



Design of VLSI Based Power-Saving Streetlight System and Automatic Traffic Controller with Automatic Transfer Switch

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Abstract: The number of road accidents is increasing due to the power outage of the traffic light system and the streetlight system's maintenance fees was too high. Therefore, a proposed solution that includes automatic traffic light controller, energy-saving streetlight controller and automatic energy transfer switch had been designed to overcome these issues. The proposed traffic light is on a four-way junction which has one sensor for each direction. This traffic light controller has 3 different conditions which will act differently when all directions had detected vehicle, or when vehicle is not detected, or when vehicle is detected in some directions. Apart from this, a streetlight controller is also designed to minimize the power usage and the streetlight will only turn on when vehicle is detected. The proposed solution was designed in Quartus 18 via Verilog Hardware Description Language (HDL) and functional simulation is used to verify the proposed circuit is functioning correctly. The Verilog HDL files were input to the Synopsys Design Compiler for logical synthesis and IC Compiler for physical synthesis. After both logical and physical synthesis, the design was then analysed in terms of speed, area, and power consumption through the generate report commands. Besides, the proposed energy-saving streetlight was programmed into Field Programmable Gate Array (FPGA) and connected with AC Dimmer Module and LED bulb to measure the power consumption and the reduction of power consumption of the LED bulb. As for the result, the designed chip had a total area of $392.002199 \mu m^2$, positive critical timing slack of 0.1 ns and power consumption of 0.1196 mW. The streetlight was able to achieve a reduction in power consumption by 77.87%.

Keywords: Automatic traffic system, power saving streetlight, automatic energy transfer switch, logical synthesis, physical synthesis

1. Introduction

Traffic systems are one of the most critical aspects that impact the daily lives of regular road users. For instance, traffic light controllers provide instructions to road users and tell them when to pass the roads and when to stop. A good traffic system leads to the smooth flow of traffic. For example, an ideal traffic system can control the flow of vehicles properly and does not create excessive waiting time for road users. However, some of the current traffic light systems do not have a backup power supply in the event when the traffic light unexpectedly shuts down due to a sudden loss of power, or if it does, the system does not have a mechanism to minimize the power usage. As for the streetlight system, it should provide intense illumination during the onset of dark weather conditions, thus ensuring that road users can travel in a safe and well-lit environment. Furthermore, these light sources have been shown to improve the peripheral vision of drivers and provide some sense of security for road users. Nonetheless, the cost of maintenance of the streetlights is too high, where over RM 80 million was spent in 2018 for the maintenance of these facilities [1]. Therefore, to provide a safer traffic light control system and a more energy-efficient streetlight system that utilizes current technology, a new traffic system should be introduced. The proposed system will utilize a solar source and power from the grid line

according to the situation faced. A solar source is widely used in traffic light systems and also as a backup system [2]-[5]. The Field Programmable Gate Array (FPGA) has also been used in traffic light controllers [6]-[8]. Thus, a combination of these will further enhance the proposed system.

2. Methodology

This project is focused on the design of an energy-saving street light system and a stable traffic light system that can be employed during a power outage using Verilog codes which are integrated into a Very Large-Scale Integration (VLSI) design for optimizing its area and power consumption.

2.1 General Methodology

The first part of the project is to design the circuit for the system, including the controllers. The next step is to transform the design into Verilog HDL codes and tested via functional simulation. Then it is tested using FPGA in the Quartus Prime to verify the function of the proposed solution is correct.

Third, the design is input into the Design Compiler of Synopsys tool for logical synthesis. During the logical synthesis phase, design constraints were introduced to ensure the design achieves the desired timing goals and other design requirements such as area and power consumption. After the successful logical synthesis, the design is written in DDC format. The DDC format contains a design netlist, constraints, and attributes so that the design can be re-read into Design Compiler or IC Compiler.

Afterward, physical synthesis is conducted via the IC Compiler from the Synopsys Tools. First, the design is initialized in ICC, and then the floorplan is defined in it. After the floorplan is successfully defined, the placement of the cells is performed and followed by the Clock Tree Synthesis (CTS). During CTS, clock tree skew is analysed and a timing report is generated. Routing is then performed to route the clock nets and followed by routing the signal nets. Then post-route optimization is performed on timing, logical and physical Design Rules Check. Lastly, the design for manufacturability is performed and the design is exported into GDSII format. Lastly, to verify the power-saving feature of the proposed streetlight controller, hardware was set up and a wattmeter was used to record the power consumption of the system and the results of reduction were calculated. The flow in designing the proposed system is according to the digital design flow as introduced by Synopsys [9], [10].

