SINGLE LED VS LED-ARRAY VLC SYSTEM PERFORMANCE ANALYSIS

SYAZWAN BIN BAHADOR

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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SYAZWAN BIN BAHADOR

This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronic Engineering with Honours

Faculty of Electronic and Computer Engineering
Universiti Teknikal Malaysia Melaka

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DECLARATION

I declare that this report entitled “Single LED vs LED-Array VLC System Performance Analysis” is the result of my own work except for quotes as cited in the references

Signature : ………………………………

Author : SYAZWAN BIN BAHADOR

Date : ………26 JUNE 2020………

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Bachelor of Electronic Engineering with Honours.

Signature : ……………………………………

Supervisor Name : FAUZI BIN HAJI ABDUL WAHAB

Date : 26/06/2020

DEDICATION

I would like to dedicate to my beloved parents that always support, been source of inspiration and strength of my life, Bahador Bin Mahmud and Rosada Binti Khalid. To my siblings that always there encouraging me to be a better person in future. Also to my humble and kind hearted supervisor for his guidance and advice, Encik Fauzi Bin Haji Abdul Wahab. And lastly to Allah S.W.T, thank you for His guidance, strength, protection and healthy life. With all of these, we offer to you

ABSTRACT

Optical communication is a type of light communication in the range of the electromagnetic spectrum, which is Infrared, Visible Light, and Ultra Violet light that used to transmit signals in the transmission system. This system operates in the visible band referred to visible light communication. Visible light communication is suggested to overcome the problem of radio frequency spectrum as it has more advantages. Visible Light communication uses light pulse to transmit data instead of radio wave. White LED is used as the light source for both illumination and communication purpose. Visible light communication has a secured data transmission channel as light cannot penetrate wall. The designed transmitter and receiver of the system is tested in simulation using the software OptiSystem for the optical part and software Proteus 8 for the electrical part, thus further developed into a prototype. The simulation in OptiSystem is done with different length of FSO Channels and different number of LED settings. The simulation in Proteus 8 is done for transmitter unit and receiver unit. The optical and electrical part is used Arduino Uno to obtain the final prototype. The result gained from the project will be analyse and compared in different distance between of LED to LDR, power received of LDR, and brightness of LED.

ABSTRAK

Komunikasi optik adalah sejenis komunikasi cahaya dalam jangkauan spektrum elektromagnetik, yaitu cahaya inframerah, cahaya yang dapat dilihat, dan cahaya ultra violet yang digunakan untuk mengirimkan isyarat dalam sistem transmisi. Sistem ini beroperasi dalam jalur yang dapat dilihat yang disebut komunikasi cahaya yang dapat dilihat. Komunikasi cahaya yang dilihat disarankan untuk mengatasi masalah spektrum frekuensi radio kerana ia mempunyai lebih banyak kelebihan. Komunikasi Cahaya Terlihat menggunakan nadi cahaya untuk menghantar data dan bukannya gelombang radio. LED putih digunakan sebagai sumber cahaya untuk tujuan pencahayaan dan komunikasi. Komunikasi cahaya yang dapat dilihat mempunyai saluran penghantaran data yang selamat kerana cahaya tidak dapat menembus dinding. Pemancar dan penerima sistem yang dirancang diuji secara simulasi menggunakan perisian OptiSystem untuk bahagian optik dan perisian Proteus 8 untuk bahagian elektrik, sehingga dikembangkan lebih lanjut menjadi prototaip. Simulasi di dalam OptiSystem dilakukan dengan tetapan jarak dan bilangan LED yang berbeza-beza. Simulasi dalam Proteus 8 dilakukan untuk unit pemancar dan unit penerima. Bahagian optik dan elektrik digunakan Arduino Uno untuk mendapatkan prototaip *akhir. Hasil yang diperoleh dari projek ini akan dianalisis dan dibandingkan dalam pelbagai LED hingga LDR, penggunaan kuasa, dan kecerahan LED.*

ACKNOWLEDGEMENTS

In the name of Allah, the Most Gracious and the Most Merciful

Alhamdulillah, thanks to Allah S.W.T for His blessings and the strength for me to complete this project for my final year project successfully. First of all, I would like to most thanks and to give most appreciation to my supervisor Encik Fauzi bin Haji Abdul Wahab for the guidance, patience, non-stop encouragement and positive comment that give me spirit on completing this final year project.

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LIST OF SYMBOLS AND ABBREVIATIONS

VLC	:	Visible Light Communication
LED	:	Light Emitting Diode
FSO	:	Free Space Optic
OWC	:	Optical Wireless Communication
UWOC	:	Underwater Wireless Communication
RF	:	Radio frequency
MIMO	:	Multi-Input Multi-Output
LDR	:	Light Dependent Resistor
LOS	:	Line of Sight
NOS	:	Non Line of Sight
APD	:	Avalanche Photo Diode
LCD	:	Liquid Crystal Display

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Visible Light Communication also known as VLC is a recent research field in the technology of wireless communication. This concept is on modulation of the white LEDs broadcasting electromagnetic waves. The wave is in the visible light frequencies which helps to communicate between devices in the same room while providing illumination of lighting purposes. A simple modulation is to be analyzed using electronic modulator, demodulator, single LED or LED array, photodiode, transmitter and receiver. For high data rate VLC the transmitter and receiver must be compatible. Designing a high data rate transmitter and receiver is very complex and expensive. Multiple reflection paths are considered in this study. The transmission of data under VLC system will be observed and analyzed.

LED is an appropriate as a data transmission source because it can regulate at a high rate. It is possible for white LED simultaneous illumination and communication. The recent technology, in concurrence with lighting, it benefits in two ways. The first one is Visible Light Communication (VLC) systems with little shadowing anticipated illumination level and lighting distributions fixtures can reach a high power transmission. Secondly, the total cost can be lessen because elements of the communication can be effectively incorporated with the white LED [1].

To construct a VLC system which is practically indoor that there are various circumstance to be handled. Controlling the limitations that is complied with the various path of transmission channel is one of the most challenging design circumstances as to establish a uniform performance of the communication and also distribution by illumination for each position around the indoor surrounding. A separate research has been carry out on the title of "Illumination Distribution Using Array of LED" which concentrate more towards the design controls of the beam and the array position placement of LED. In result, the optimization scheme was static and limits the illuminations. In order to enhance the communication performance, adaptable equalization methods which improvement of the receiver front-end design are make use of which make the receiving terminal of the complexity and the cost are over concentrated [2].

1.2 Background of Project

Recently, VLC method has been one of the concept that move forwards for wireless optical communication. Interval wavelength of 380nm to 780nm is the electromagnetic spectrum are the light signals which able to be spotted by human naked eyes stated [3]. There are possibilities on achieving illumination and move data at the same time by means of LEDs that is the prominent lighting equipment lately. In this way, the room's interior lighting and transferred data will be achieved without requires extra communication system. The name of this technology is call as Visual Light Communication. Fundamental entries in a VLC system are the transmitter (LEDs), receivers (photodetectors), modulation of data to optics and the optical communication channel. In VLC, optical lighting and optical transmission are the important requirements for the communication. The communication and lighting was made possible by the system and the influence of inter symbol interference and reflection were discussed. The transmission loss due to inter-symbol interference and attenuation from reflection points [4].

Based on research, [5] stated that the concepts of VLC system using white LEDs in addition to the investigation of potential capabilities of power line communications and white LED indoor communications for broadband access. The implemented a visible-light communication system for lighting and high data rate (indoor communications) in a model room such that there is no blind spot in the room for data communications. Refer to [6], different technique can be applied to upgrade the data rate which one among them is equalization process. In this work they also consider different parameters for improving data rates which are Optical filtering, Transmitter equalization, Receiver equalization and Optical Multi-Input Multi-Output (MIMO) transmission. Different techniques can be combined together to get higher rates for visible-light communication but the system will be more complex. Based on [7], the audio and video can be transmit with the maximum distance of 3m. They developed and imitated the lighting model within room domain which shows close relationship between light's layout sources and distribution of illuminance.

Referred to [8], a secure VLC system using data-superposition of dissimilar LEDs were created whereby it can save the information from being detected by adjacent users. This system used the modulation of on-off keying (OOK). Based on [9], when this technology is applied practically, each Wi-Fi router can be replaced by light sources which pledge a secure, cleaner and brighter future.

1.3 Problem Statement

Light interference between two waves (light). Recently, the existing VLC system uses a single LED. By using a single LED, results shows that the transferred data is with different coverage in a space. The data transfer by a single LED has a limited space for each of the LED with a certain radius length.

1.4 Objectives

1. To design a VLC system that consist of transmitter and receiver unit.
2. To analyze data transmission of VLC using single LED and LED array such as distance between LED to LDR, power received of LDR and brightness of LED.

1.5 Scope of Work

This project's scope includes the following areas:

1. Both simulation and prototype will be done with the construction of the transmitter unit and a receiver unit in both software and hardware.
2. Simulation includes electronics part and optical part where the electronic part will be designed using Proteus software and the optical part will be designed and analyze using Optisystem software.
3. Design will be tested in software and prototype whereby the data input to transmitter and data output from receiver will be compared.
4. Once it successful, it will be further tested by compared the distance between LED to LDR, power received of LDR and brightness of LED.
5. A standard white LED will be used as the light source as transmitter and LDR sensor as receiver.

1.6 Thesis Outline

This thesis is divided into five (5) chapters to cover the research work that is related to the analysis of data transmission performance in wireless optical communication system employing fundamental modulation technique specified in VLC system. After this chapter, followed by chapter two that focus more on literature review or the researches done previously on wireless optical communication, defines VLC data transmission system and characteristics of LED lights. This chapter also explains and compares the methods used for wireless data transmission. In chapter 3, the representation of methods knowledge, modeling and implementing VLC system into a modeling tool as well as the constructs needed will be studied. In chapter 4, focuses on the analysis and discuss about the methods using the proposed VLC system and it will be supported with graphs and tabulated data. Chapter 5 recapitulates the major findings of the thesis and propose the issues inviting future researches.

CHAPTER 2

BACKGROUND STUDY

This chapter is to explore and overview the project based learning on the past research. In this study, the pro and cons of the previous research are also showed and compared. Other than that, research on the components that have been used in other researched is also studied. By analyzing the previous projects, the possibilities that affect the quality in their project can be analyzed and reviewed. Lastly, some recommendations have been made to overcome the problem exist in the previous study.

2.1 Visible Light Communication (VLC)

For data transmission, VLC uses light pulses. For contrast, VLC would use LED lights mounted transceivers which illuminate a room and also at the same time transmit data rather than using Wi-Fi routers. When simple sources of light are used, the amount of access points can be ascend. This device uses the clear spectrum (visible), a subset of the electromagnetic spectrum, which is not yet commonly used. In addition, the transmission bandwidth is 10,000 times more available in this scope and more accessible when count the sources in use [8]. Figure 2.1 show the block diagram of VLC system [8].

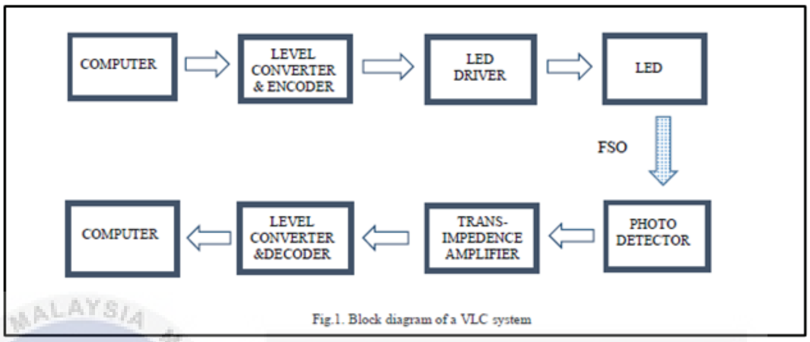

Figure 2.1: Block diagram of VLC system

By implementing OptiSystem technology, the process of VLC with the use of RZ-OOK modulation are influenced by the optical background noise. Elimination of noise are carried out using the technique of filtering [10]. Figure 2.2 show Block diagram of proposed RZ-OOK VLC system using optisystem [10].

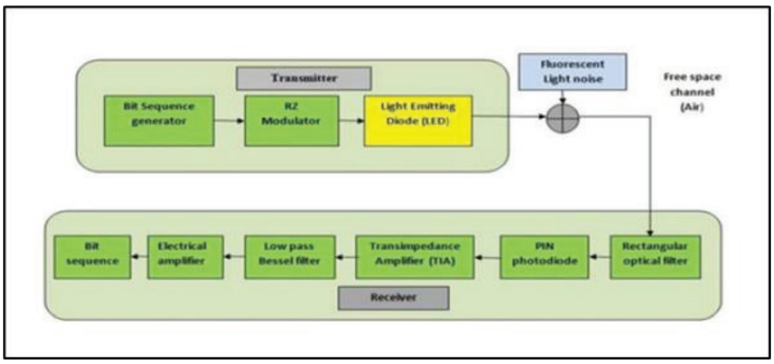

Figure 2.2: Block diagram of proposed RZ-OOK VLC system using Optisystem

VLC was developed primarily as a cable replacement from one point to another of method of data communication. Li-Fi defines a complete set of system for wireless networking which involves user (multi) communication (bi-directional). For example, a point to multipoint communication and multipoint to point communication. It also includes numerous retrieved points that construct a limited optical attocell wireless network with seamless transfer which means Li-Fi allows complete mobility of users. Thus, a brand new layer are formed in current wireless network. Facts about LEDs are, they are natural beam formers that enables local resistance of Li-Fi signals [3]. Figure 2.3 show a block diagram which defines a VLC system [3].

