Implementation and Application of Visible Light Communication (VLC) System for Wireless Data Transmission

by

Ammar Zulfadhli Bin Sotiman
14762

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Electrical & Electronic)

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CERTIFICATION OF APPROVAL

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Approved by,

(AP Dr. Nor Hisham Hamid)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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AMMAR ZULFADHLI BIN SOTIMAN

ABSTRACT

The project aims to implement the design of VLC circuit for the real-world application of wireless data transmission. It covers the use of white LEDs and commercial photodiode in order to perform the data transmission. The project started with the simulation of the circuit design by using NI Multisim to show that the circuits applied were relevant and producing the desired outcomes, which were then applied onto the breadboard to show that the design is working. The final output of the project, which is the prototype, is expected to transfer the input data from one laptop to the other laptop by only utilizing the data transmission method of VLC. Some improvements were made later to further improve the prototype.

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ABBREVIATIONS AND NOMENCLATURES

VLC	Visible Light Communication
LED	Light Emitting Diode
FYP	Final Year Project
USB	Universal Serial Bus
TTL	Transistor-transistor Logic
UART	Universal Asynchronous Receiver/Transmitter
OOK	On-Off Keying
DSL	Digital Subscriber Line
ISDN	Integrated Services for Digital Network
RF	Radio Frequency
UTP	Universiti Teknologi PETRONAS

CHAPTER 1
INTRODUCTION

1.1 Background

The fast pace environment of today's modern world demands the rapid growth of communication technology in order to have faster data transmission with high reliability and security. Numerous types of connections were made in the past for data communication, which includes cables, wire lines (e.g. DSL, ISDN, and T1) and wireless connections. Wireless connections enable high speed data transmission by utilizing radio waves as its medium, which is still an ongoing developing technology. Since radio waves are one of the types of waves in the electromagnetic spectrum, researchers have been very interested to utilize visible light as a potential wireless communication in the future, known as Visible Light Communication (VLC), since visible light is another type of waves in the electromagnetic spectrum which is inherently safe to be used than other types of known electromagnetic waves.

The development of light emitting diodes (LEDs) in recent years opened up a new possibility for data transmission. LED technology is greener, cheaper and more energy efficient for illumination purposes, which makes it more favorable to be used than the conventional lighting system using incandescent and fluorescent lamps. A unique attribute of LEDs compared to the incandescent lights is the high speed switching capability, in which the LEDs can switch on and off thousands of times per second. The switching happens at very high speeds far beyond the human eye ability for detection, thus the illumination appears to be constant without any flickering. The use of LED in VLC may help in achieving greater speed in transmitting signals, in addition to the cost reduction for integrating illumination and communication in one device. The implementation of VLC as an indoor and short range communication may also have better security than using radio waves as a method of signal transmission, as visible lights can be easily blocked by physical matters which prevents the data encrypted from being transmitted outside the required perimeter.

1.2 Problem Statement

The current radio frequency (RF) technology as a medium of wireless data transmission is more complex to be installed and may cause security issues as the transmitted signals could travel over a wide range, which may be intercepted and decrypted by certain people and misused the information received. Since visible light is another type of electromagnetic waves, it is possible to replace RF technology with VLC for indoor and short range wireless communication. If visual light communication (VLC) is used rather than the conventional RF communication, cost and complexity reduction of lighting and communication systems can be achieved as both of them are integrated into one by using LEDs. Eventhough this technology looks promising, it is still in research phase and is not commercially available yet. Nonetheless, it can be seen that the researches done regarding VLC in Universiti Teknologi PETRONAS (UTP) was closer to none. Thus, there is a need to promote the concept of VLC and its advantages, in addition to demonstrate the working VLC module. This project should induced further research and development program of VLC in the department and researchers in the campus.

1.3 Objectives

- To research the viability of visible light as a medium of signal transmission
- To implement VLC circuits for data communication system via white LEDs.
- To demonstrate a working prototype as a proof-of-concept for VLC feasibility

1.4 Scope of Study

The research covers the study of VLC to transmit data by utilizing white LEDs. This includes a proper design of a prototype that is able to transmit signal via VLC, in order to show the real implementation of this technology and its feasibility.

CHAPTER 2
LITERATURE REVIEW

2.1 Visible Light Communication (VLC)

The development of efficient blue light emitting diodes (LED) two decades ago led to the development of white illumination LEDs in the market, all thanks to the researches done by the winners of the Nobel Prize in Physics for the year 2014, Isamu Akasaki, Hiroshi Amano and Shuji Nakamura, due to their great contribution in the invention of bright and efficient blue LED, that is an unsolved challenge in the LED industry for over thirty years prior to 1990s (BRIGHT, 2014). There are two ways on creating white light. As it is well-known, white light can be created by combining three of its primary colours, namely red, green and blue lights. Thus, by proper combination of red, blue and green LED technologies, a white illumination source can be created. However, a more popular technique utilized by present devices in order to emit white light involves the use of blue LED that is covered with yellow phosphor (Zeyu, Chau, & Little, 2011). White lights via LEDs opened up a new future in communication technology, namely the visible light communication (VLC).