2.2 Automatic Traffic Controller

This traffic controller is designed for a four-way traffic junction and has two states, one is when a vehicle is present and another one is when no vehicle is present. Both states will have different times of green light count for the traffic lights. When there is no vehicle present, the green light will be significantly shorter for every direction, while the green light will be longer for the direction that the vehicle presents for more vehicles to pass the traffic junction.

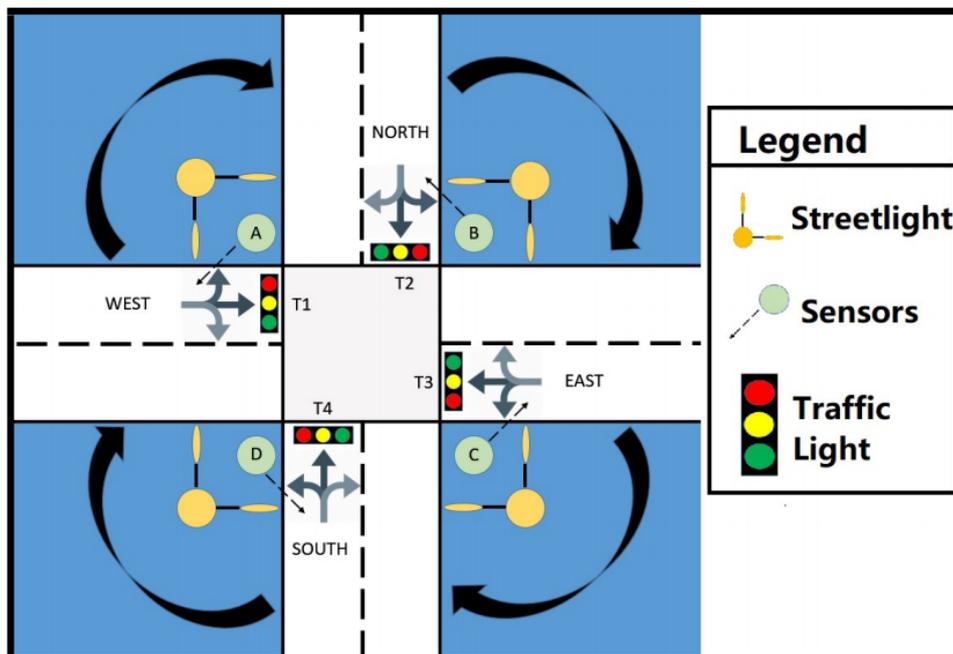


Fig. 1 - Road structure of the four-way junction

Fig. 1 shows the road structure of the four-way junction. There were four traffic lights, one facing each direction. The T1 traffic light is indicating the traffic instruction for vehicles in the west direction, T2 for the north direction, T3 for the east direction and T4 for the south direction. Then four sensors around the traffic junction, where sensor A detects traffic from the west direction, sensor B detects the north direction, sensor C detects the east direction and sensor D detects the south direction.