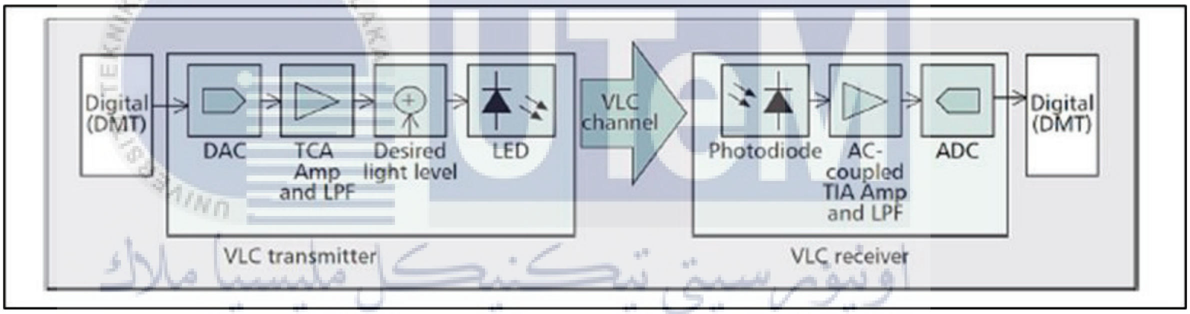

Figure 2.3: A block diagram which defines a VLC system

2.2 FSO System (Free Space Optic)

Free Space Optic communication is a technology of optical communication that use light transmit in a free space which then transfer data for the computer networking or telecommunication. This technology is useful but it is not practical because the cost are high. Free space optical communication has several benefits over radio frequency communication because the spectrum of radio frequencies is greater than the optical wavelength. The advantages of open-space optical communications are enormous data transfer capability, less power required, unlicensed reach, cost-effective and high level of security [11]. The transmitter's LED sends information through the light shaft as an optical fiber or FSO contact across free space. When the lens was connected to a sensitive receiver, the end of the beam lights was then recorded. Figure 2.4 show FSO communication system block diagram [11].

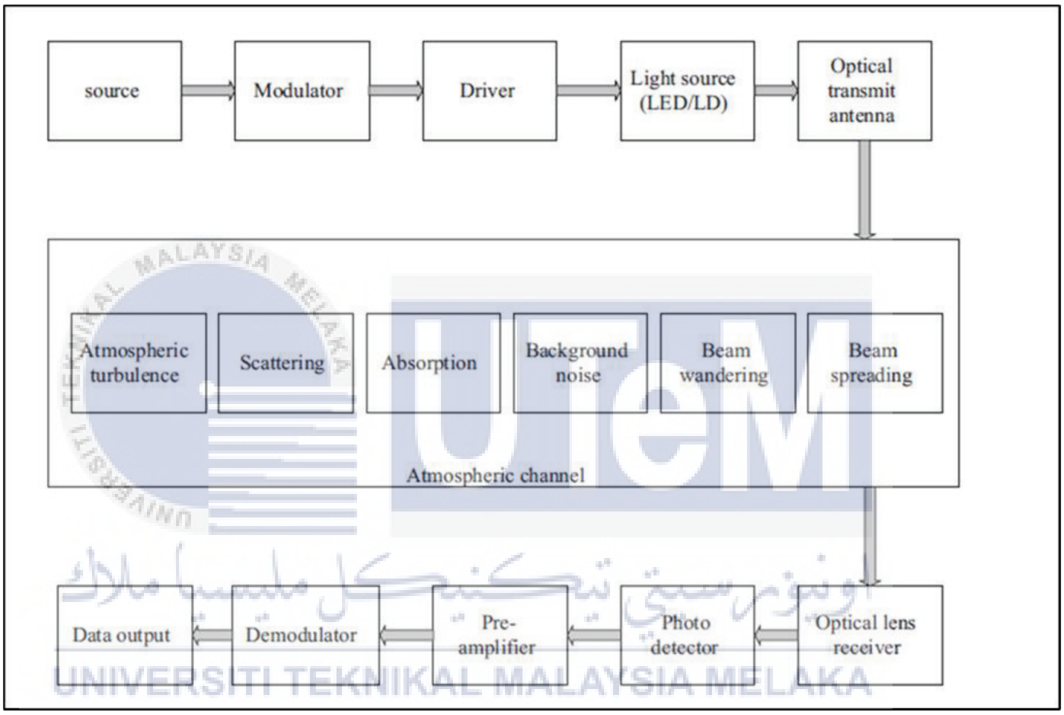

Figure 2.4: FSO communication system block diagram

This atmosphere is the propagating medium for optical communication in free space. The atmosphere can be described as a collection of condensed gas strata all over the planet. As terrestrial FSO systems and also weather phenomenon are in the troposphere region, so only troposphere composition must be considered. The troposphere consists primarily of nitrogen, oxygen, carbon dioxide, water vapor and other particulate matter such as haze, dust etc. Oxygen strongly absorbs wavelengths below 0.3 m, whereas water and carbon dioxide have a severe effect on longer wavelengths. The atmosphere is about 0.3 m to 0.8 m clear [25].

2.3 Optical Wireless Communication (OWC)

OWC or also known as Optical Wireless communication is a structure which engage white LEDs towards wireless (indoor) network. Utilized as a lighting device, LED also able to be applied as communication device which uses white ray as the medium. The optical wireless communication type is visible. This LED is dual-purpose, which act as source of light (lighting) and also communicator (communication). There are two causes from the function, how fast LEDs is switch and visible light wave's modulation for the free space communications. [4] Nevertheless, the results for OW receivers developed intangible reception display less sensitivity than RF antennae. This is due to the photo-electric conversion from the mechanism. Uncontrolled and short distance links for indoor of OW spectrum which produce SNR value for the OW itself is higher. The LOS (Line Of Sight) point to point links have higher bandwidth and little interference. Each room that have spectrum can be use again as formed signal which limits within the room that cannot appear when the RF is used. Establishment of the recent efficient white LEDs at houses or offices, can incorporate indoor illumination with VLC [12].

Furthermore, the polarization state of a laser beam provides a mode of information transmission in OWC systems such as the polarization modulation framework and the polarization multiplexing framework by expanding the transmission limit and efficiency [13][26]. The author in [14] calculated the outage probability of a submerged wireless optical communication (UWOC) network in the form of multi-hop transmission and simultaneous relaying. Line of sight (LOS) and Non Line of Sight (NOS) structure optical wireless networks for indoor spaces [15].

Optical wireless communication requires the possibility of underwater communication, whereby the current standard submerged communication system has limited data transmission and a substantial delay in propagation rendering it incompatible with certain submerged equipment [16]. The research of [17] using solar powered board as a detector in an underwater wireless optical communication system (UWOC) rather than PIN diodes and APDs, showing that solar powered boards have a wider receiving area and lens-free operation making it increasingly suitable for data accumulations of wireless underwater sensor networks. The design in Figure 2.5 shows the proposed UWOC framework which uses solar powered board as a locator [17].

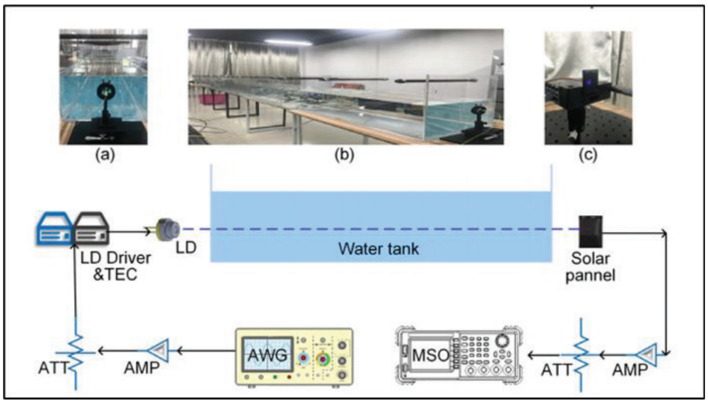

Figure 2.5: Setup for proposed UWOC framework uses solar powered board

2.4 Photodiode/Photodetectors/Light Dependent Resistor (LDR)

A photodetectors or also familiar as photodiode act as a receiver which receive entity of a system of OWC. This helps to absorb the impinging photons of fronted surface. It also helps on generating an electrical signal over it. The transformation of photonic energy to electrical energy can be accomplished in different manner. As a consequence, for example, photon absorption has produced photoelectric effects and free electrons emerge which make vacuum photodiodes or photomultipliers that are used as carriers. Another method is to release an electron and a whole pair by dropping photons into a semiconductor photodiode junction zone, such as p or pin diodes. Subsequently, to release their excessive energy, these freed carriers shift to the corresponding regions, such as conductance and valance bands. There are many types of photodetectors available that possess specific characteristics, such as photomultipliers, photoconductors, phototransistors, and photodiodes. In fact, photodiodes are the most preferred devices as a photodetector because of their small in size, high of sensitivity, and rapidly response. P-I-N (PIN) and Avalanche Photo Diode (APD) are the primary types of photodetectors. [3]

Table 2.1: Requirement for Photodetector

	Requirements that an ideal photodetector
1)	Sensitive to the wavelength interval associated
2)	long operational life
3)	minimally affected from the temperature fluctuations
4)	Efficient accomplishment of noise such ambient, dark, etc.
5)	noiseless physical structure
6)	Small in size
7)	Reliable
8)	cost effective

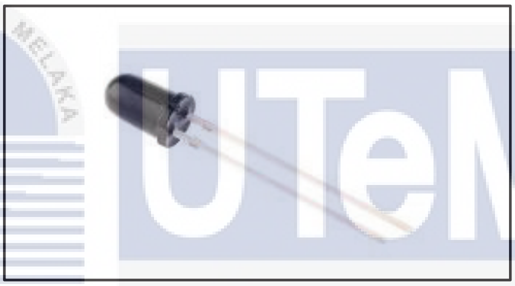

Figure 2.6: Photodiode's pin

A photodiode act as an active component which transform lights to into a voltage that is photovoltaic or photocurrent. The p-n junction of the silicon semiconductor serves as the physical base for this operation. When photons are absorbed with minimum intensity by the sensor, this leads to the creation of reimbursing carriers (electron-hole pairs), which are isolated in the region of space-charge and thus produce the capacitance. A PIN diode consists of a close proximity-intrinsic semiconductor layer – usually a space-charging area – situated between a p-type diode and an n-type substratum. The term is often used for inverse conductivity elements, given the component does not use any other non-linear effects.

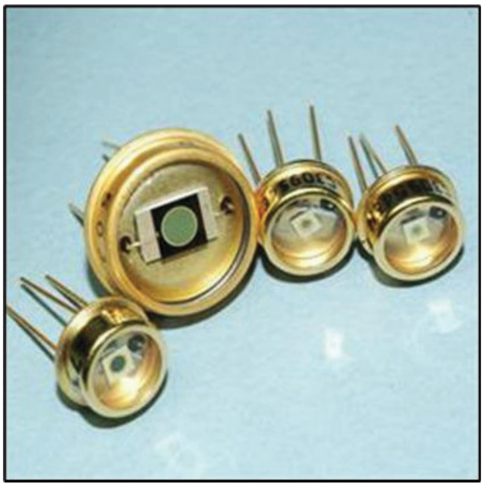

Figure 2.7: Avalanche photodiode basics

An avalanche diode linear relation to a Schottky photodiode could also be used, although that use of the form is much less in common. The main contrast between the photodetector of the avalanche and other types of photodiode is that its strong reverse bias. It makes the photon / light impact produced holes and electrons to multiply the avalanche. These charging carriers are pulled away from each other by the very high electrical field as a photon reaches the depletion field and generates an electron hole sets. Their speed will increase to such an extent that will produced additional whole electron sets which repeat the cycle when they collide with the lattice. The action of avalanche allows multiple increases in the diode gain, providing a much higher level of sensitivity.

The Light Dependent Resistor offers infinite resistance in the darkness and offers very few ohms when there is light. The light from the LED is detected by using LDR and the data is sent to the Arduino [21]. Though the ambient light affects the nature of the transmitted signal, LDR is able to effectively detect the signal. Based on the high of the streetlight this average gap in reality needs to be higher. For this purpose, amplifiers are required when the LiFi is inserted into actual scenario [24] .

The LDR detects the quick LED flicker. The length of the flashes, generated by the flickering, is measured using a special feature in the Arduino IDE. Depending on the duration, the pulses HIGH and LOW are differentiated and a binary bit stream is generated [23].

2.5 Light Emitting Diode (LED)

Li-Fi uses Light Emitting Diodes (LED) which have high modulation bandwidth and energy efficient illumination. These LED's have high switching speeds that allow them to modulate in accordance with the stream of bits sent. This transmission occurs in a parallel stream, so that more data is transmitted at the same time. The speed of switching is too fast to be visible to the naked eye and therefore this transmission is not noticeable [30]. LED lighting can also affect contact efficiency as we adjust the intensity of modulation [29].

The aim of the VLC system's LEDs is to give light to be used for data transmission. LEDs can do it by flipping on which would be a logic 1 and switching off which would be a logic 0. Users had to make sure the LEDs they picked were bright and could turn into high frequency. The transmission distance and the data rate would be low without LEDs capable of those properties. This system incorporates light spectrum of all types, such as visible light, infrared. The Li-Fi is not limited to LED or Laser technologies or a receiving technique in particular. Li-Fi offers additional features for existing and future networks , devices and end users [22].