VLC, with the help of light emitting diode (LED), involves the use of visible light for communication system, in which illumination and wireless communication can be merged together into one module (Komiyama, Kobayashi, Watanabe, Ohkubo, & Kurihara, 2011; Salian, Prabhu, Amin, Naik, & Parashuram, 2013). By having a very high speed on-off response capability, white LEDs are seen to be a very promising device in realizing VLC (Liwei, Fang, Yu, & Yongjin, 2013), in which Salian, Prabhu, Amin, Naik, and Parashuram further explained that the rapid switching between on and off of the LED is way faster than the human eyes can perceive, thus enabling digital signal to be transferred in a high data rate without detection or annoyance to human eyes. Furthermore, Liwei, Fang, Yu, and Yongjin stated that in addition to the high lightening efficiency of white LED, the device consumes low power and having a longer lifespan than standard fluorescent illumination, making LED the most suitable component to be used in VLC system.

Nonetheless, there are some disadvantages of the application of VLC, in which the main obstacles are the distance of data communication and data rate (Haruyama, 2012, 2013). According to Haruyama, the typical distance for VLC is in the range of 100 metres, which is quite short compared to the communication using radio frequency (RF) signal and it can also be easily interrupted by disrupting the line-of-sight between the transmitter and receiver. Besides that, the other problem involving VLC, as explained by Haruyama, is the typically low data rate, ranging between kilobits per second (kbps) to 10 megabits per second (Mbps). However, such problems can be handled and managed to be advantageous. The short distance of VLC and easily interruptible transmission can enhance the security of data transmission, since this property of signal isolation prevents eavesdropping on an in-building communication (Jovicic, Junyi, & Richardson, 2013) and the signal cannot penetrate the building which can be intercepted by others. The typically low data rate, on the other hand, can be overcame in the near future, as many researches has been done in increasing the data rate of VLC, in which one of the researches was able to obtained the data rate of between 540 Mbps and 1080 Mbps by designing a Gigabit front-end system using single channel VLC (Pisek, Rajagopal, & Abu-Surra, 2012). A promising potential of Gigabit data rate communication is seen through various researches done, in which some of them includes flicker mitigation and dimming support of VLC in order to have energy efficiency and proper illumination in tandem with maintaining communication and data transmission (Rajagopal, Roberts, & Sang-Kyu, 2012).

CHAPTER 3
METHODOLOGY

3.1 Research Methodology

Further researches of the suitability of VLC are done by using all resources available, which includes the use of online journals, books and internet websites. The researches were also done to find the most suitable circuit design to be implemented in the project and the possible improvements to be applied onto the design.

In order to fulfill the objectives of this project, it is crucial in using simulation software and electronic devices in designing the prototype for VLC. However, due to the limited time frame provided, the design of the VLC circuits were adapted and re-designed based from the literature reviews, in which one of them was from Gujjari (2012). The VLC circuits are divided into two parts, which are the transmitter and the receiver. The transmitter electronics basically consist of LED driver circuit and white LED matrix whereas the receiver electronics consist of transimpedance amplifier and comparator. The laptop COM port and the VLC circuits are connected by using USB-to-TTL modules, in which responsible to convert the binary data into voltage and vice-versa. The block diagrams of the transmitter and receiver can be referred to Figure 1 and Figure 2 below. The signal input and output is displayed by using two laptops, with specific interface programmed to enable the sending and receiving of data through the USB-to-TTL cables attached to the transmitter and receiver.

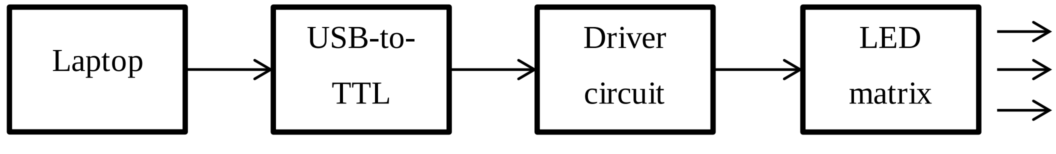

Figure 1. Transmitter Block Diagram

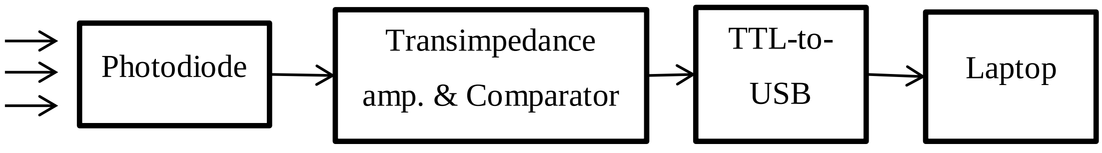

Figure 2. Receiver Block Diagram

Initially, the circuit designs to be implemented are simulated through the simulation software in order to verify the functionality of both the transmitter and receiver circuits. There are numerous simulation software available, however, Multisim from National Instruments was chosen to be used for this project due to its ease of use and large component databases. The version of the software used for this project is Multisim 11.0.1. As stated previously, the VLC circuits are applied from the literature reviews obtained. However, they are adjusted and re-designed depending on the availability and suitability of the components.