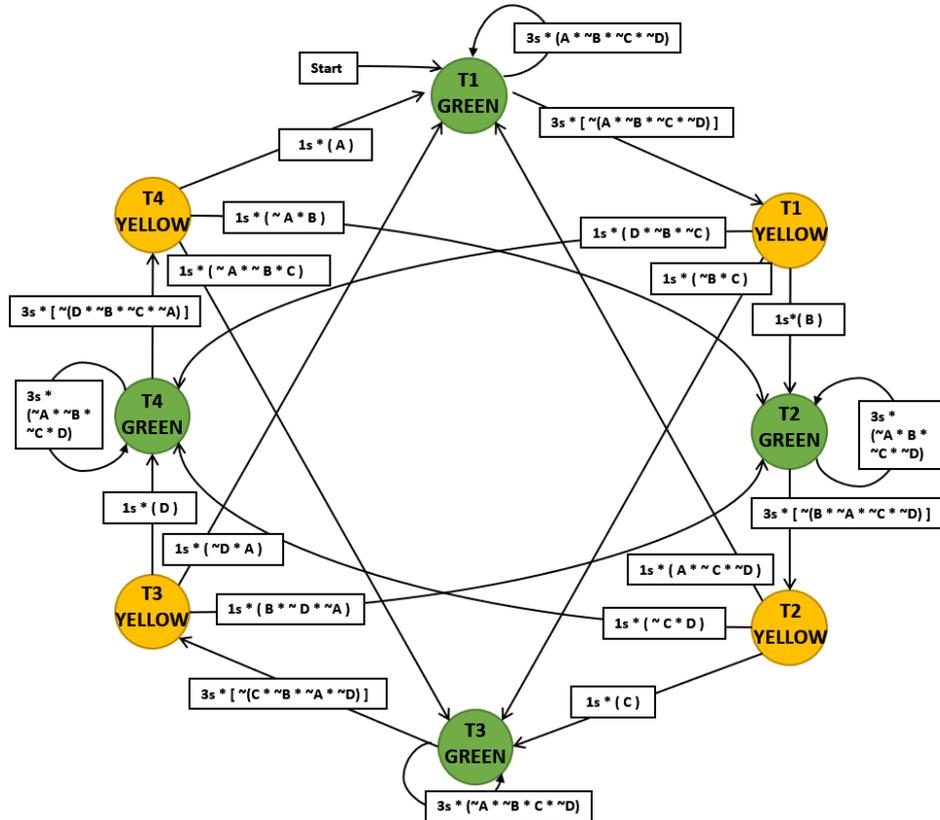


Fig. 2 - State diagram of the automatic traffic controller

Fig. 2 shows the state diagram of the automatic traffic controller, where there were two states for each traffic light T1, T2, T3 and T4. For every state, there were unique conditions that will determine what will the traffic light controller does next based on the state diagram in Fig. 2. In the case when vehicles were not detected in all directions, the traffic light controller will enter the idle state where the green lights toggle between T1, T2, T3 and T4. But if suddenly a vehicle was detected in any direction, the current traffic light will finish the green light first, and then give the green light to that direction with the vehicle. This is the main difference between the proposed system with the existing system where the proposed system can give a priority to the direction when a vehicle is detected in that particular direction.

2.3 Power-Saving Streetlight Controller

The power-saving streetlight controller will be able to sense the presence of the vehicle far before the vehicle reaches the traffic junction. If the vehicle is detected by the infra-red (IR) sensors, this controller will send a signal to the streetlight to increase the light intensity during the nighttime, else if there is no vehicle, the streetlight will be dimmed down by using Pulse Width Modulation (PWM) technique. The maximum light intensity will as 100% duty cycle while the no-car-present light intensity is 40% of the duty cycle. PWM allows streetlights to dim according to the maximum duty cycle of the signal. Therefore, this will create an energy-efficient streetlight as the streetlight can light up the surrounding environment when no vehicle is present and able to provide maximum light to the vehicle when a vehicle is detected by the sensor.

2.4 Automatic Energy Transfer Switch

The transfer switch will read the voltage value of both the solar battery and grid power, then it will determine the suitable power source for the system. The transfer switch will primarily utilize solar power, only when the r power is not available then it will switch the whole system toward the power. This is to prevent the power outage for the grid power and make use of the solar power to lower the maintenance cost. The concept is similar to Kasali *et al.* [11].

2.5 System Block Diagram

The proposed solution has 3 controllers as sub-modules. Then for controlling all the 3 controllers, a top controller is introduced. The approach to designing the whole controller is using the hierarchical method. Therefore, a Top Module is the highest-level hierarchical block that includes all the sub modules. Fig. 3 shows the block diagram of the system which contains all the sub-modules which are the automatic traffic light controller, power-saving streetlight, and automatic energy transfer switch.