Table 2.2: Category of LED

Category	Importance	Desirable	Undesirable
Brightness	1	> 10000 mcd	< 1000 mcd
Frequency	1	> 1 MHz	< 100 KHz

It is favorable to have a high level of brightness so that data can be effectively transferred under ambient light over longer distances. The rate of the frequency is also important. The LEDs will turn on and off quickly in order to transmit data quickly enough [18].

Table 2.3: Comparison of LED

Led	Brightness	Colour
RL5-R12008	12000 mcd	Red
RL5-W18030	18000 mcd	White
WP71131T	80mcd	Red
LW514-BULK	32000 mcd	White

2.5.1 White LED

Only with development of high-lumen of efficiency white lighting LEDs, VLC is becoming an excitement to the technology in conjunction since lighting enables low-cost data transmission. White LEDs posed on replacing the incandescent lamps and also fluorescent lamps which is the light sources for the next generation. There are lots of advantages from white LEDs, such as long-life expectancy, high-lighting efficiency, easy maintenance and environmental friendliness compared to traditional light sources. Additionally, LEDs can be amplified at a high rate of speed, making them ideal as a data transfer source. [1]

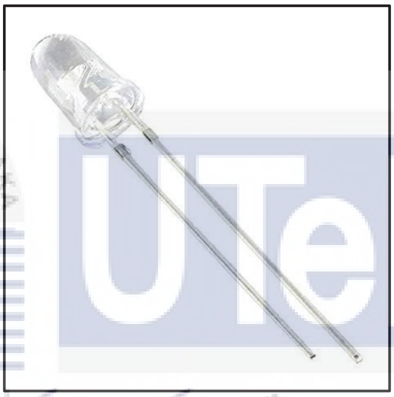

Figure 2.8: White LED

2.5.2 Single LED

$$C_{SISO} = log_2(1+\frac{g^2 Pt}{\sigma^2\ B})$$

In a singular VLC channel, transmission is attained using one LED and one PD. The efficiency CSISO of the transmission link is given where Pt is the transmitting power independent of illumination, B is the transmitter bandwidth, π2 is the total noise in an AWGN channel and g is the channel gain. The total g^2Pt / σ^2B defines the channel characteristic of the SNR. There are 2 distinct kinds of the distribution link: a line-of-sight (LOS), (direct and nondirect) link, and a non-line-of-sight (NLOS) link [19]. A non-direct line of sight (ndLOS) of single ray distribution show in Figure 2.7 [19].

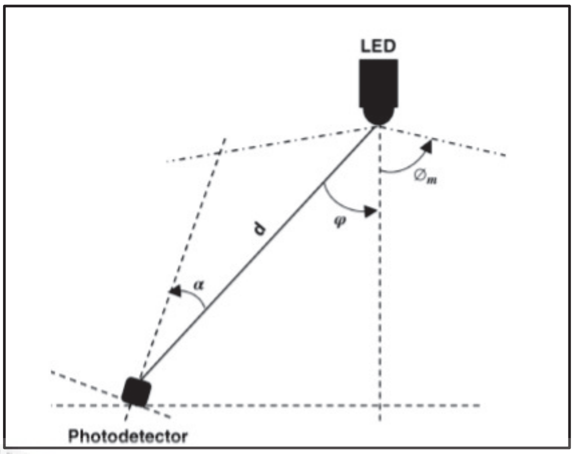

Figure 2.9: A non-direct line of sight (ndLOS) of single ray distribution.

2.5.3 Multi LED

In this article, a connection of sixteen (16) LEDs are used to amplified using modulated driving approaches, generating a 25 MHz maximum BW. It can be used to apply a 40 Mb/s non-return-to-zero (ON–OFF keying) connection that operating at low inaccuracy and offering ambient light at levels that is suitable for common office setting. An approach is propose to transmitter-equalization using a set of resonantly amplified LED's. Each LED has a specific maximum power output, generated by using external components to amplify the LED's electrical response. Careful frequency selection enables an overall high net BW channel [10]. A test-bed system of VLC by using sixteen (16) Array of resonated white LEDs is show in Figure 2.10 [10].

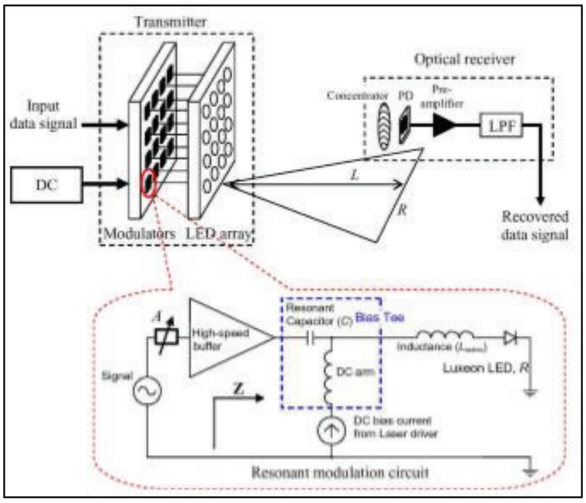

Figure 2.10: A test-bed system of VLC by using sixteen (16)

Array of resonated white LEDs

The ideal approach is by using the great number of LEDs used in simultaneous communication lighting though in this case, synchronization between transmitter arrays and the correct receiver array is difficult to sustain. An optical MIMO is a major interest that provides a way to necessary transmitter-receiver synchronization. Figure 2.9 show the typical indoor environment [5].

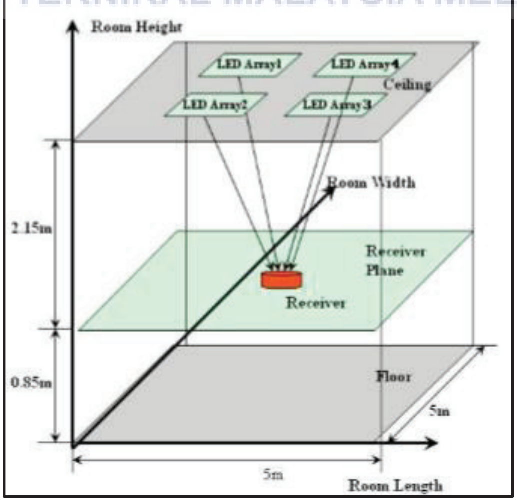

Figure 2.11: Typical indoor environment

2.6 Radio Frequency (RF) Spectrum Network

One of the natural resource of state, RF spectrum's usage is controlled for the elimination of signal interference and emissions as well as for effective spectral usage. Instead of developing additional base stations to increase the power, having spectrum is easier for mobile operators. It also lessens the market penetration opportunity for future potential competitors. When demand for wireless networks data continues to rise, the spectrum of radio frequencies had become rapidly overcrowded. Therefore, the remainder spectrum is diminishing and spectral control increasingly has become an issue. Developments have taken place to utilize the Terahertz frequency range in between RF and microwave spectrum, which would require developing a completely new network class consistent with the wavelength range. By turn, infrared light has a spectrum 10,000 times larger than electromagnetic waves. The radio waves correlate to a frequency range between 3 kHz and 300 GHz while the infrared light correlates to a frequency band between 400 THz and 780 THz. Future VLC transmitters can be up to 12 billion for 12 billion light bulbs operating worldwide for unauthorized, usable bandwidth. [12].

One of primary drivers of this interest is the increasing lack of radio frequency (RF) resources due to the growing demand for high rate wireless communication systems. Certain sections of the available spectrum must also be used for transmitted data, in this context the non-licensed reusable visible range is a possible alternative to promote and complement RF communications [19].

RF transmission is sparsely affected by fog and mostly by rain. For this reason, we consider the first sub-system to be a hybrid RF / FSO link, using the selection technique combining (SC) diversity to select active link. Consequently, the realization of the outdoor signal transmission depends on the state of the RF and FSO channel, which show different sensitivity to snow and rain [28].

VLC systems provide a higher data rate compared to the existing RF system, but their confining to smaller cells results in a limited coverage area limiting the mobility of users. The VLC light data cannot penetrate an obstacle [27]. As far as health is concerned, because visible light does not produce radiation as with radio frequency (RF) contact, it can even be used in the presence of highly inflammable materials [20].

CHAPTER 3

METHODOLOGY

This chapter is about information and explanation about the methods used for this project. For this methodology there were three parts. First, the entire project flowchart that represented the complete workflow throughout the project. Secondly, the block diagram of the whole project which enables the readers to understand how the system works in a simple and easier manner. Lastly, the software and hardware part of the project were described and explained on the components and methods used.

3.1 Project Flowchart

The flowchart of the entire project is shown in Figure 3.1 and flowchart of the working process is shown in Figure 3.2. Literature review based on the research carried out on previous projects and the knowledge gained was applied. The project was designed to create a system prototype using Opti-System software. The prototype was designed and constructed according to the software design. After that, the prototype was tested to verify the hardware functionality. The comparison of input and output information and further recording to the laptop.