3.2 Project Workflow

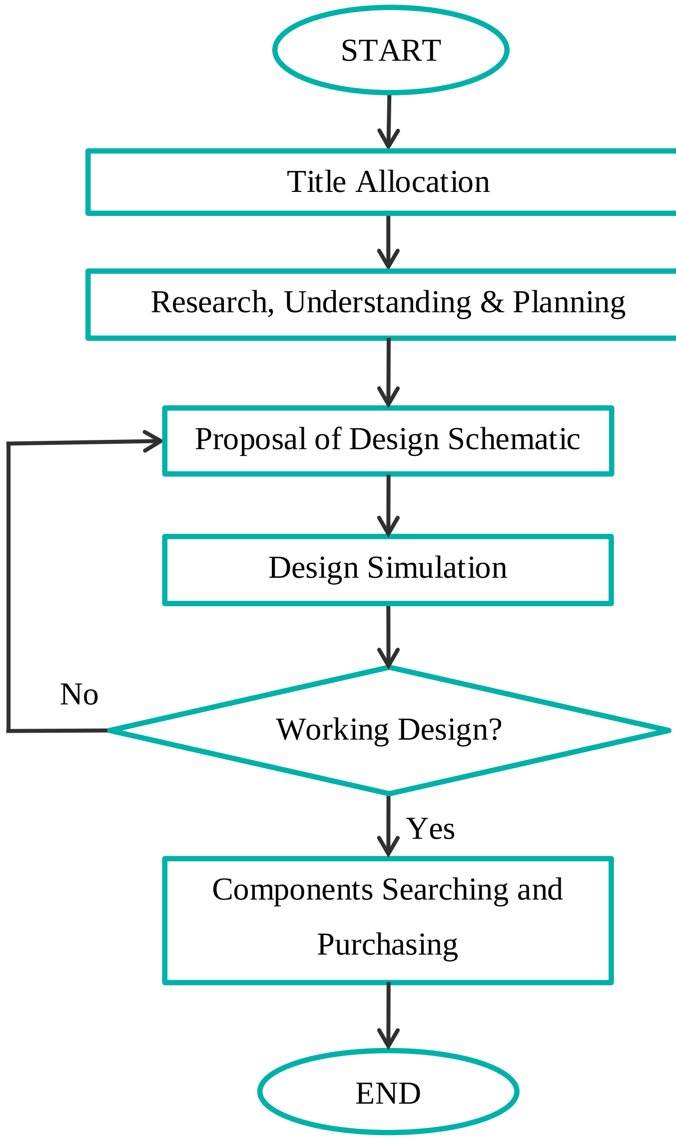

Figure 3. FYP 1 Project Workflow

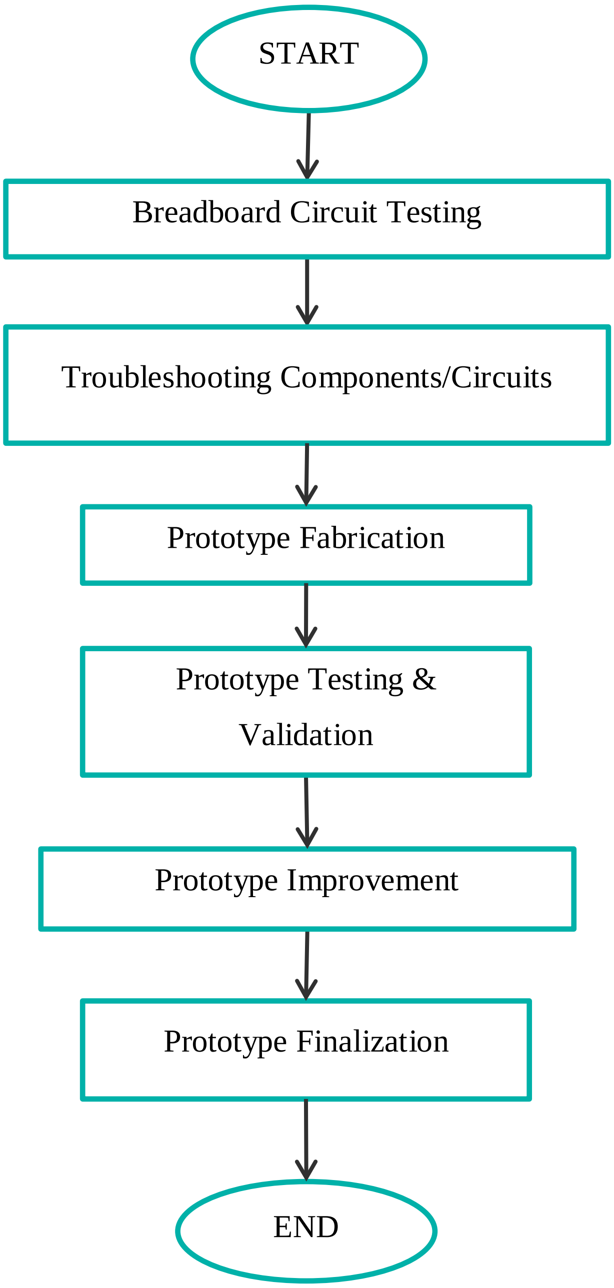

Figure 4. FYP 2 Project Workflow

3.3 Key Milestone

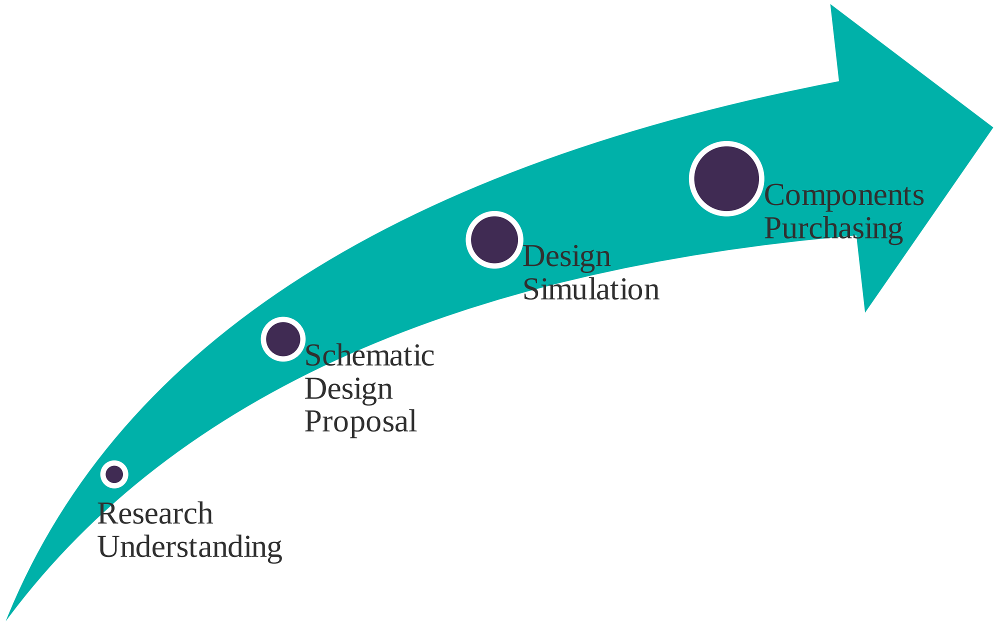

Figure 5. Key Milestone for FYP 1

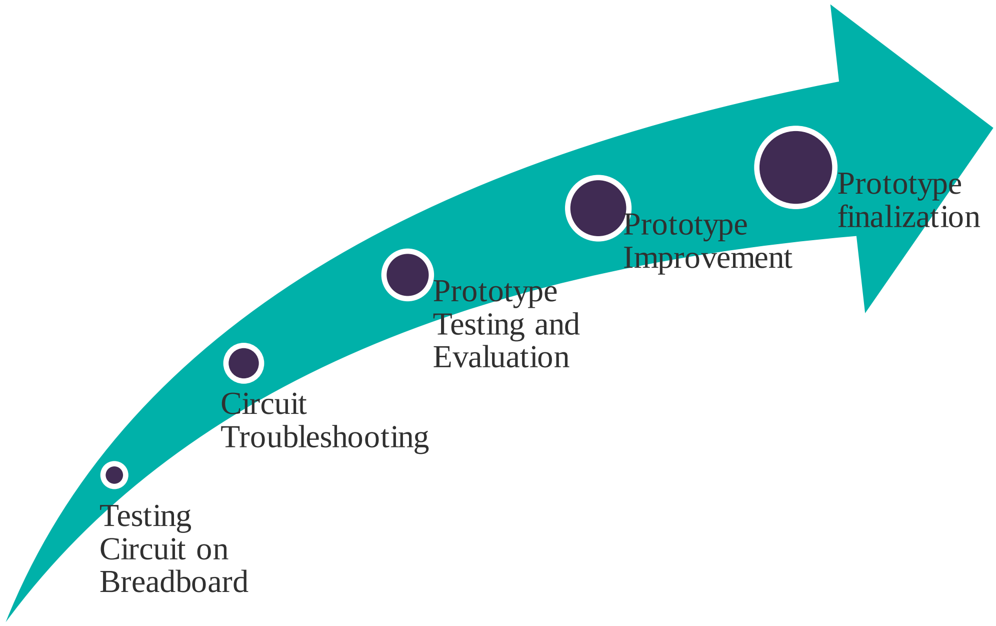

Figure 6. Key Milestone for FYP 2

3.4 Gantt Chart

Table 1. Gantt Chart for FYP 1

NO	TASK	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Title														
2	Research, Understanding and Planning														
3	Proposal of Design Schematic														
4	Design Simulation & Validation														
5	Components Searching and Purchasing														

Table 2. Gantt Chart for FYP 2

NO	TASK	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Breadboard Circuit Testing & Validation														
2	Prototype Fabrication														
3	Prototype Testing & Validation														
4	Prototype Improvement														
5	Prototype Finalization														

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Simulation Results

Since visible light communication (VLC) modules are not readily and commercially available in the market, the sample circuit was adapted from the thesis made by Gujjari (2012) from the literature reviews and was adjusted according to the availability of the components. The simulation was done using Multisim 11.0.1 software, from National Instruments. The simulation done for this project was divided into two parts, which are the transmitter and receiver circuits.