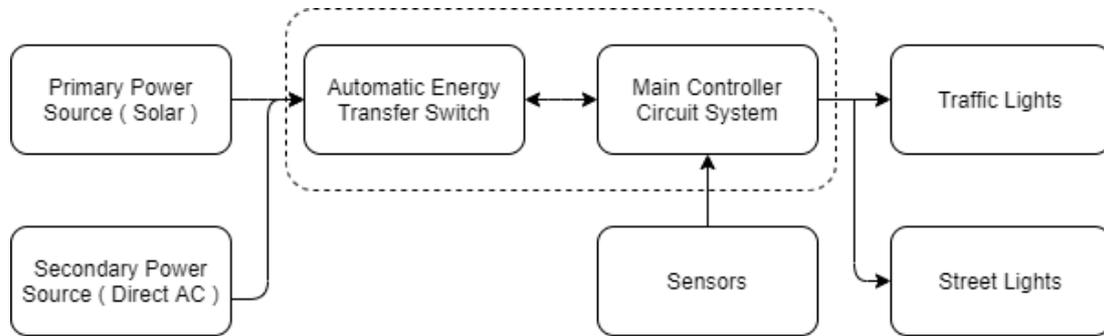


Fig. 3 - System block diagram

2.6 Hardware Testing for Power-Saving Streetlight Controller

To prove that the energy-saving streetlight is working and can reduce up to 30% of the total power consumption, hardware involving FPGA, PWM voltage regulator controller and LED bulb is set up. Fig. 4 shows the circuit connection for the testing. PWM signal from the FPGA is connected to the PWM input port of the PWM voltage regulator, then the power source from the 240V AC or solar source is connected to the upper terminal block and the load (LED bulb) is connected to the lower terminal block. The input source is connected to a wattmeter for measuring the power consumption for this system before being connected to the input port of the PWM voltage regulator controller. Then the input of the FPGA is connected to the IR sensor and Light Dependent Resistor (LDR) sensor, for indicating the presence of the vehicle and the light intensity of the surrounding environment.

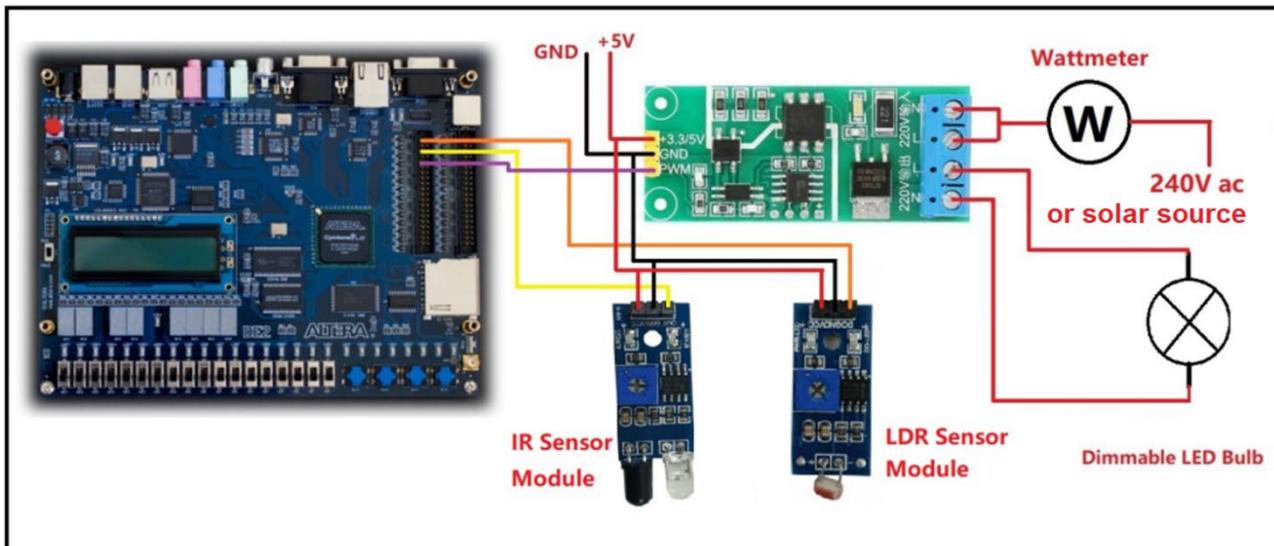


Fig. 4 - Circuit connection for energy-saving streetlight system

3. Results and Discussions

3.1 Automatic Traffic Controller

The traffic controller designed was simulated in Quartus 18 Prime for its functional simulation results. Fig. 5 and Fig. 6 show the simulation results of the traffic controller when dealing with different conditions. Fig. 5(a) shows the result when no vehicle was detected in every direction, therefore an equal amount of green light signal is given to every direction and toggling between T1, T2, T3, and T4. After every ending of the green light, there will be a 20 ns of yellow light, and if in that direction did not have any yellow or green light, then it will turn to a red light state.

Fig. 5(b) shows the result when only one direction was detected with the vehicle, and in the other 3 directions, there were no vehicles detected. The green light signal was only given for the direction (T1) which had detected a vehicle, while the other (T2, T3 and T4) will be red. This condition will remain until another direction has detected a vehicle or that direction (T1) was cleared with the vehicle.