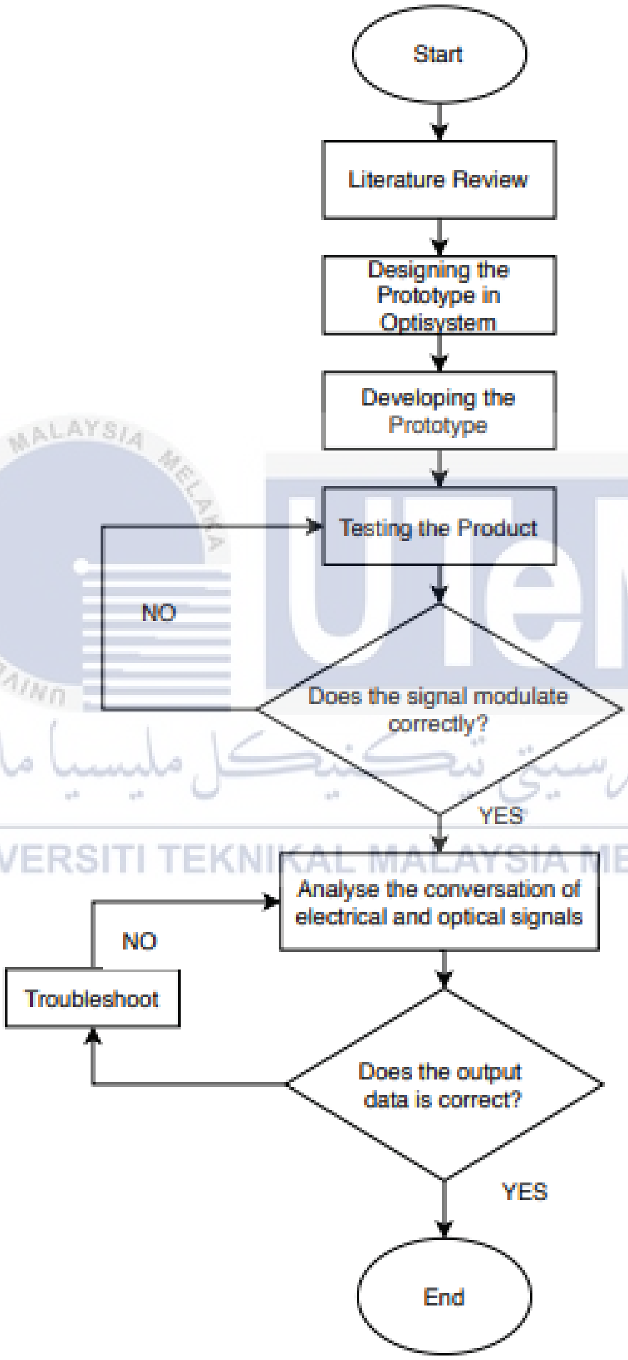

Figure 3.1: Flowchart of the entire project

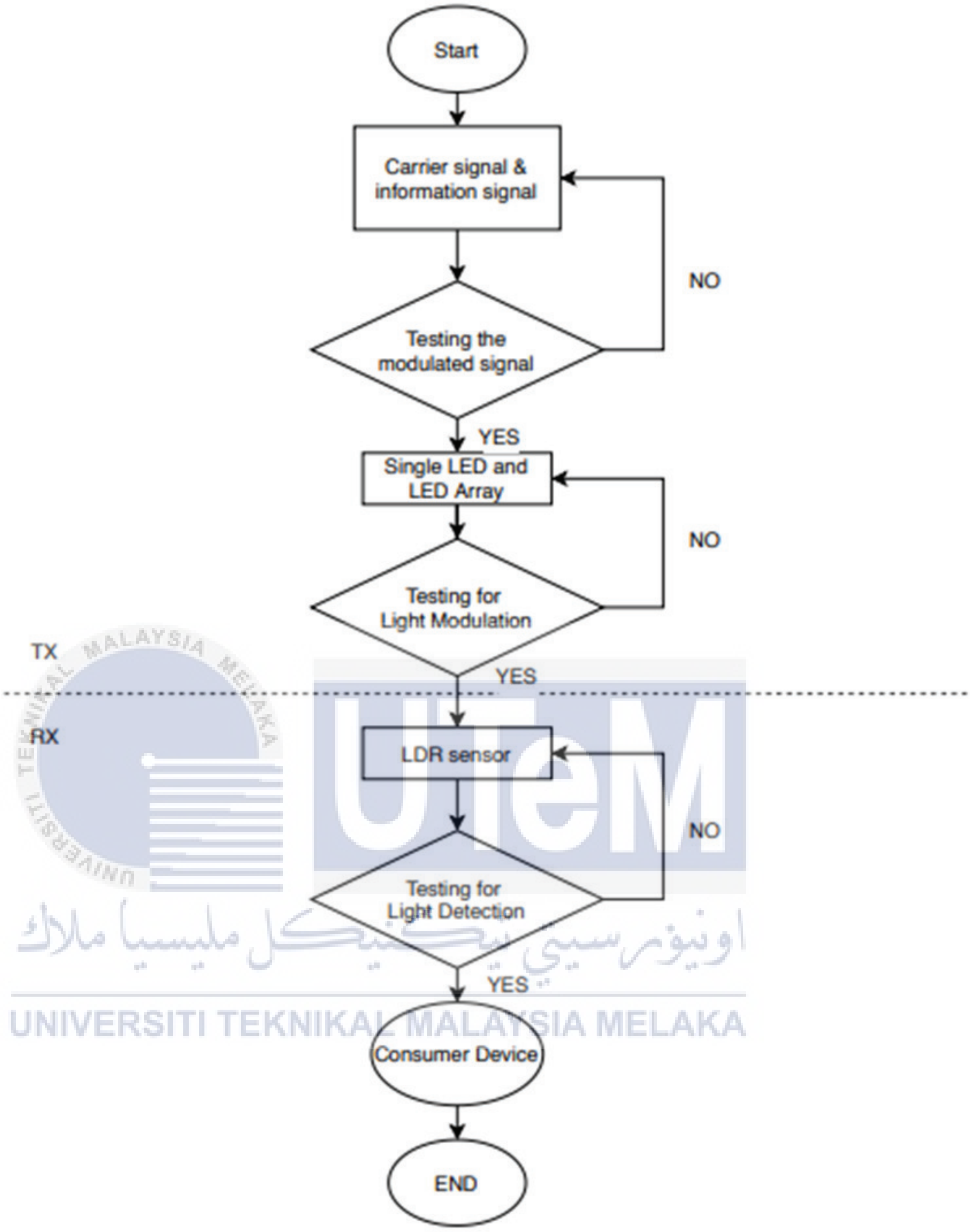

Figure 3.2: Flowchart of the working process

3.2 Project Block Diagram

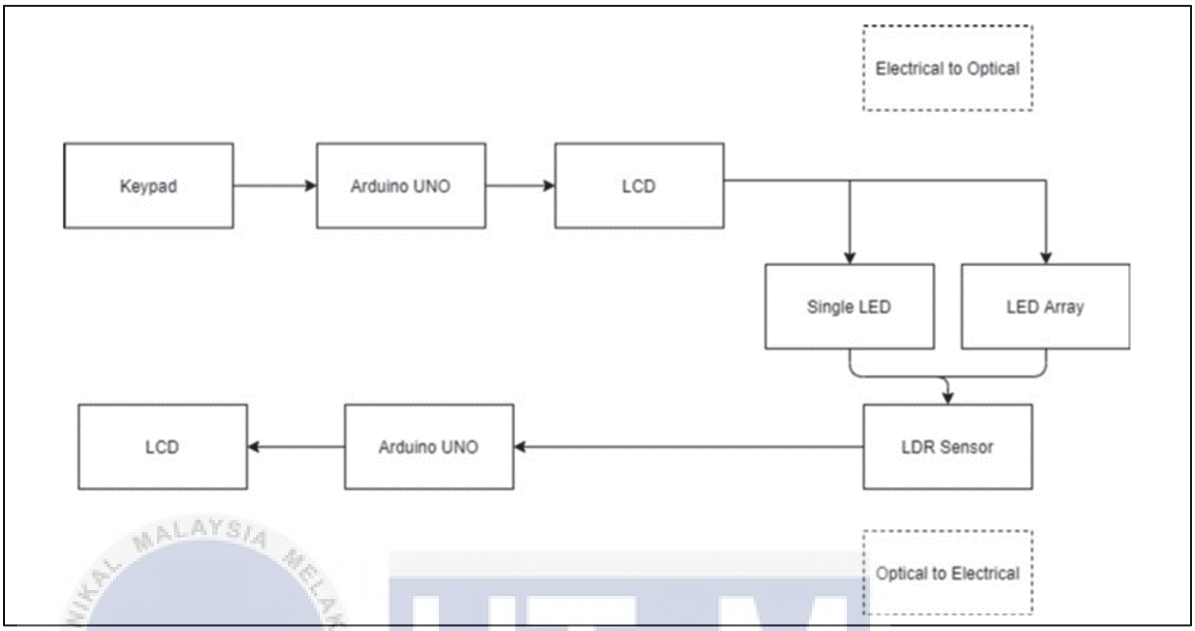

Figure 3.3: Block diagram of project

Referred to the block of diagram shows the entire project process flow whereby the keypad is the input signal that will give instruction data to the Arduino UNO. The Arduino UNO will process the data then LCD A will display the message at the same time the LED will converted the electrical to an optical signal once the data receive. The data will send through light, then the receiver part consist of LDR sensor will receive the data. The LDR will converted the optical signal to electrical signal then Arduino UNO process the data, LCD B display the message from the keypad.

3.3 Software

3.3.1 Optisystem

The software used in this project for optical part is OptiSystem. Firstly the optical circuit was designed in the software using selected components that was available. Then it was simulated to get the output signal. The resulting signals were further compared with the values of the input. The elements used in the circuit were pseudo-random bit generator, a non-return-to-zero (NRZ) pulse generator, White Light source where it acts as the carrier source with the wavelength and a Mach-Zehnder modulator. For a single LED circuit was used single optical transmitter and for LED array circuit, four optical transmitters were used. An avalanche photo diode (APD) and a low-pass Bessel filter are used in the receiving side. Using the selected components, the circuit was constructed in the software and the input signal and output signal is analyzed with BER analyzer. Firstly, both circuit was observed. This simulation was then further tested using the different distance of FSO channel. This simulation was done to find out the power received of photodiode and the output signal.

3.3.1.1 Optical Circuit Design

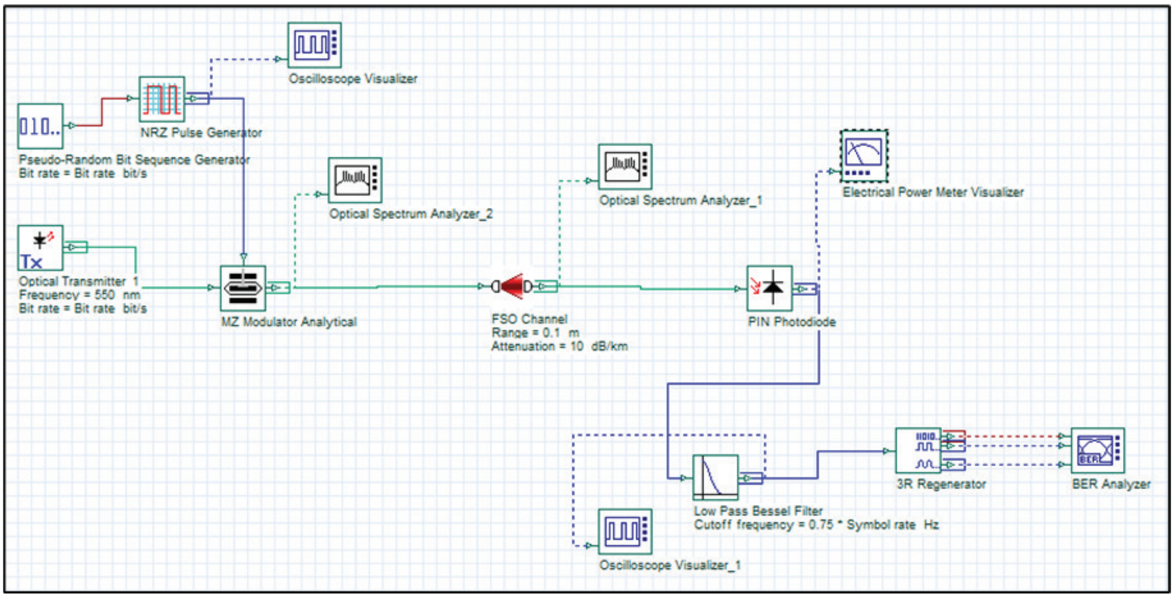

Figure 3.4: Schematic circuit design for simulation in Optisystem

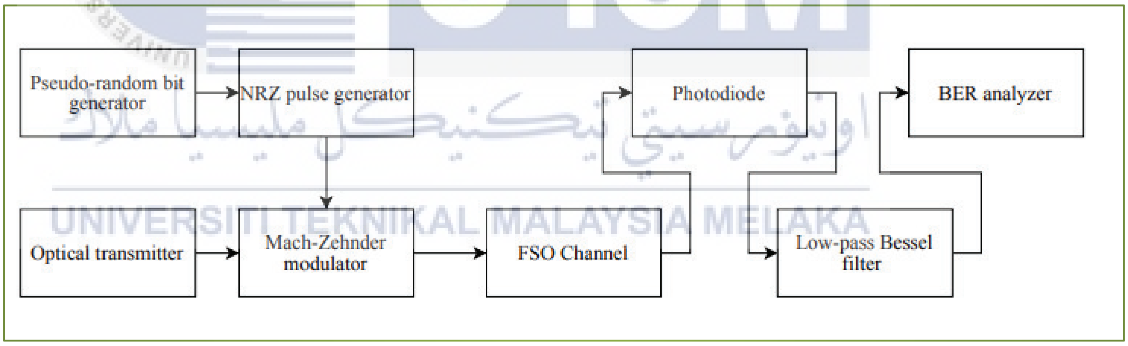

Figure 3.5: Schematic circuit design block diagram.

3.3.2 Proteus

The software used in this project for the electrical part is Proteus 8. Two circuit designed in Proteus 8 includes the transmitter circuit and receiver circuit. The component used for transmitter circuit were Arduino UNO, keypad, white LED, LCD, resistor. Where else, the components used in receiver circuit were Arduino UNO, LCD, LDR sensor, resistor, LM358. Transmitter circuit was observed using oscilloscope. The simulated circuits were further built on breadboard for testing.

3.3.2.1 Electrical Circuit Design

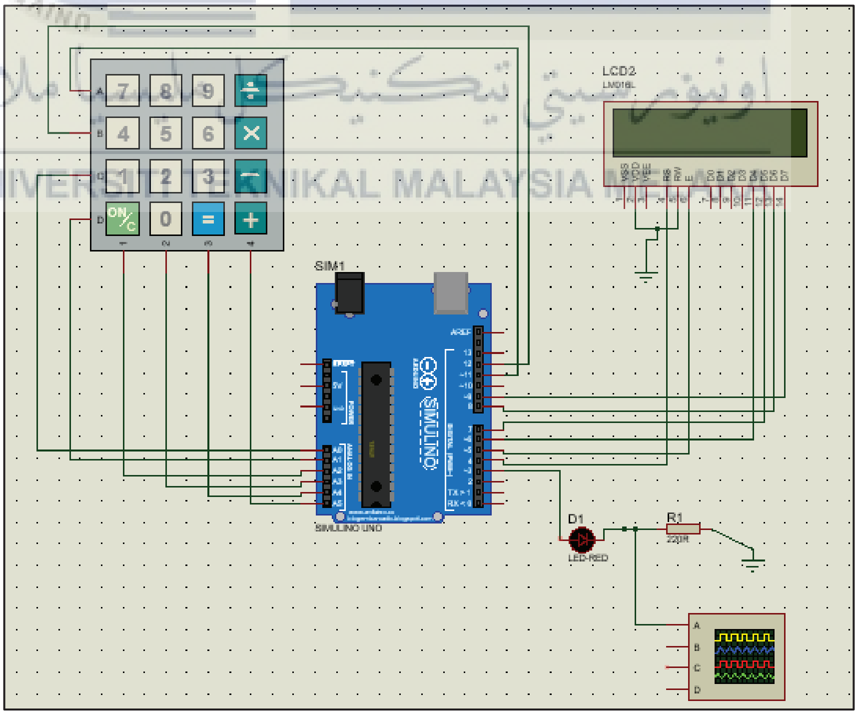

Figure 3.6: Schematic circuit design for transmitter unit in Proteus

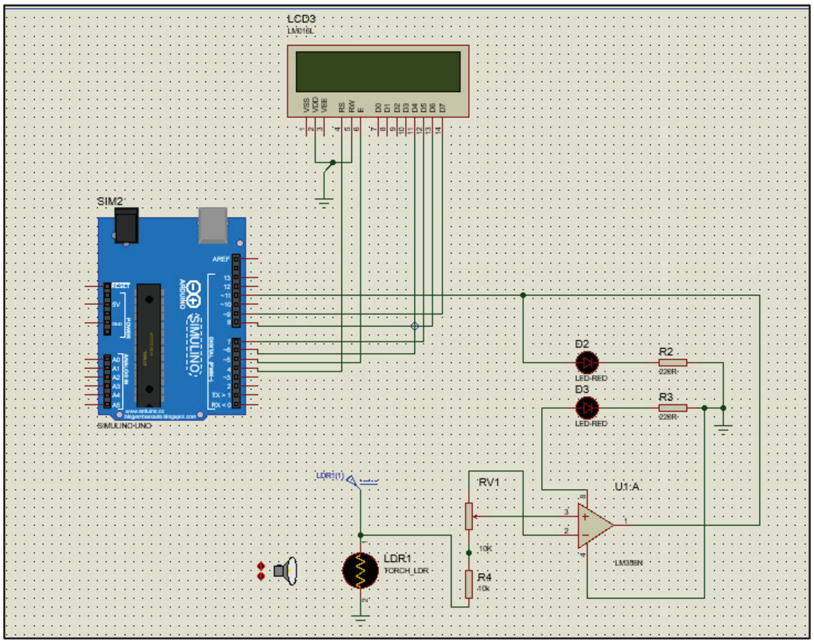

Figure 3.7: Schematic circuit design for receiver unit in Proteus

3.3.3 Arduino IDE

An Arduino IDE is an open source program, which is convenient to compose and upload to the board. It works on window, as well as the environment is written in Java system. Since this project used two Arduino UNO, one Arduino was for the transmitter part and another Arduino was for receive part. Both the coding for transmitter and receiver shown below. The Arduino library used for this project was Keypad, Wire, LCD, LiquidCrystal_I2C, and Software Serial.

