates that there is a traffic jam and that route is blocked for the vehicles to move and,
- Yellow light indicates that the route has medium flow of vehicles.

In verilog code, am using vehicle as the keyword for detecting the presence of vehicle

- If vehicle = 1; presence of vehicle in country road is detected
- if vehicle = 0; presence of vehicle is not detected in country road.

Following are the binary values given to the three colours.

- RED = 00;
- GREEN = 01;
- YELLOW = 10;

State Models

State variable	Binary value	Highway road traffic color	Country road traffic color
S0	000	GREEN	RED
S1	001	YELLOW	RED
S2	010	RED	RED
S3	011	RED	GREEN
S4	111	RED	YELLOW

Table 1 State variables and the assignments and their corresponding change in traffic lights for each state

From the Table 1, In the traffic controller system, signal colors for the highway and country roads follow a structured, safety-oriented sequence across five states, designed to optimize traffic flow and prevent accidents. Beginning with **State S0** (binary 000), the highway road signal is **GREEN**, allowing vehicles to move freely, while the country road signal is set to **RED** to restrict access. This prioritization reflects the higher volume and speed on highways. As the system advances to **State S1** (binary 001), the highway signal changes to **YELLOW**, signalling drivers to prepare to stop, while the country road remains **RED**. This cautious transition helps reduce abrupt halts, allowing drivers ample reaction time.

When reaching **State S2** (binary 010), both the highway and country road signals are set to **RED**, bringing all traffic to a stop. This brief pause, with no vehicle movement allowed, establishes a buffer, ensuring a safe, conflict-free transition between the highway and country road signals. In **State S3** (binary 011), the system prioritizes the country road: the highway signal remains **RED**, while the country road signal turns **GREEN**, allowing traffic to flow freely in that direction.

Finally, in **State S4** (binary 111), the country road signal transitions to **YELLOW**, signalling drivers to prepare for an upcoming stop, while the highway signal remains **RED**. This phased transition is essential for smoothly rerouting priority back to the highway, ensuring the return to **State S0** where the highway receives a **GREEN** signal again.

This sequence supports safety and efficiency, giving drivers clear cues and ample time to respond. By carefully managing traffic priorities and establishing predictable signal changes, the controller system reduces the risk of confusion or collision. This setup is crucial in maintaining organized traffic flow on both the high-speed highway and the lower-traffic country road. Here we are neglecting the red-to-red combination for country road, because we are assuming there is less traffic on country road. Here the default state is **State S0,** which means high way is always functional huge vehicle so we can give more consideration to the high way road.

State diagram

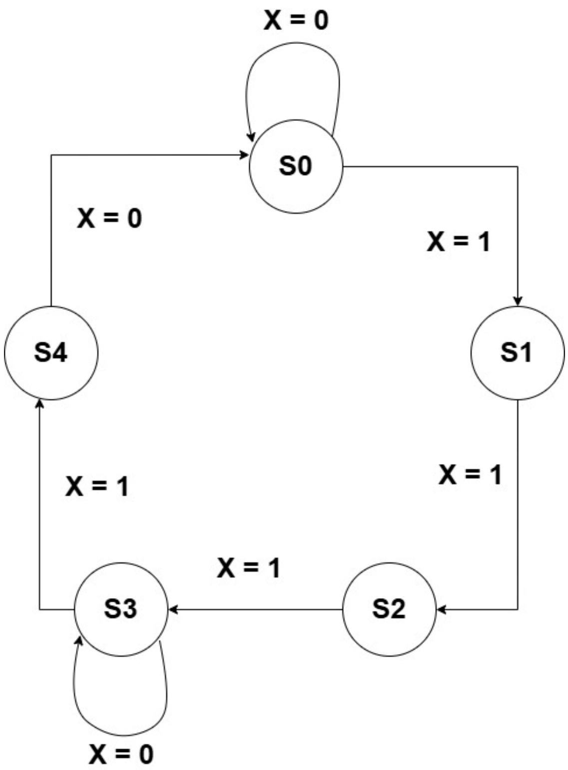

Figure 3 state diagram of the traffic controller

From the Figure 3 state diagram for the traffic controller illustrates how traffic signals transition across five distinct states (S0, S1, S2, S3, and S4) based on an input variable, X, which likely represents the detection of a vehicle on the country road. This system is designed to manage the traffic flow on both the highway and country roads, giving priority to the highway when the country road is clear and allowing a safe, orderly transition when a vehicle is detected on the country road.