Fig. 6(a) shows the simulation for vehicles detected in 2 directions. The green light will only be toggled in those two directions while the other two directions are constantly on the red line, unless traffic is detected. The period for green light will be constant for that two or above directions that present with vehicles.

Fig. 6(b) shows the simulation result of the automatic traffic controller when all directions detected the vehicle. The pattern of the traffic light will be the same as when no vehicle is detected at all the traffic junctions, which means no extra green light or attention to any of those four directions.

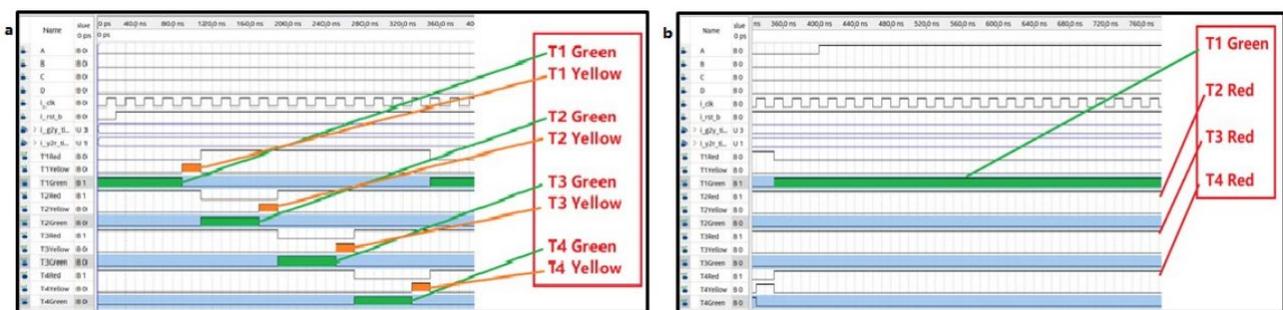


Fig. 5 - (a) result 1; (b) result 2

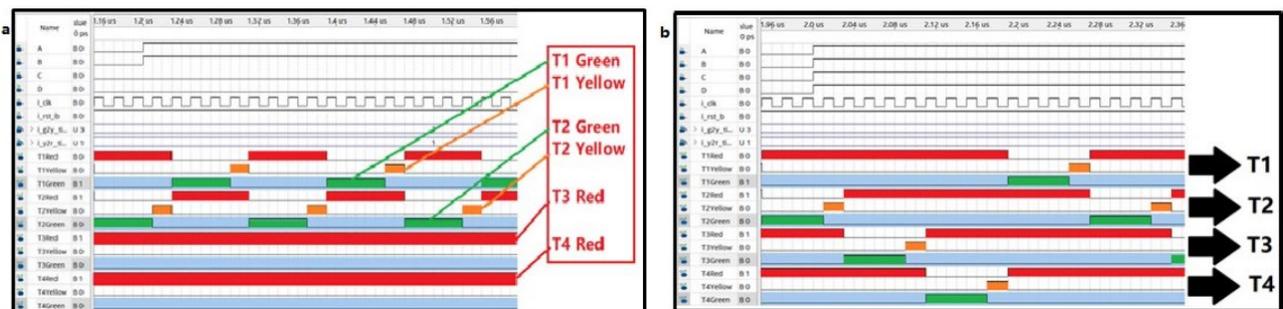


Fig. 6 - (a) result 3; (b) result 4

The simulation results as shown in Fig. 5 and Fig. 6 had shown that the automatic traffic light controller has worked well and performed its function. These are under normal operation and also when the sensor detects the presence of a vehicle in a certain direction.

3.2 Power-Saving Streetlight Controller

Fig. 7 illustrates the result of power saving for the system. Waveform $i_dc[1]$ indicates the light detect sensor, which detects the light intensity of the surrounding environment while the $i_dc[0]$ is the vehicle sensor detector which detects the presence of a vehicle. So, when the surrounding is dark, the streetlight will be turned on, but with a lower light intensity that is generated by the PWM if there is no vehicle present. This helped to reduce the power consumed by the streetlight as the streetlights were not always turned on to the maximum. However, when there is a vehicle present, the streetlight will be turned on to maximum to provide maximum illumination for the road user. The results show that the streetlight controller had functioned well according to the specifications.