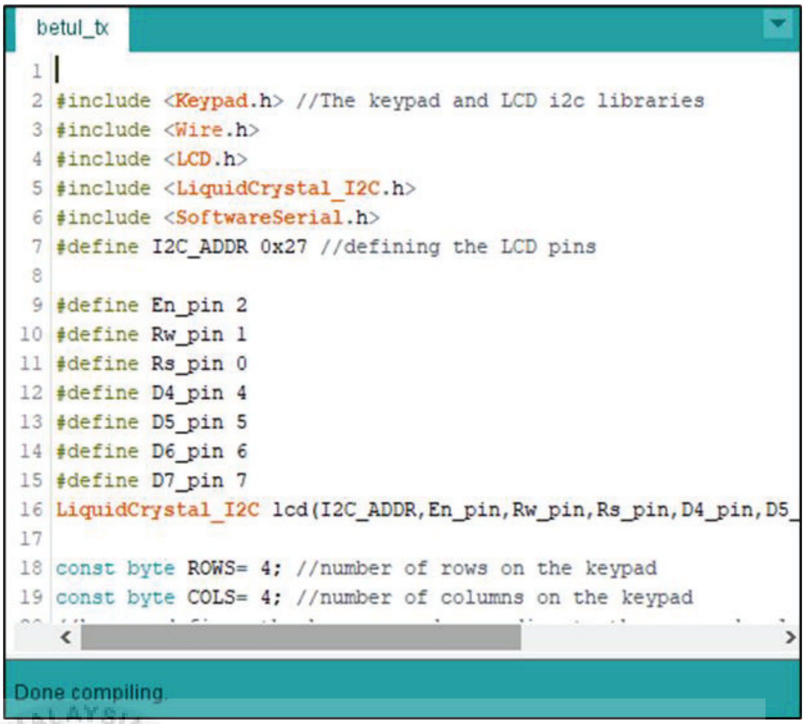

Figure 3.8: Arduino coding for transmitter unit

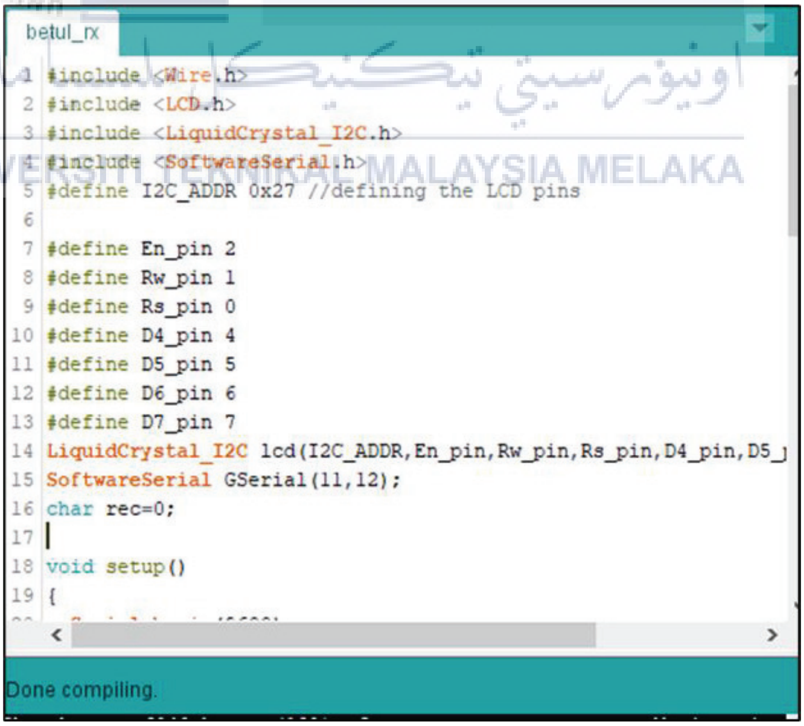

Figure 3.9: Arduino coding for receiver unit

3.4 Hardware

The prototype of this projects requires Arduino UNO, white LED, red LED, LDR sensor, Liquid Cristal Display, Keypad, potentiometer and IC chip.

3.4.1 Arduino UNO

Figure 3.10: Arduino UNO

This project consists of two Arduino UNO that will process data at transmitter part and receiver part. Arduino UNO is microcontroller in this project that will manage and process data.

3.4.2 White LED 5mm

Figure 3.11: White LED

White LED was use for single LED and LED array. This white LED helps on transmitting data through light from one point to another point.

3.4.3 Red LED

Figure 3.12: Red LED

Red LED was function as indicator to the receiver, when the LDR is detect any presence of light the red LED will turn ON.

3.4.4 LDR Sensor

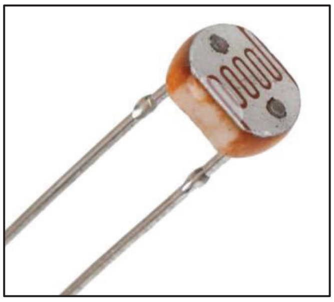

Figure 3.13: Light Dependent Resistor (LDR)

LDR sensor on this project is the receiver that will capture light from the transmitter LED and will convert the optical signal to electrical signal.

3.4.5 Liquid Crystal Display (LCD)

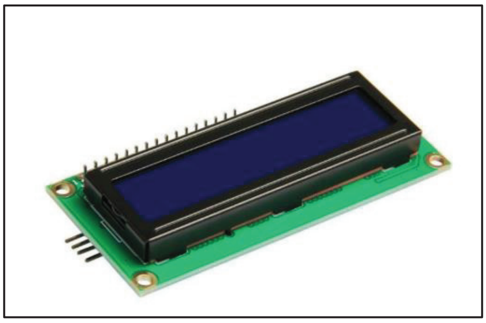

Figure 3.14: 16x2 Liquid Crystal Display (LCD)

LCD as the display data that sending from the keypad, both circuit used the LCD.

3.4.6 Keypad

Figure 3.15: 4x4 Keypad

Keypad function as the input signal, the data will send when the keypad is pushed. The 4x4 is mean that the keypad have 4 rows and 4 colombs.

3.4.7 Potentiometer

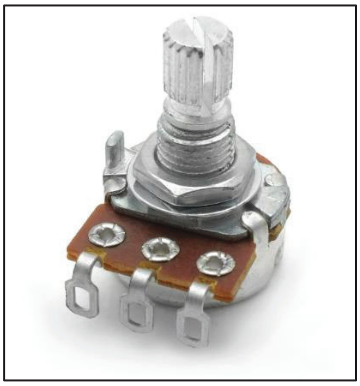

Figure 3.16: 250K Potentiometer

Potentiometer is a main part for LDR sensor, the value of resistor will adjust according to the distance of LED to LDR. Less distance of LED to LDR, more the value of resistor.

3.4.8 IC Chip

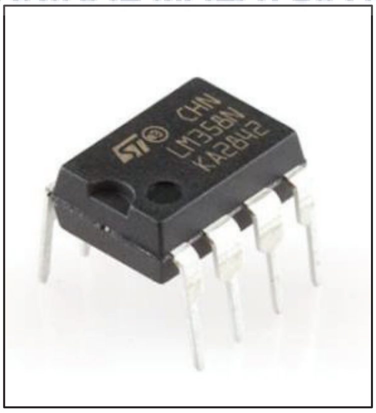

Figure 3.17: LM358

LM358 is a microcontroller in receiver circuit.

3.5 Conclusion

The project flow was performed according to the defined flowchart. Based on the schematic circuits, the optical and electrical parts are designed. The outcome for each parts of the projects were observed and documented hence analyzed and discussed in chapter 4.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter discuss about the overall project analysis of all the results and discussion. The results were the outcome of all the methods proposed which includes the software and hardware part. This discussion would be mainly based on the analysis of the optical and electrical part.

4.1 Prototype Design

Prototype was completed based on the planned schedule that the prototype includes the transmitter part and the receiver part. The transmitter part shown was a box that consist of the keypad, LCD and LED on the side of the box. Keypad function is to give instructions to the Arduino, then the data will process to LCD and LED. For the receiver part, the box that has a LCD and LDR sensor to capture the light sensor.

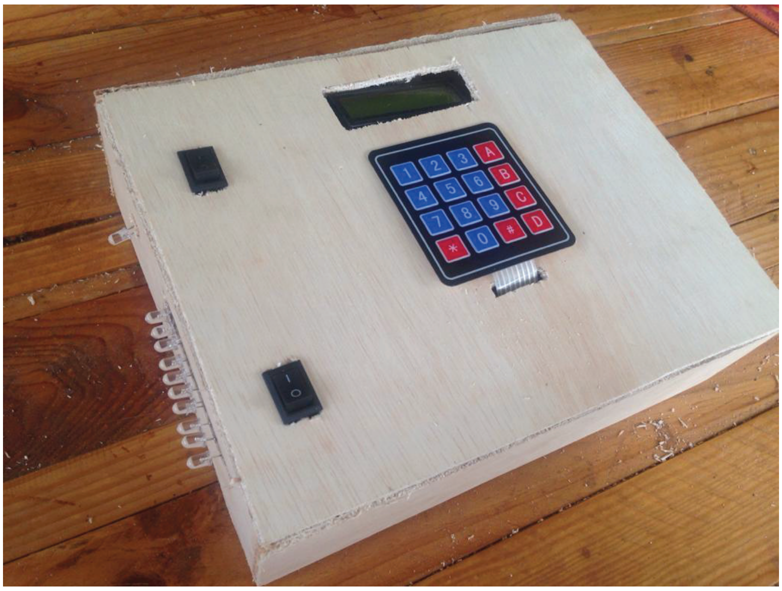

Figure 4.1: Displayed transmitter unit

Figure 4.2: Displayed receiver unit

4.2 Circuit Design

The circuit was done for both the transmitter and receiver unit were constructed on breadboard. Firstly, the circuits were designed and simulated using the software Proteus 8. The circuits was design on the breadboard using jumper wire to connect from one component to another component.

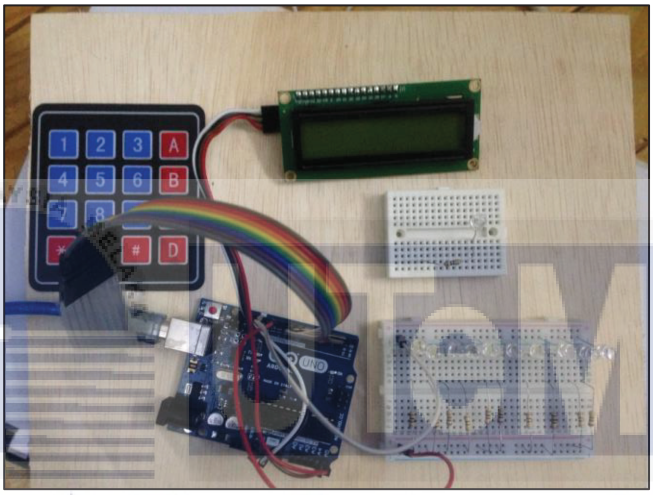

Figure 4.3: Transmitter circuit built on bread board

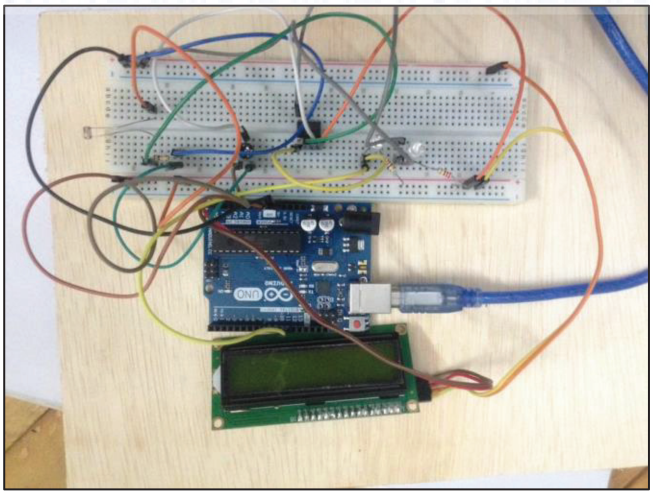

Figure 4.4: Receiver circuit built on bread board

4.3 Software

This project consists of two parts of simulation which were optical and electrical. The Optisystem software used for optical parts whereas Proteus for electrical part. The OptiSystem simulation of single LED and LED array was done to design the overall project flow and after that the Proteus simulation was done to design and test the transmitting and receiving circuit boards.

4.3.1 Optisystem

The overall optical project flow of single LED and LED array was designed in the software and simulated with increasing distance of FSO channel and determine power received of the photodiode.