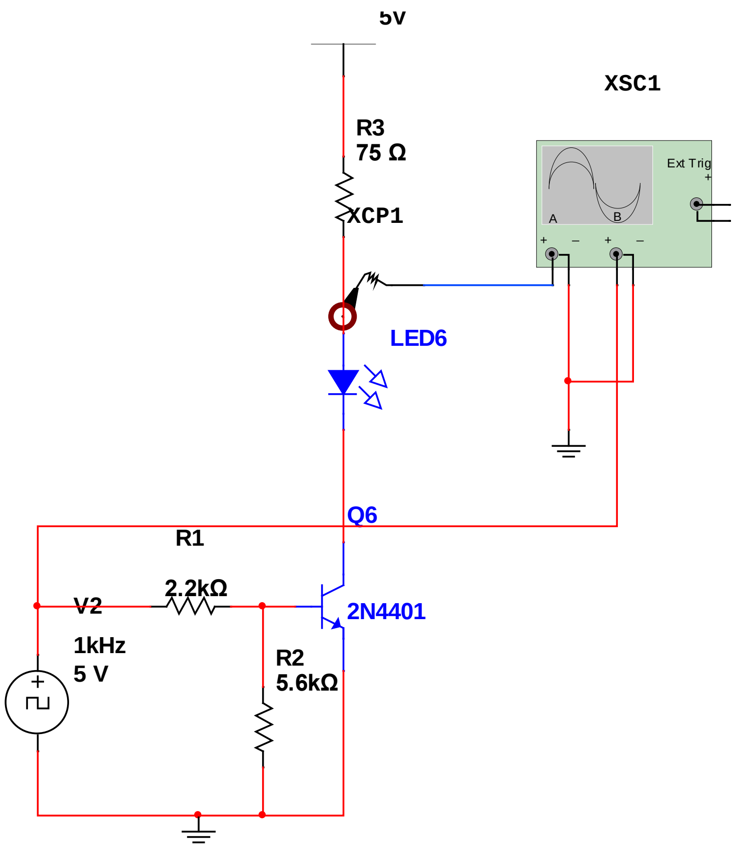

Figure 7. Transmitter Simulation Circuit

Figure 7 shows the design of the transmitter for the VLC circuit. The circuit was simulated by using 1 kHz clock voltage source of +5V to partially mimic the binary inputs from the computer through the USB, since the output would be 0's and 1's or

HIGHs and LOWs. The 2N4401 transistors act as switches in which allow current to pass through the LEDs when the input is +5V and turn off the LED when the input is 0V. This method is known as the On-Off Keying (OOK) modulation, in which will be responsible in transmitting the binary data to the photodiode. Since white LEDs are not readily available in the Multisim software, blue LEDs were used in the simulation. By having a forward voltage of 3.45V and forward current of 20 mA, blue LED is the most suitable LED to be used in the simulation rather than the red and green LEDs because the values are the closest to match with the white LEDs available in the market. The resistor, R_3 is a series resistor connected to the LED in order to act as a current-limiting resistor which stabilizes the current passing through the LED. The value of R_3 was selected based on the calculation made from the formula:

$$R_3 = \frac{V_s - V_f}{I_f}$$

where R_3 = Series resistor (ohm)

V_s = Supply voltage (V)

V_f = LED forward voltage (V)

I_f = LED forward current (A)

From the formula, it was calculated that the value of R_3 is equal to 75.5 ohm. This value however will only be used in the simulation since the forward voltage of the component in the software is equal to 3.45V. The same calculation was also done during the hardware implementation since the forward voltage of the white LED purchased is different from the values in the simulation.

The oscilloscope as seen in Figure 7 was connected with current probe to measure and visualize the output produced from the LED. Figure 8 shows the simulation result obtained from the oscilloscope at the transmitter circuit.

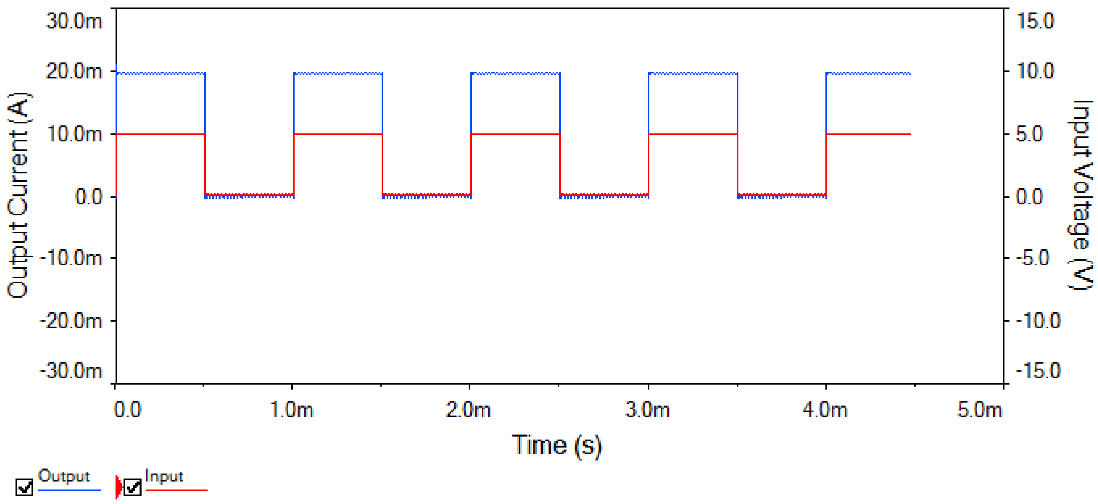

Figure 8. Output Result of Transmitter from Oscilloscope

Channel A of the oscilloscope (blue colour) was connected to the output current of the LED while Channel B (red colour) was connected to the source as reference. The ratio of the current probe was set to 1 mV/mA, which means that an output of 3 mV seen at the oscilloscope equals to 3 mA. From the result, it can be seen that when the transistor is operating in saturation, the current flowing through the LED was approximately 19.7 mA while the source input was 5V (Digitally HIGH). Meanwhile at cutoff operation of transistor, the current flowing through LED was approximately 0A while the source input was 0V (Digitally LOW). The output had virtually no delay to the input. From these results, it can be assumed that when binary inputs of 1 and 0 are sent from the laptop to the transmitter circuit, the LED will turn ON and OFF almost instantly with respect to the input received, which are HIGH and LOW. The output of this circuit was fed to the receiver circuit through VLC.