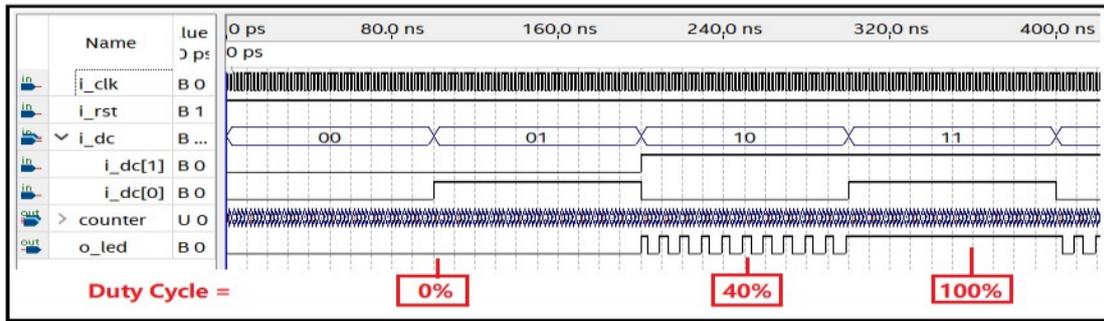


Fig. 7 - Result of power-saving streetlight controller

3.3 Automatic Energy Transfer Switch

The automatic energy transfer switch is aimed to control the power source of the whole system. It will read the voltage from both the solar battery and grid power source, then determine the suitable power source to connect to the loads. By default, the power source will be set to a solar battery, and if the solar battery is not enough to supply the power, then the grid power comes in the help. But if both the grid power and solar battery are out, the switch will connect the load to a grid power source to prevent the damage to the solar battery (overuse), until the grid power is available again and the solar battery is recharged and suitable to be used again.

Fig. 8 shows the simulation result of the automatic energy transfer switch on the Quartus Prime using the University Program Vector Wave File (VWF). Different conditions of both grid power and solar battery voltage level had been simulated. The first condition is when the solar battery is stable and usable, the output will be set to one, which means the load is connected to the solar battery. Second, if the solar battery is low (unable), the output will be 0 and the load will be disconnected from the solar battery and reconnected to the grid power source. Lastly, when both solar battery and grid power are not available, which means that the system is down, the output will be 0 and the loads are connected to a grid power source to prevent the damage to the solar battery. The simulation results show that the automatic energy transfer switch has worked well and performs its function.

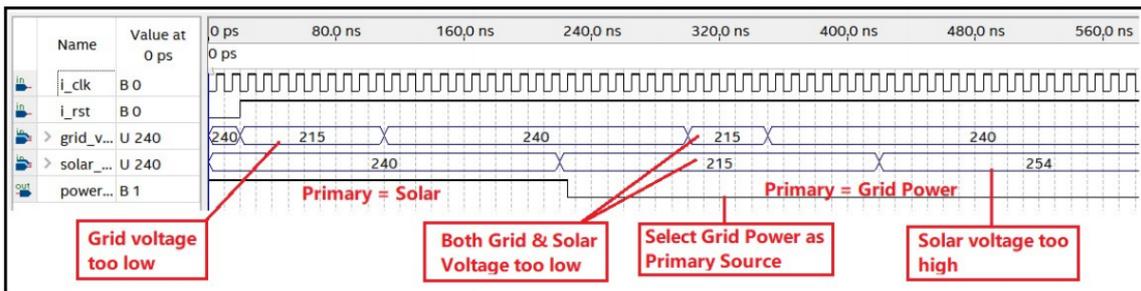


Fig. 8 - Result of automatic energy transfer switch

3.4 Top Module

After all those sub modules were completed and had been verified to work successfully and achieved the expected behavior, those sub modules were then integrated into Top Module. This module will control all the sub-modules and the whole operation of the system. Fig. 9 is the simulation result of the Top Module, showing the expected behaviors of all other sub-modules when the respected inputs are given. This Top Module will hold everything to other sub-modules, and changes that are made on this module will affect other outputs.