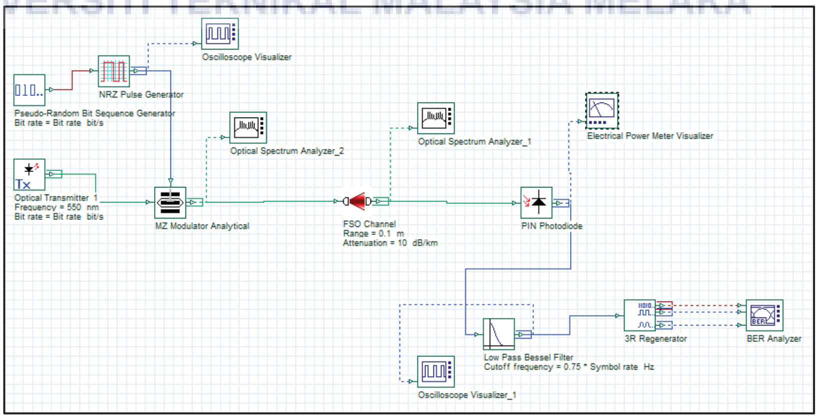

Figure 4.5: Schematic circuit for single LED and single photodiode

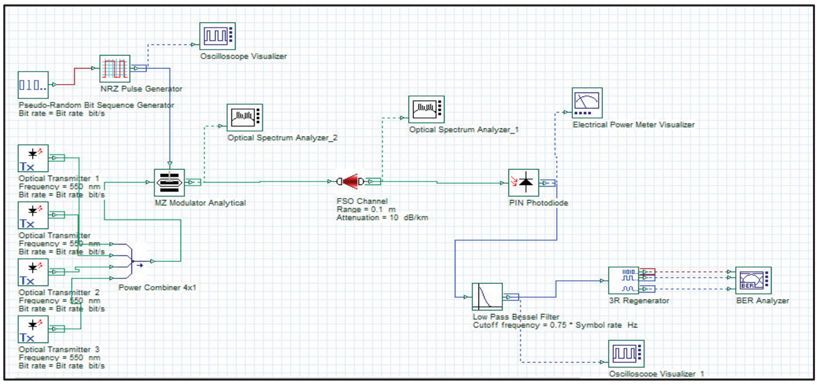

Figure 4.6: Schematic circuit for LED array and single photodiode

Table 4.1: The result of the power received of photodiode and distance between LED to FSO channels for single LED and LED array

Distance between LED to FSO channel (cm)	Single LED	LED Array
	Power received of photodiode (μW)	Power received of photodiode (μW)
10	58.113	59.767
20	57.844	60.525
30	56.905	58.534
40	55.761	57.100
50	55.102	56.276

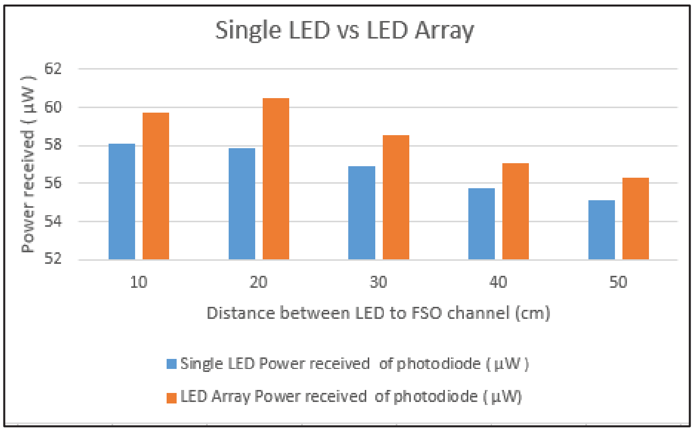

Figure 4.7: Compared distance between LED to FSO channel and power received of Photodiode for Single LED and LED Array

For the Figure 4.7 shows that, the power received for the single LED are decreasing at constant depend on the more distance of FSO channel. Based on the graph it can be observed that the power received is decreasing from 58.113 µW to 55.102 µW. For the LED array, the power received are increasing and decreasing because of the LED array might have some interference from another LED. As in simulation, the value of the power received always changed also due to interference.

Figure 4.8 until Figure 4.12 below show the output signal for single LED with increasing the distance of FSO channel. This graph is the Q-factor vs time and all graph is bell shape. Based on the graph it can be observed that from 0 to 0.4 time/s the Q factor are increase sharply, this is due to data received from the transmitter. At the time 0.46 time/s, Q factor is the peak point at 20.06. Lastly, after the data have been received the value of Q factor will drop exponentially decreasing.

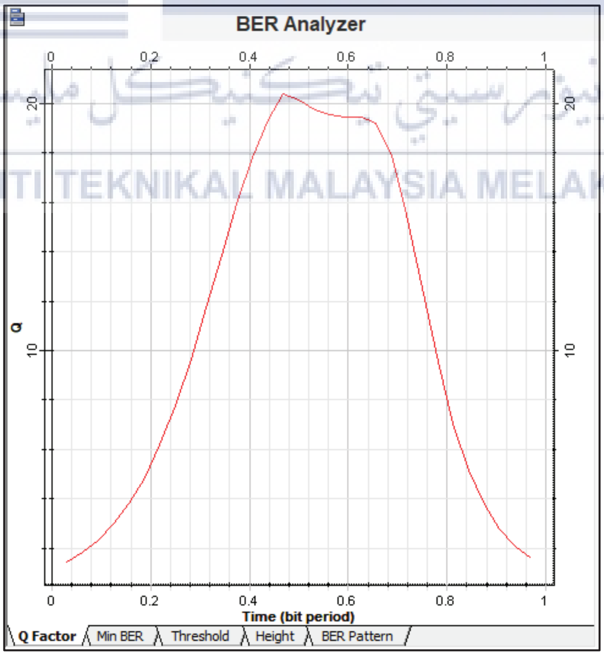

Figure 4.8: Output signal for single LED with distance 10cm

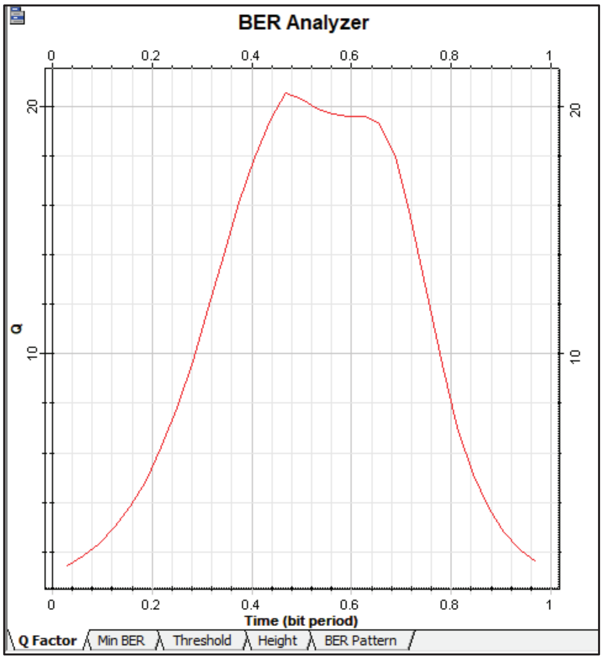

Figure 4.9: Output signal for single LED with distance 20 cm

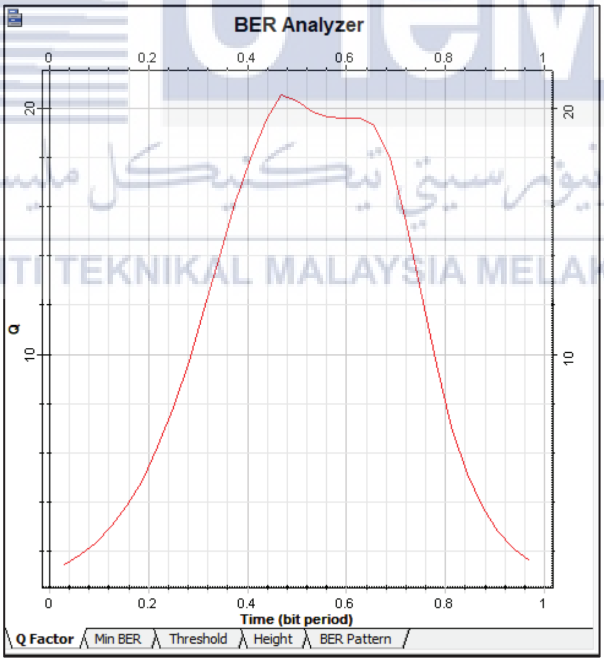

Figure 4.10: Output signal for single LED with distance 30 cm

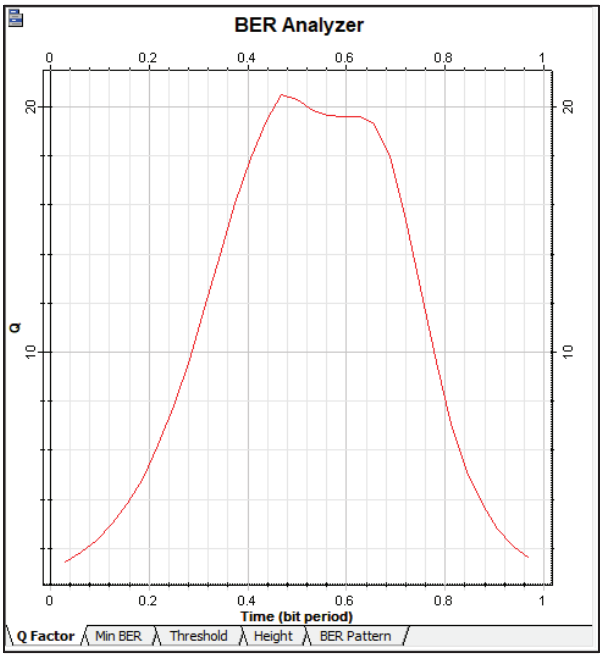

Figure 4.11: Output signal for single LED with distance 40 cm

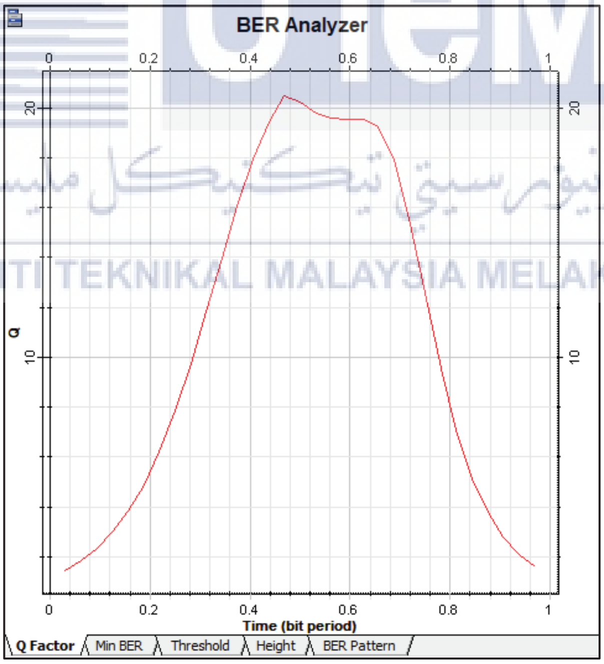

Figure 4.12: Output signal for single LED with distance 50 cm

Figure 4.13 until Figure 4.17 below show the output signal for LED array with increasing the distance of FSO channel. All the graph is in different shape from each other due to the fact of interference.