In **State S0**, the highway road signal is **GREEN**, allowing traffic to move freely on the highway, while the country road signal remains **RED**, restricting access. This state is maintained as long as X = 0, meaning there are no vehicles on the country road. However, if a vehicle is detected on the country road (when X = 1), the system transitions to **State S1**. In this state, the highway signal changes to **YELLOW** while the country road signal remains **RED**. The purpose of this state is to warn drivers on the highway to prepare to stop, signaling an upcoming change in priority.

When the system moves to **State S2**, both highway and country road signals are set to **RED**. This brief pause ensures all traffic is halted before switching access from the highway to the country road, creating a buffer for safer transitions. While in S2, if X=1 (indicating that the vehicle is still present on the country road), the system advances to **State S3**.

In **State S3**, the highway signal stays **RED**, and the country road signal changes to **GREEN**, allowing traffic to flow on the country road. This state persists as long as X = 1, allowing continuous movement for vehicles on the country road. When X = 0 (indicating that there are no more vehicles waiting), the system proceeds to **State S4**.

In **State S4**, the highway signal remains **RED**, while the country road signal switches to **YELLOW**. This state serves as a warning for country road drivers to prepare to stop, signalling the end of their priority period. Once the country road is clear and X=0X = 0X=0, the system transitions back to **State S0**, where the highway signal turns **GREEN** again, resuming its priority.

For the transition of the State S1 to S2 to S3, time delay is considered and also for the transition of the S4 to S3

For the transition for the S0 to S1, we need the reference of vehicle sensor value for transition

For the transition for the S3 to S4, we need the reference of vehicle sensor value for transition

The time delay is consider as follows:

- YELLOW to RED delay = 3-time unit
- RED to GREEN delay = 2-time unit.

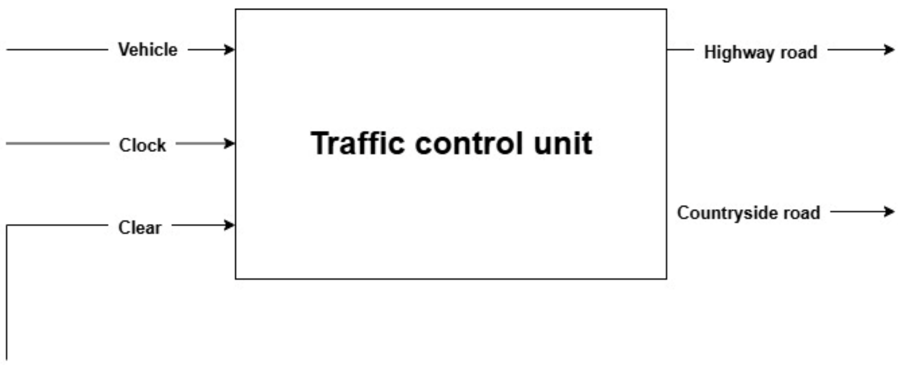

Figure 4 traffic control unit

From the figure 4, The diagram represents a traffic control unit designed to manage the flow of vehicles at the intersection of a highway road and a countryside road. The unit employs a straightforward yet effective approach to control traffic signals based on input from vehicle detection, clock signals, and a default setting. The input and output ports of this system are crucial for its operation.

Inputs:

1. **Vehicle Input:** This input detects the presence of a vehicle on the countryside road. When a vehicle is detected, the unit receives a signal indicating that there is traffic waiting to enter the highway road.
2. **Clock Input:** The clock signal provides the timing mechanism for the traffic control unit. It ensures that the traffic signals are updated at regular intervals by changing on every positive clock edge. This synchronization allows the system to operate in a timely and orderly manner.
3. **Clear Input:** The clear input acts as a default setting for the traffic control unit. When the clear input is active, it ensures that the highway road has a green signal, allowing vehicles to pass through without interruption, while the countryside road has a red signal, stopping vehicles from entering the highway.