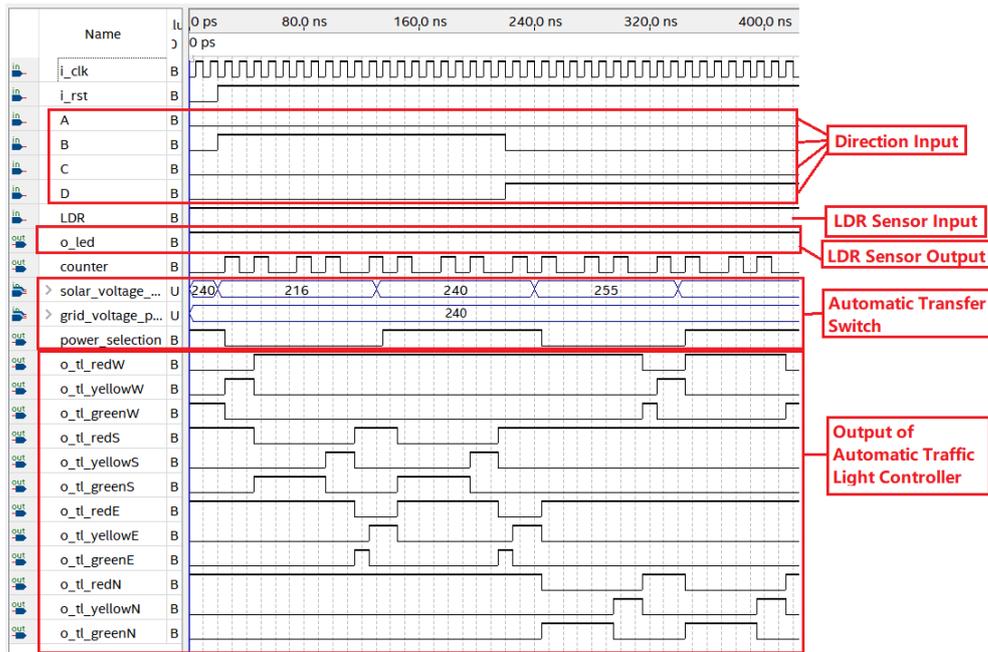


Fig. 9 - Result of top module

3.5 Streetlight Power Reduction Analysis

Fig. 10 shows the actual connection of the hardware including the DE2-115 board, AC Dimmer Module, IR Sensor Module, LDR Sensor Module, wattmeter and LED bulb based on the circuit design as depicted in Fig. 4. Fig. 10(a) shows the result of a 0% duty cycle when no vehicle is detected and during the daytime, the power consumption of the LED bulb is 0.00 W. Then Fig. 10(b) shows the results of a 40% duty cycle when nighttime was detected and no vehicle was detected, the power consumption of the LED bulb is 1.6 W.

Fig. 11 shows the results of a 100% duty cycle when nighttime and vehicle were detected, where the power consumption of the LED bulb is 7.2 W. The results of power consumption of LED lamps were calculated based on the value of the wattmeter on each duty cycle. The final value obtained on power reduction for the proposed controller was 77.78%.

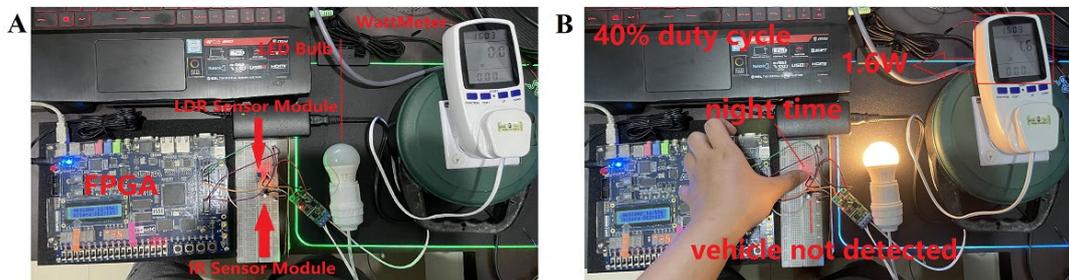


Fig. 10 - (a) 0% duty cycle; (b) 40% duty cycle

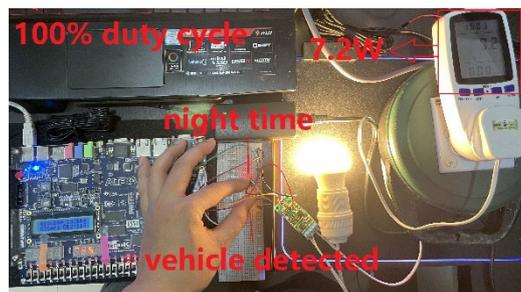


Fig. 11 - 100% duty cycle

3.6 Design Compiler Report

The project is then synthesized logically in Design Compiler after the development in Quartus Prime. After the process of logical synthesis, the static timing analysis was available for the project. Default report_timing command was used to check the timing analysis of the project in Design Compiler based on the constraints created, report_timing command will generate setup and hold a timing report of the critical path. Besides timing reports, power and area reports can be obtained by inserting the report_power command that generates the power report and the report_area command that generates the area report for the design. The results were tabulated in Table 1.