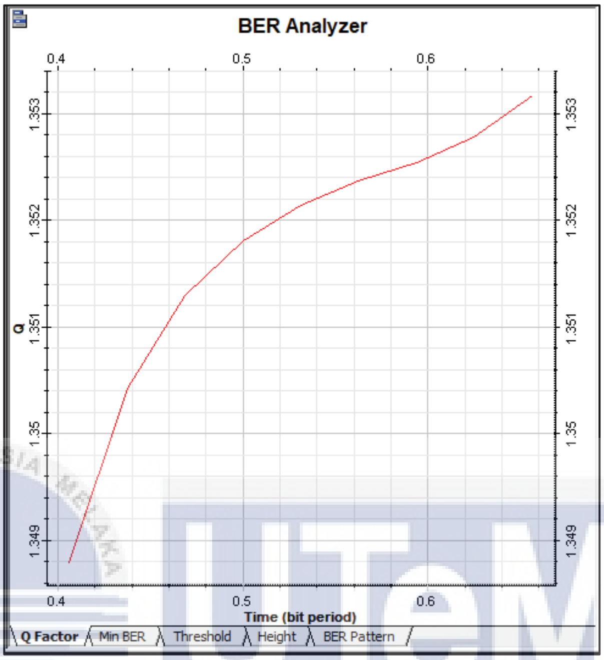

Figure 4.13: Output signal for LED array with distance 10cm

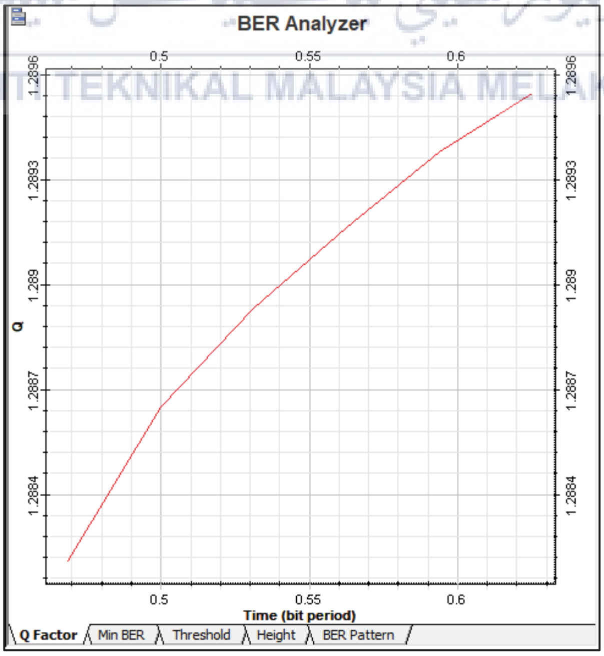

Figure 4.14: Output signal for LED array with distance 20 cm

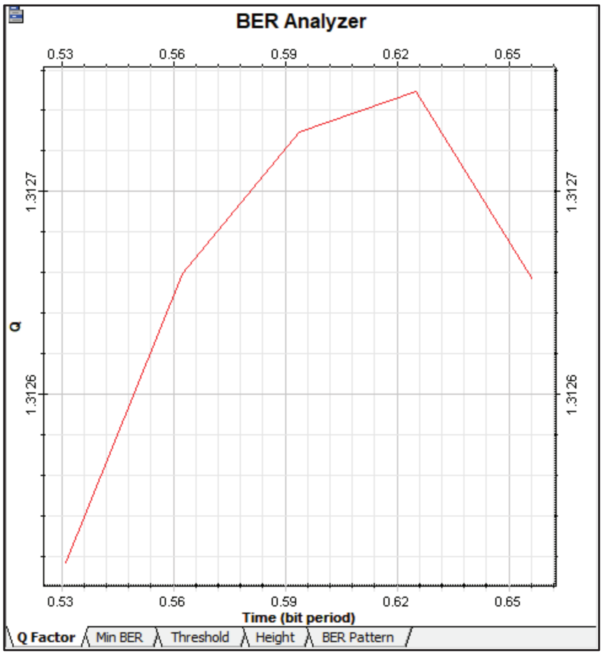

Figure 4.15: Output signal for LED array with distance 30cm

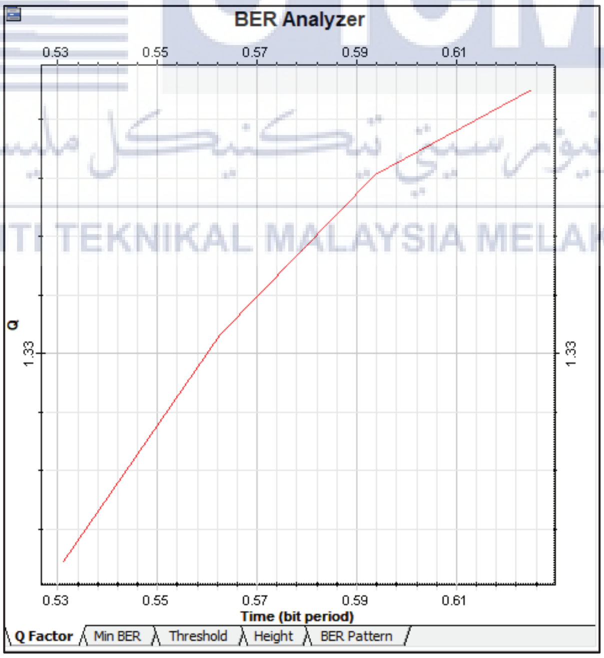

Figure 4.16: Output signal for LED array with distance 40 cm

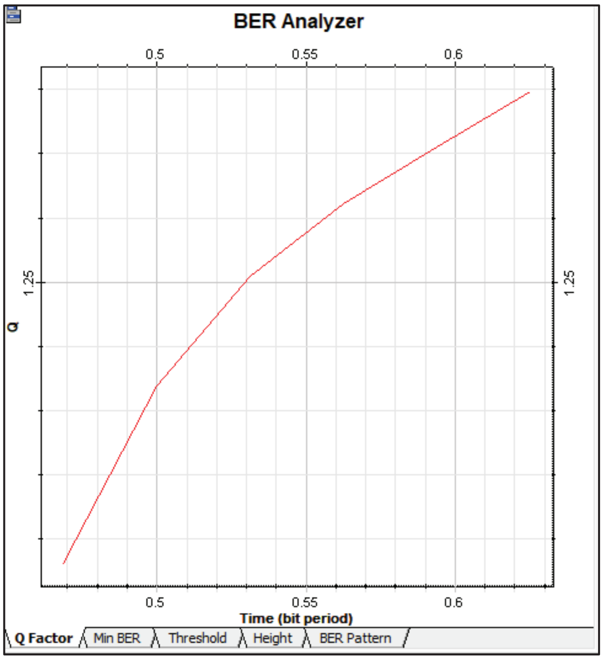

Figure 4.17: Output signal for LED array with distance 50 cm

4.3.2 Proteus

4.3.2.1 Transmitter Circuit

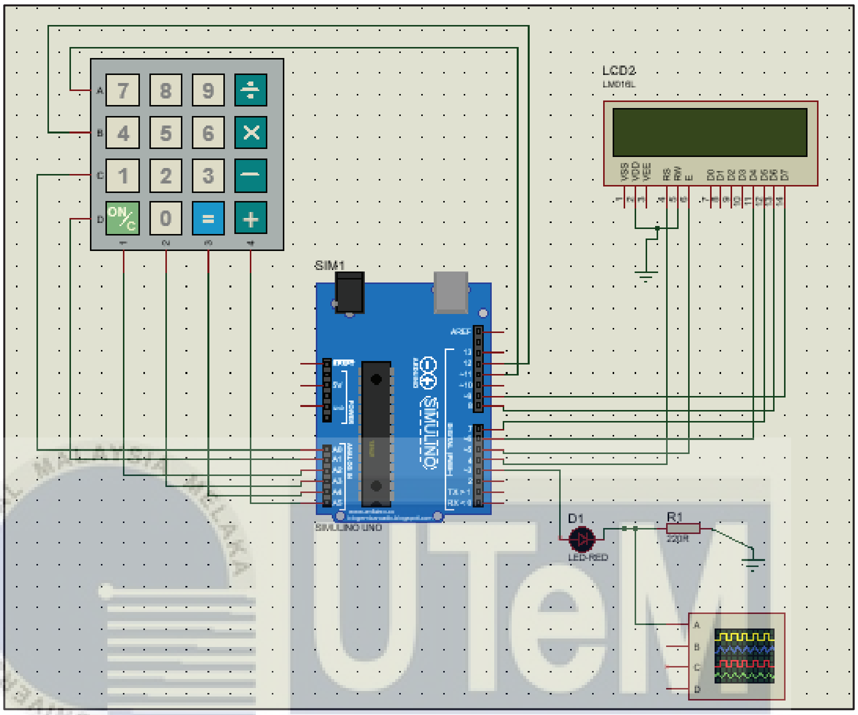

Figure 4.18: Simulation circuit of transmitter unit for single LED

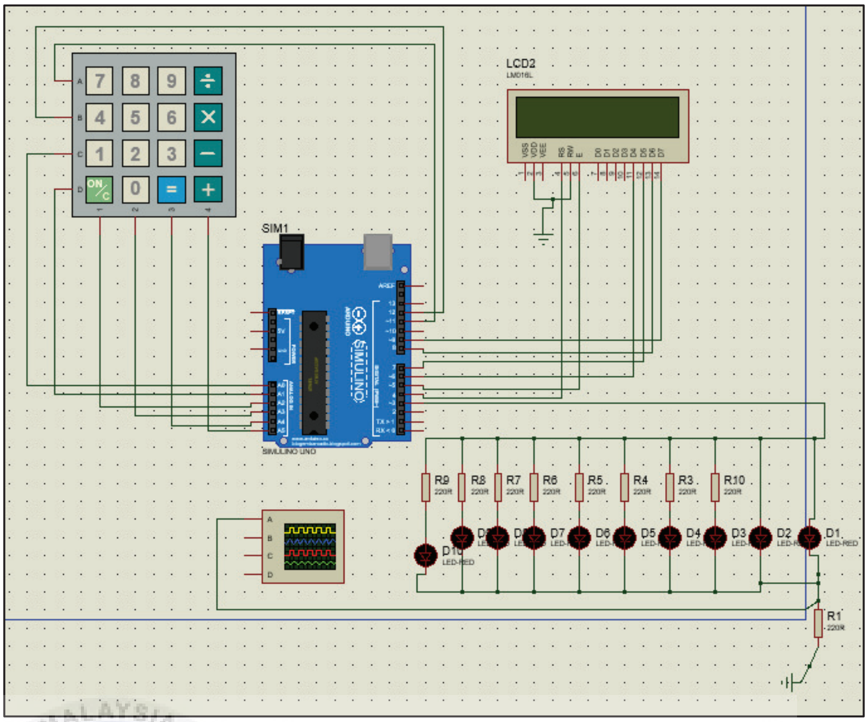

Figure 4.19: Simulation circuit of transmitter unit for LED array

Figure 4.18 and Figure 4.19 shows the simulation circuit designed of transmitter unit for single LED and LED array. 5mm LED was used for sending the data through light to the LDR sensor. The transmitter consists of modulator whereby the input signal was modulated before transmitting the data.

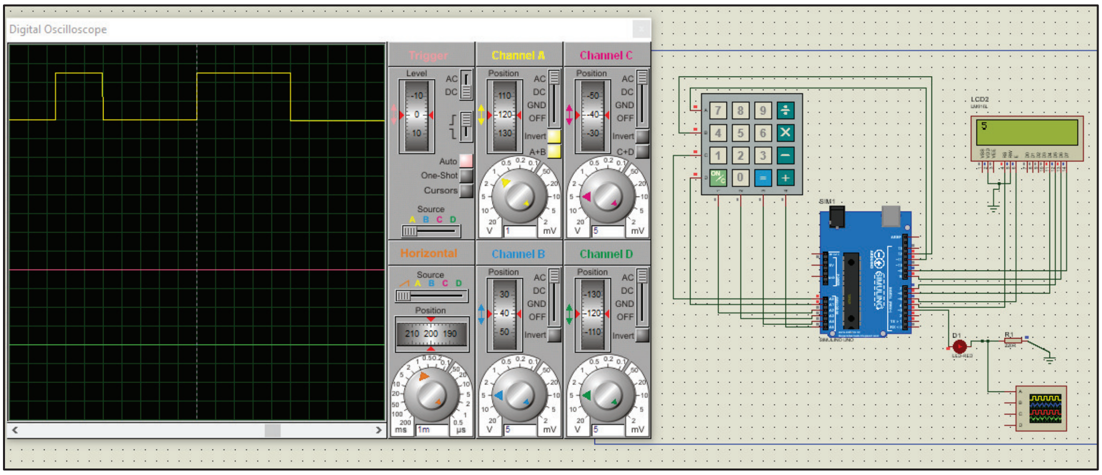

Figure 4.20: Simulation output signal of simulation unit for single LED

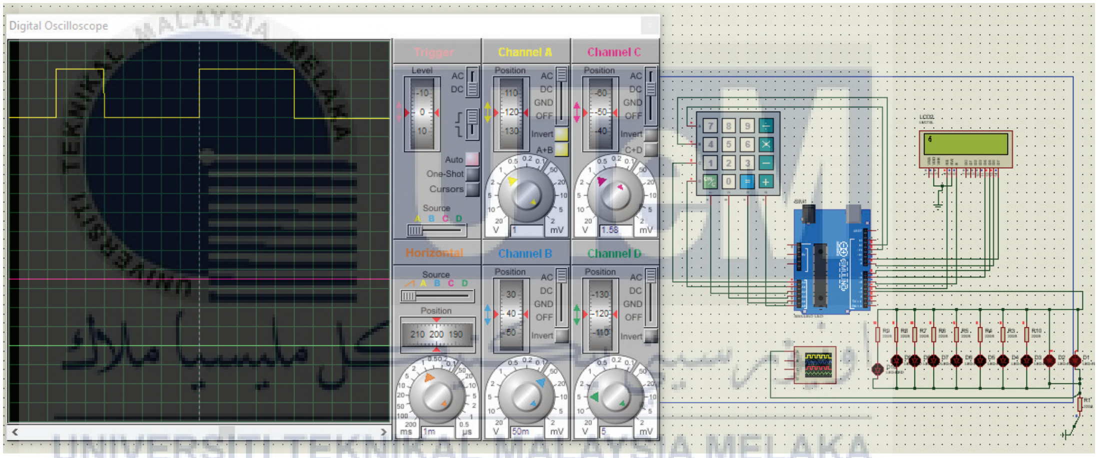

Figure 4.21: Simulation output signal of simulation unit for LED Array

Figure 4.20 and Figure 4.21 shows the output waveform for the output of circuit which is when the data send, the waveform will change for LOW ('0') to HIGH ('1'). The LCD will display the number when the keypad was pushed.