Outputs:

1. **Highway Road Signal:** This output controls the traffic signal for the highway road. By default, when the clear input is active, the highway road is given a green signal.
2. **Countryside Road Signal:** This output controls the traffic signal for the countryside road. By default, when the clear input is active, the countryside road is given a red signal.

The traffic control unit's operation begins with the clear input setting the initial conditions: the highway road remains green, and the countryside road remains red, ensuring smooth flow of traffic on the highway. When a vehicle is detected on the countryside road (through the vehicle input), the control unit prepares to alter the traffic signals. On the next positive edge of the clock signal, the system updates the signals: the highway road signal turns red, and the countryside road signal turns green, allowing the detected vehicle to proceed onto the highway.

This dynamic control of traffic signals based on real-time vehicle detection and clock synchronization optimizes traffic flow, reduces congestion, and enhances safety at the intersection. The clear input's role as a default setting maintains order when there are no vehicles on the countryside road, ensuring that highway traffic is not unnecessarily halted. Overall, this traffic control unit exemplifies how logical inputs and outputs can be effectively used to manage and streamline vehicle movement at critical junctions.

Verilog Code

Design module

```
module traffic_controller_unit(
HW, CR, clock, vehicle, clear
    );
    // defining the delay of Yellow to Red light transition delay
    parameter Y_to_R_delay = 3;

    // defining the delay of Red to Green light transition delay
    parameter R_to_G_delay = 2;

    input clock, clear;
    // for checking if their is any vehicle is their on the country road
    input vehicle;
    /*
    HW: high way
    CR: Country Road
    2 bits for three state of signals
    Red: 0, Yellow: 1, Green: 2
    */
    output [1:0] HW, CR;

    reg [1:0] HW, CR;

    // status of lights
    parameter RED = 2'd0, YELLOW = 2'd1, GREEN = 2'd2;

    // state definition
```

```
/* {High way : Country Road}
S0 = GREEN RED
S1 = YELLOW RED
S2 = RED RED
S3 = RED GREEN
S4 = RED YELLOW
*/
parameter S0 = 3'd0, S1 = 3'd1, S2 = 3'd2, S3 = 3'd3, S4 = 3'd4;

// Internal state variable
reg [2:0] state;
reg [2:0] next_state;

// state changes at postive edge of clock only
always @(posedge clock)
   begin
//       if (clear) state <= S0;
//       else state <= next_state;

       assign state = clear ? S0 : next_state;
   end

// assigning the high way and country road values
always @ (state)
   begin
       case (state)
           S0 : begin HW = GREEN; CR = RED; end
           S1 : begin HW = YELLOW; CR = RED; end
           S2 : begin HW = RED; CR = RED; end
           S3 : begin HW = RED; CR = GREEN; end
```

```
            S4 : begin HW = RED; CR = YELLOW; end
        endcase
    end

// state machine using the case statement
always @ (vehicle or state)
    begin
        case (state)
            S0 : next_state = vehicle ? S1 : S0;
            S1 : begin
                    repeat (Y_to_R_delay) next_state = S1; next_state = S2;
                 end
            S2 : begin
                    repeat (R_to_G_delay) next_state = S2; next_state = S3;
                 end
            S3 : next_state = vehicle ? S3 : S4;
            S4 : begin
                    repeat(Y_to_R_delay) next_state = S4; next_state = S0;
                 end
            default : next_state = S0;
        endcase
    end

endmodule
```