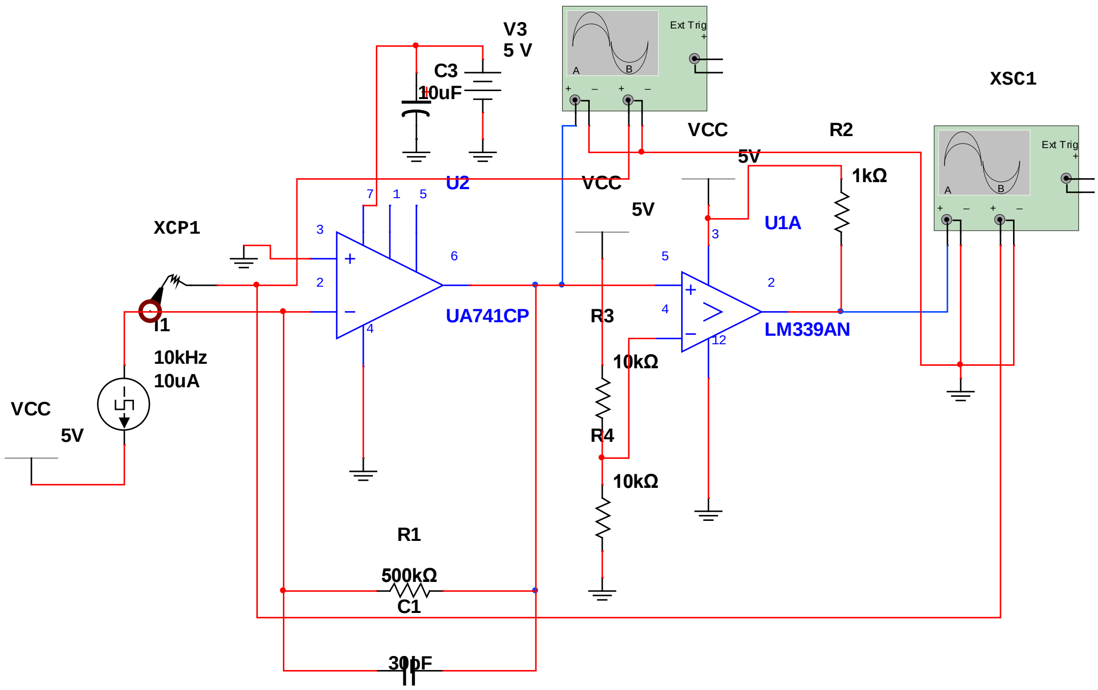

Figure 9. Receiver Simulation Circuit

Figure 9 shows the receiver circuit to be simulated and applied. Since the receiver circuit design in the thesis made by Gujjari (2012) was not applicable in the simulation, the circuit was re-designed by using basic transimpedance amplifier and comparator circuit. The inability of any simulation software to simulate the input of photodiodes was overcome by replacing the photodiode with current source. This is due to the fact that the photodiode produce current when light waves hit the surface of the semiconductor. Thus, for this VLC project, the OOK modulation of the LEDs from the transmitter was received by the photodiode and interpreted as current source in this simulation. The UA741CP op-amp acted as the transimpedance amplifier in which converts the current from the photodiode into voltage output. This output was then fed into the LM339AN comparator to produce a stable 0V or 5V, representing binary outputs of 0's and 1's respectively. The result of the receiver simulation can be seen in Figure 10, which is obtained from the first oscilloscope, namely XSC1 seen in Figure 9.

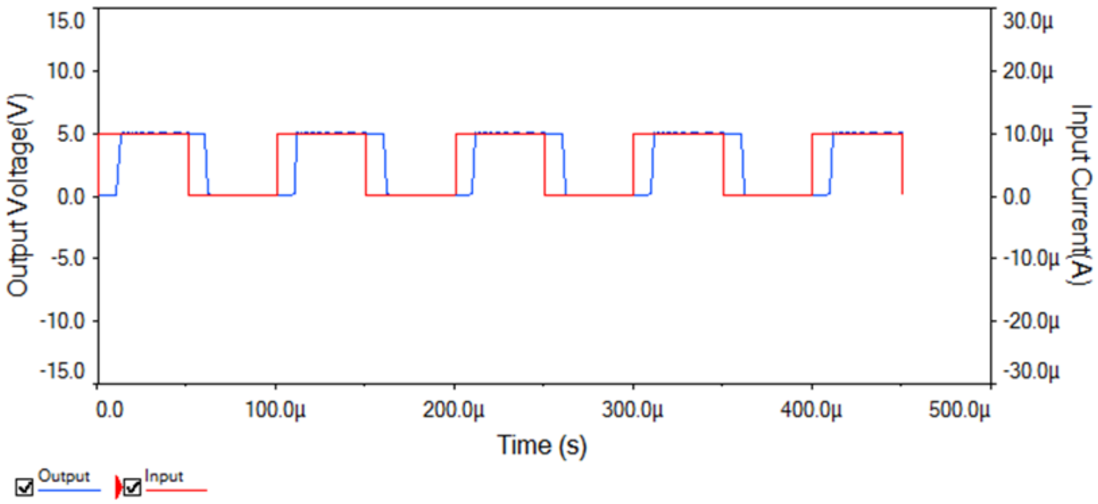

Figure 10. Output Result of Receiver from Oscilloscope

From this result, it is shown that the voltage output that will be sent to the USB is 5.0V when the input of the photodiode is about 10 µA, which represents digitally HIGH output. On the other hand, the voltage output is about 0.109 V when the photodiode input is approximately 0A. There is a slight delay in the fall time which is about 21.780 µs, which is due to the discharging of the capacitor. From the simulation of the receiver circuit, it can be seen that the circuit was virtually able to receive the OOK modulation from the transmitter and convert them into varying currents by the photodiode. The circuit then converts these currents into HIGH and LOW voltage signal which will be interpreted as bits 1 and 0.