Table 1 - Design compiler report

Design Analysis Metrics	Result
Setup Timing (Slack)	0.00 ns
Hold Timing (Slack)	0.42 ns
Power Consumption	0.1199 mW
Area	376.07 μm^2

3.7 IC Compiler Report

After the logical synthesis was conducted in the Design Compiler, the design from Design Compiler is then input into IC Compiler to conduct the physical synthesis process which consists of the definition of floorplan, placement and optimization, clock tree synthesis and optimization, routing, and design for manufacturing. After the processes of physical synthesis, the design analysis metrics can be obtained to do a comparison with the results from the Design Compiler and also with project specifications. The same commands used to generate timing, power, and area reports were inserted into IC Compiler from Design Compiler. The results were tabulated in Table 2. Then the design was synthesized into a chip. Fig. 12 depicts the final layout of the design after physical synthesis.

Table 2 - IC compiler report

Design Analysis Metrics	Result
Setup Timing (Slack)	0.01 ns
Hold Timing (Slack)	0.41 ns
Power Consumption	0.1196 mW
Area	392.00 μm^2

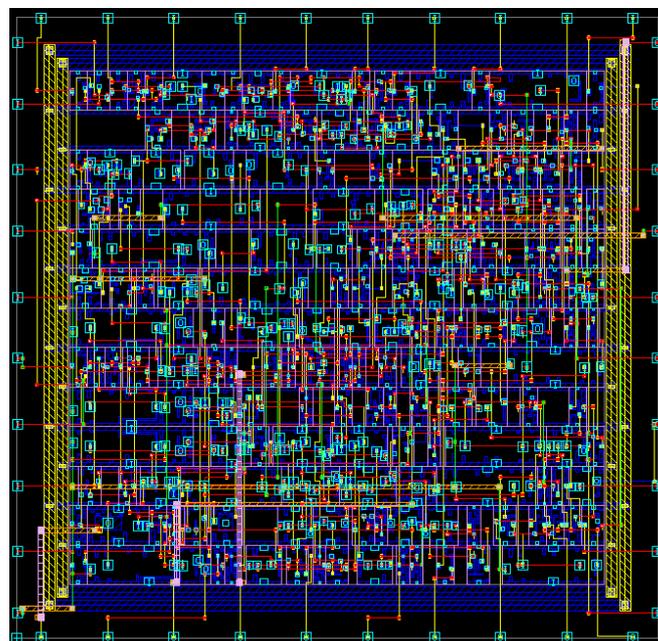


Fig. 12 - Final layout of chip

3.8 Comparison Results of Area, Power and Timing

Table 3 summarizes the result findings from the Design Compiler and IC Compiler in terms of area, power, and timing. From the result, it shows area had been increased for around $16 \mu m^2$, but the setup timing had increased a slack of 0.01 ns, which shows that the chip area is increased to increase the timing in the chip. Nevertheless, this will not affect the overall performance of the system since the difference is too small.

Table 3 - Summary of results

Parameter	After Design Compiler	After IC Compiler
Setup Timing (Slack)	0.00 ns	0.01 ns
Hold Timing (Slack)	0.42 ns	0.41 ns
Power Consumption	0.1199 mW	0.1196 mW
Area	376.07 μm^2	392.00 μm^2

4. Conclusion

In this study, the proposed system that consists of an automatic transfer switch, traffic light controller and energy-saving streetlight controller had been designed in Quartus 18 via Verilog HDL code. Then a functional simulation was carried out in Quartus 18 to verify the proposed system. The system functions correctly under all the specified requirements. Then the designed system is input into Synopsys software Design Compiler for logical synthesis and IC Compiler for physical synthesis, to design the proposed system into an integrated module. The power consumption of the proposed power-saving streetlight was successfully reduced by 77.78%, from the full power of 7.2W to 1.6W. The design had undergone logical and physical synthesis and met the timing constraints with a slack of 0.1 ns, power consumption of 0.1196 mW and total chip area of $392.002199 \mu m^2$.

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