Test bench

```
module traffic_controller_unit_tb();

    // Inputs
    reg clock;
    reg clear;
    reg vehicle;

    // Outputs
    wire [1:0] HW;
    wire [1:0] CR;

    // Instantiate the traffic controller unit
    traffic_controller_unit uut (
        .HW(HW),
        .CR(CR),
        .clock(clock),
        .vehicle(vehicle),
        .clear(clear)
    );

    // Clock generation
    initial begin
        clock = 0;
        forever #5 clock = ~clock; // Clock period = 10ns
    end

    // Stimulus process
    initial begin
```

```
    // Initialize inputs
    clear = 1;
    vehicle = 0;

    // Apply reset
    #10 clear = 0; // Clear reset after 10ns

    // Case 1: No vehicle on the country road, HW should stay GREEN
    vehicle = 0;
    #50;

    // Case 2: Vehicle detected on country road, transition from S0 -> S1 -> S2 -> S3
    vehicle = 1;
    #50;

    // Case 3: Vehicle stays on the country road, HW stays RED, CR stays GREEN
    vehicle = 1;
    #50;

    // Case 4: No vehicle, CR transitions to YELLOW and HW returns to GREEN
    vehicle = 0;
    #50;

    // Case 5: Toggle clear signal, state should reset to S0
    clear = 1;
    #10 clear = 0;

    #50 $finish;
end
```

```
    // Monitor the outputs
    initial begin
        $monitor("Time = %0t | HW = %0d | CR = %0d | State = %0d", $time, HW, CR,
uut.state);
    end

endmodule
```