4.2 Prototype

The components are connected onto the breadboards based on the simulation circuits of the transmitter and receiver. Minor changes in the values of resistors were made based on the formula stated previously. The connection of the transmitter circuit can be seen in Figure 11 while the receiver circuit is displayed in Figure 12.

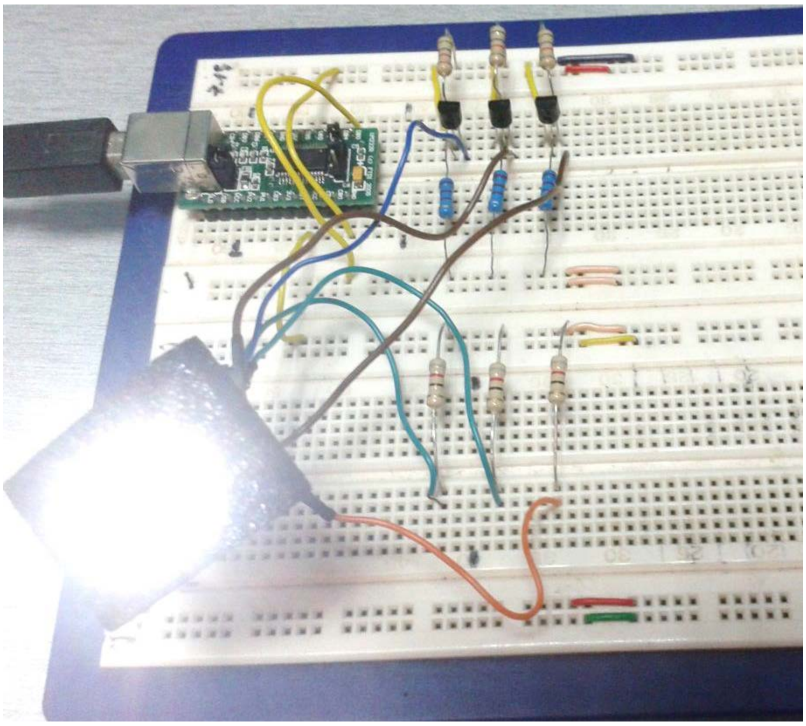

Figure 11. Prototype of Transmitter

For testing purpose, only one LED driver was tested rather than three parallel-connected LED drivers as shown in Figure 11. The result would not have any major difference except for the intensity of the white light, which is dependable on the number of LED drivers used. The light intensity only affects the distance that the data can travel. Since the major purpose of this testing is to test the successfulness of the data transmission from the transmitter to the receiver, the transmission distance would not be taken into account for the time being, however, it would be considered later in the experiment once data transmission from the transmitter to the receiver is established.

To establish connections between the circuits and the laptops, two UM232R USB-to-Serial UART development module are used, whereby one is connected in the transmitter circuit to send the binary data from the computer while the other one is connected in the receiver circuit to accept the data and transfer them to the computer. The VLC prototype used three 40CD white LEDs (manufactured by Cree with model number C503D-WAN) which are bright enough to be used during the testing period. The BPW20RF photodiode used in Figure 12 is suitable to be used on the prototype to match with the simulation, since the minimum reverse light current, I_r is 20 μA when the reverse voltage, V_r is 5V as stated in its datasheet.

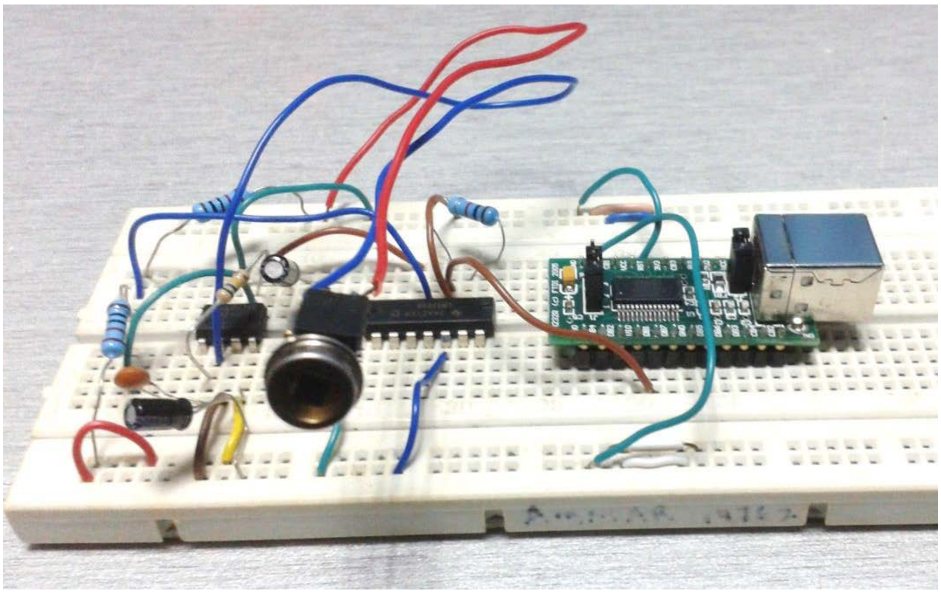

Figure 12. Prototype of Receiver

For ease of data transmission between the COM ports of the computer to UM232R USB-to-Serial UART, a program called the Terminal v1.93b was used as seen in Figure 13. It is an uncomplicated serial port terminal emulation executable that can be utilized for communication between different devices, which is suitable to be used for the testing and debugging period of this VLC circuit.

It is expected that the Terminal v1.93b is used to send data from one laptop to the UM232R, which later convert the binary data input into OOK modulation of the LEDs. Later, the photodiode at the receiver should receive this OOK modulation and change those signals into HIGH and LOW voltages with the help of the transimpedance amplifier that converts the current from the photodiode into voltages for the UM232R to receive. This HIGH and LOW voltages which are a representation of binary bits are sent through UM232R to the Terminal v1.93b to be analysed and interpreted back into ASCII or Hex as sent by the previous computer. However, for the time being, the data transmission from the transmitter to the receiver of the VLC circuit was not successful. The troubleshooting process was done to solve this problem. However, due to time constraint, the solution was not able to be found prior to the submission of this report. The circuits would be checked and debugged component by component in order to find the cause of error.

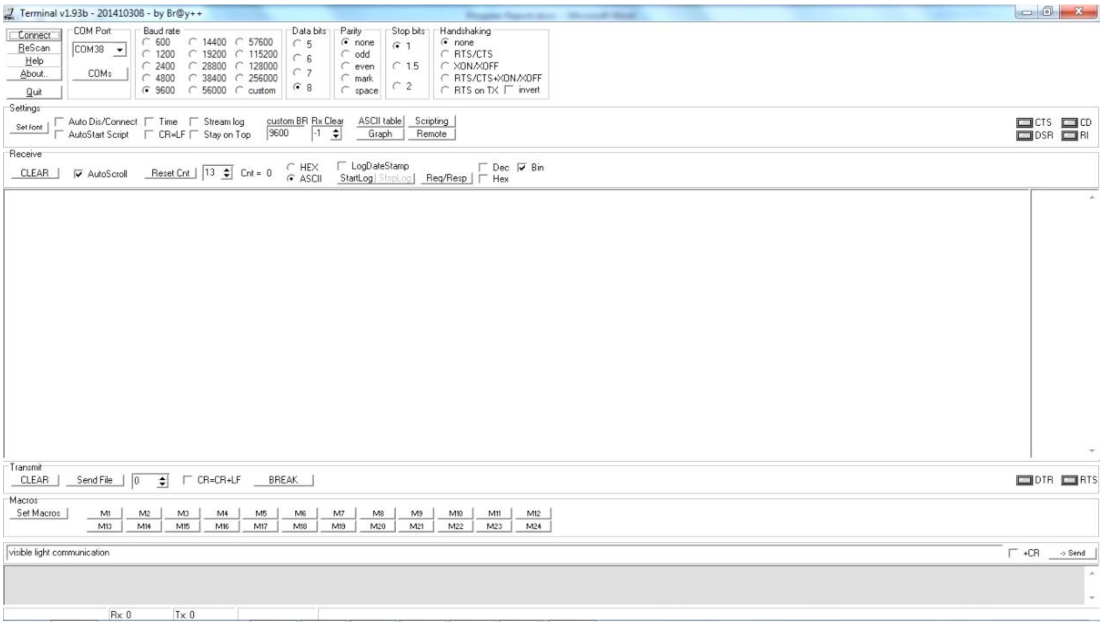

Figure 13. Interface of Terminal v1.93b

CHAPTER 5
CONCLUSION

5.1 Outcomes

Due to some problems in the hardware circuit, the only results that can be obtained are the functional operation of the transmitter and receiver circuits through simulation software. From the simulations, they showed promising results. The prototype of the transmitter and receiver circuit of the VLC has been connected onto the breadboard, however, the circuits could not obtain the same result as the simulation. The circuits are still in testing and troubleshooting phase, but due to the constraint in time, it could not be finished prior to the submission of this final report. Nonetheless, some of the objectives of this project were able to be achieved whereby the viability of visible light as a medium of signal transmission was explained and the implementation of VLC circuits for data communication system via white LEDs was successful through the simulation of the circuits in NI Multisim. The author was unable to demonstrate a working prototype as a proof-of-concept for VLC feasibility.

There are some recommendations that can be done to further improve this project, which are:

1. Replacing the 2N4401 transistor with a MOSFET. This will increase the switching speed of the transmitter, thus enable more data to be transferred in a time period.
2. Using a high-powered LED together with a current amplifier circuit. This will increase the light intensity and power efficiency of the circuit, rather than connecting multiple LEDs in parallel. This will further reduce the cost of building the circuit.
3. Checking the circuits component by component prior to complete assembly of the circuit onto the board. This may consume more time, but helps to efficiently find the error in the circuit.

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