Results

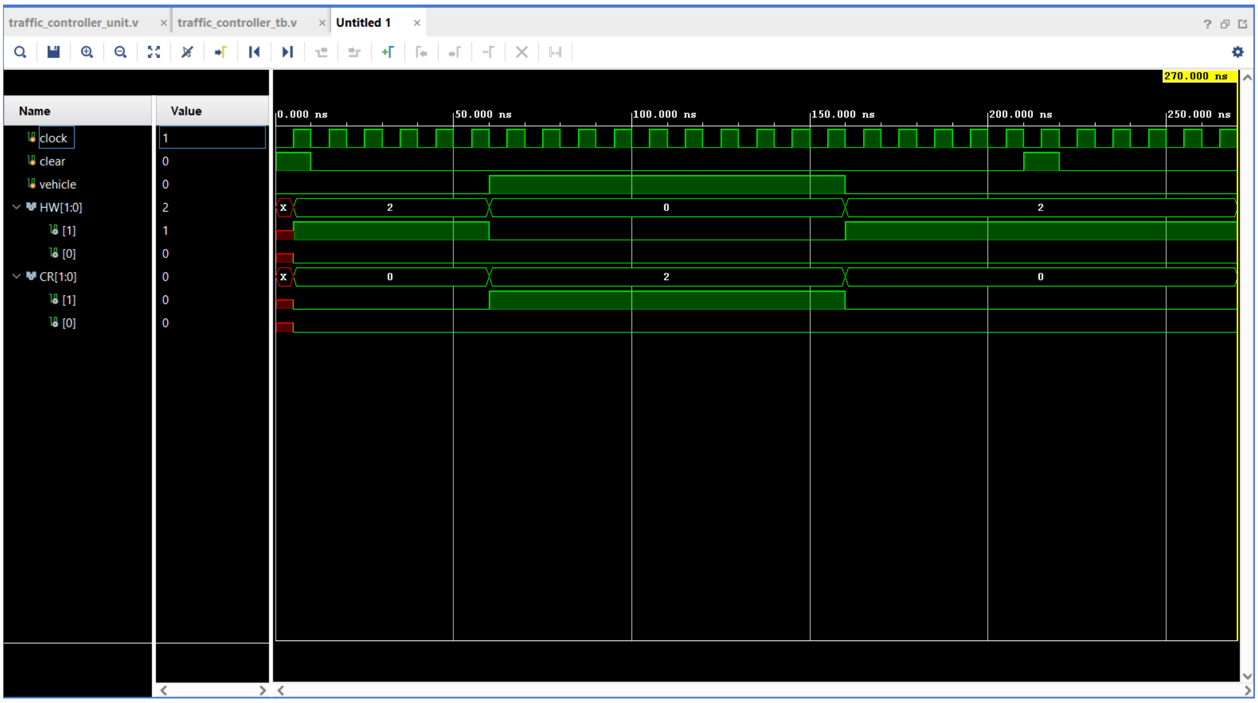

Figure 5 output waveform

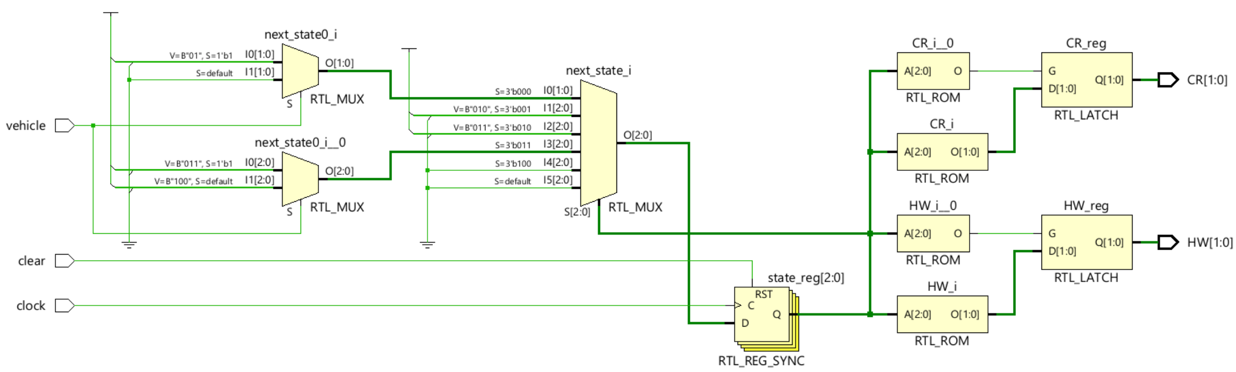

Figure 6 shematics for traffic control unit

Conclusion

The design and implementation of a traffic control system using Verilog HDL for a T-shaped intersection exemplify the practical application of digital logic design to solve real-world problems. This system, which manages traffic flow at the junction of a highway and a countryside road, leverages a sequence detector method and logical inputs and outputs to optimize traffic management, ensuring safety and efficiency.

The traffic control unit is designed to handle the intersection where a highway, with higher traffic volumes, meets a less busy countryside road. The system uses three main inputs: vehicle detection, clock signals, and a clear input to set default conditions. The vehicle input detects the presence of vehicles on the countryside road, signaling the need for the system to adjust the traffic lights. The clock input ensures that traffic signals are updated at regular intervals, maintaining synchronized and timely operations. The clear input sets the initial condition, maintaining a green light on the highway and a red light on the countryside road, thereby prioritizing highway traffic by default.

The system operates across five states (S0 to S4), with each state dictating the status of the traffic lights based on the inputs received. In State S0, the highway signal is green, allowing free movement of vehicles, while the countryside signal is red, restricting access. This state is maintained as long as no vehicle is detected on the countryside road (vehicle input = 0).

When a vehicle is detected on the countryside road (vehicle input = 1), the system transitions to State S1, where the highway signal changes to yellow while the countryside signal remains red. This yellow signal acts as a warning for highway drivers to prepare to stop, enhancing safety. The system then moves to State S2, where both signals turn red, ensuring all traffic is halted before transitioning control. This red-to-red state serves as a safety buffer, preventing potential collisions.

In State S3, the highway signal remains red, and the countryside signal turns green, allowing traffic from the countryside road to proceed. This state continues as long as there is a vehicle on the countryside road (vehicle input = 1). When the countryside road is clear (vehicle input = 0), the system transitions to State S4, where the countryside signal changes to yellow, warning drivers to prepare to stop, while the highway signal remains red. Finally, the system returns to State S0, resuming the default green signal on the highway and red on the countryside road.

The phased signal transitions (green to yellow to red and vice versa) play a critical role in ensuring driver safety and reducing confusion. By providing clear visual cues and adequate reaction time, these transitions help prevent abrupt stops and potential accidents. The use of logical inputs and clock synchronization ensures that the system responds accurately to real-time traffic conditions, optimizing traffic flow and reducing congestion at the intersection.