4.3.2.2 Receiver Circuit

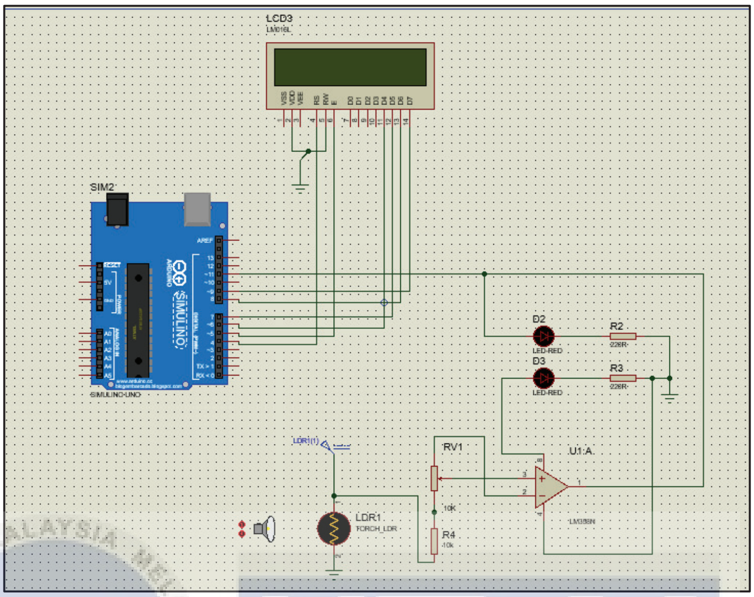

Figure 4.22: Simulation circuit of receiver unit

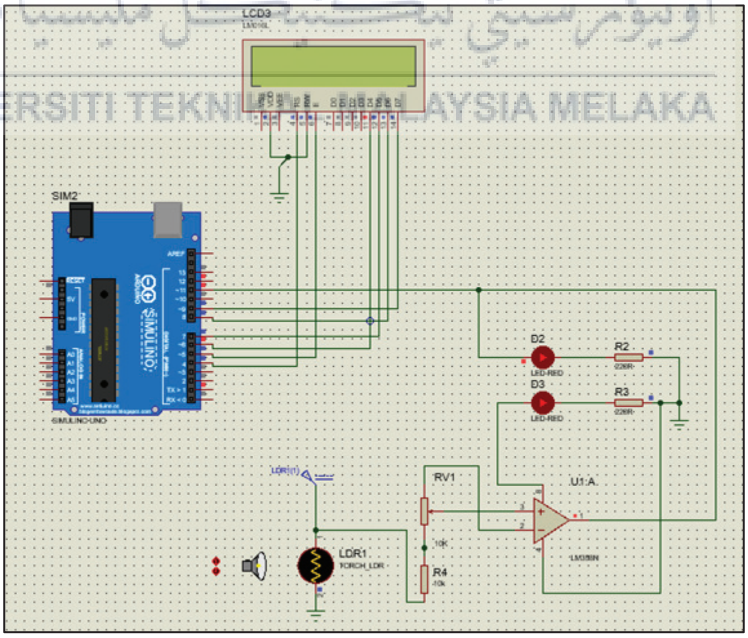

Figure 4.23: Simulation output for receiver unit

Figure 4.22 show the simulation circuit designed of receiver unit that consist of LM358 and LDR was used to capture the light. During this process the Arduino UNO is turned OFF. Figure 4.23 show the simulation when the Arduino UNO is turned ON. When the LDR sensor received light, the red LED will turn ON as an evidence of the circuit functionality.

4.4 Comparison actual result for distance between LED to LDR and power received of LDR for single LED and LED array

This section is a discussion about the outcome of the actual experiment project that shown at Figure 4.3 for transmitter unit and Figure 4.4 for the receiver unit. The power received of LDR is determine by distance between LED to LDR and the result will be compared between this device. For determine power received of LDR, formula $P = V^2 / R$ was used. The multimeter was used to measure the value of the voltage (V) and resistor (R). The resistor value was set by using the potentiometer. The distance between LED to LDR is set 10cm, 20 cm, 30cm, 40cm and 50cm simultaneously. In addition, the power received of LDR were calculated based on the resistor value of 20kΩ, 40kΩ, 60kΩ and 80kΩ.

.

Table 4.2: The result of comparison distance between LED to LDR and power received of LDR for Single LED and LED Array for resistor 20kΩ

Resistor value = 20kΩ		
Distance between LED to LDR (cm)	Single LED	LED Array
	Power received of LDR (µW)	Power received of LDR (µW)
10	72.21	75.43
20	68.73	69.01
30	64.49	70.56
40	61.17	65.37
50	59.85	64.97

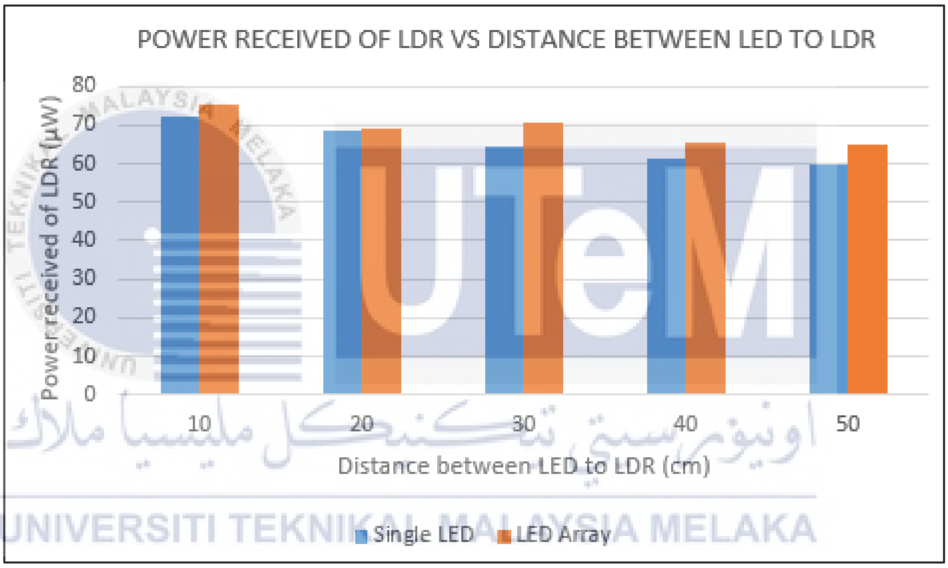

Figure 4.24: Graph of power received of LDR vs distance between LED to LDR using resistor 20kΩ

Figure 4.24 above are representing the graph from the Table 2. The power received of LDR for single LED is decreasing constantly. Next, for the LED array, the power received from 10cm to 20 cm is decrease but at 30cm the power value slightly increases. Then the power continues to decrease accordingly.

Table 4.3: The result of comparison distance between LED to LDR and power received of LDR for Single LED and LED Array for resistance 40kΩ

Resistance = 40kΩ		
Distance between LED to LDR (cm)	Single LED	LED Array
	Power received of LDR (µW)	Power received of LDR (µW)
10	34.81	36.60
20	33.64	34.81
30	31.36	34.22
40	30.25	34.81
50	26.01	30.80

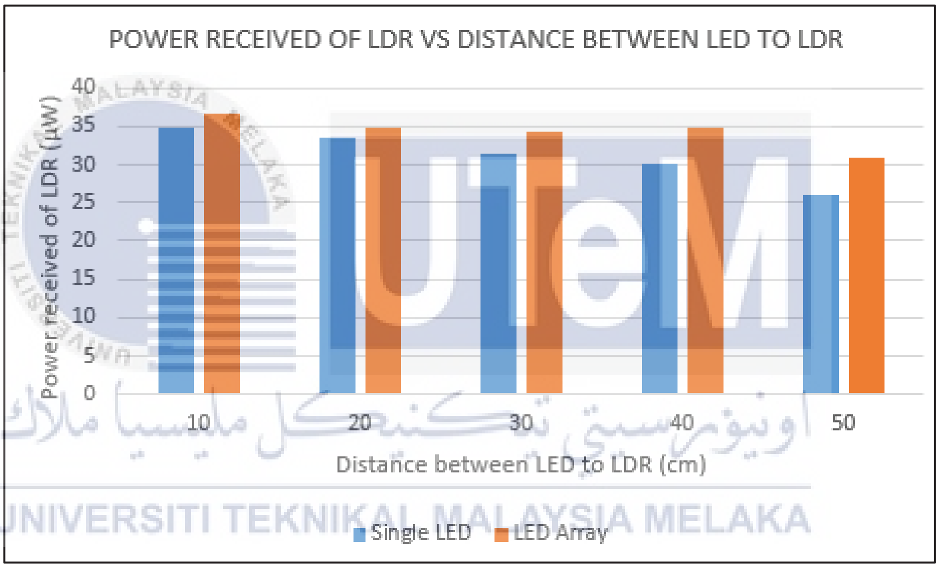

Figure 4.25: Graph of power received of LDR vs distance between LED to LDR using resistance 40kΩ

Figure 4.25 above are representing the graph from the Table 3. The power received of LDR for single LED is decreasing steadily. Meanwhile, for the LED array, the power obtained from the distance of 10cm to 30 cm is declined but at 40cm the power value slightly rises. The power will continue to decrease consistently.

Table 4.4: The result of comparison distance between LED to LDR and power received of LDR for Single LED and LED Array for resistance 60kΩ

Resistance = 60kΩ		
Distance between LED to LDR (cm)	Single LED	LED Array
	Power received of LDR (μW)	Power received of LDR (μW)
10	18.72	22.43
20	17.00	22.82
30	15.58	22.04
40	14.72	22.32
50	13.20	20.95

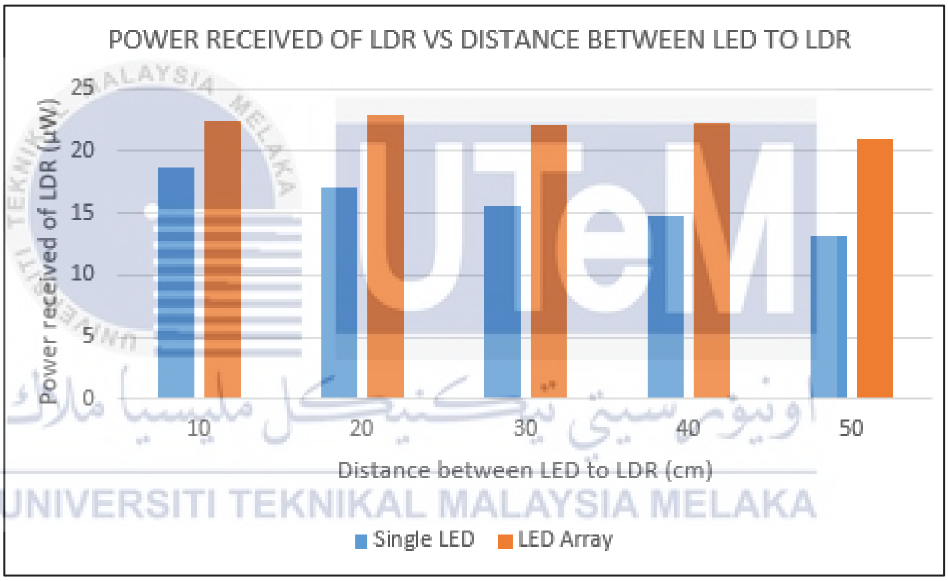

Figure 4.26: Graph of power received of LDR vs distance between LED to LDR using resistance 60kΩ

Figure 4.26 above are demonstrate the graph from the Table 4. The power received of LDR for single LED is decreasing uniformly. Subsequently, for the LED array, the power gained is different one to another.

Table 4.5: The result of comparison distance between LED to LDR and power received of LDR for Single LED and LED Array for resistance 80kΩ

Resistance = 80kΩ		
Distance between LED to LDR (cm)	Single LED	LED Array
	Power received of LDR (µW)	Power received of LDR (µW)
10	13.00	14.31
20	12.75	12.75
30	11.76	12.95
40	11.28	11.76
50	9.03	9.90

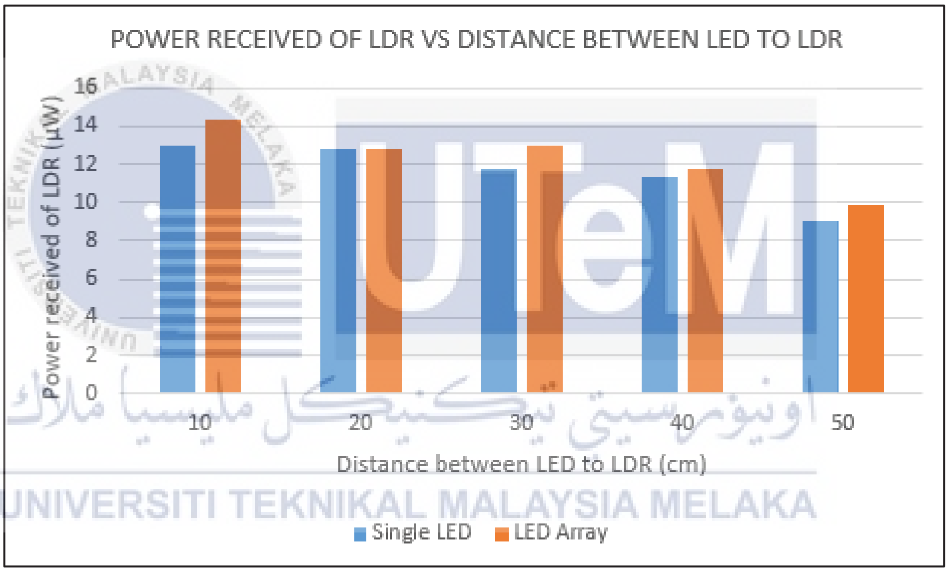

Figure 4.27: Graph of power received of LDR vs distance between LED to LDR using resistance 80kΩ

Figure 4.27 above are display the graph from the Table 5. The power received of LDR for single LED is decreasing consistently. After that, for the LED array, the power obtained from the distance of 10cm to 20cm is drop but at 30cm the power value a bit increase. Then the power will continue to decrease consistently.

The Figure 4.24 until Figure 4.27 show the graph of comparison, to be concluded that the power received of LDR for single LED is decreases constantly but for LED array the power received of LDR is decreases inconsistently. The power received of LDR for LED array not stable since there is interference of LED.

4.5 Brightness of LED

Lux Light Meter apps was used for measure the brightness of LED within a different distance. The apps will show the result value lumen of LED. The sensor hand phone was used to measure the brightness. So the light LED must direct to the sensor for get accurate value of the brightness.

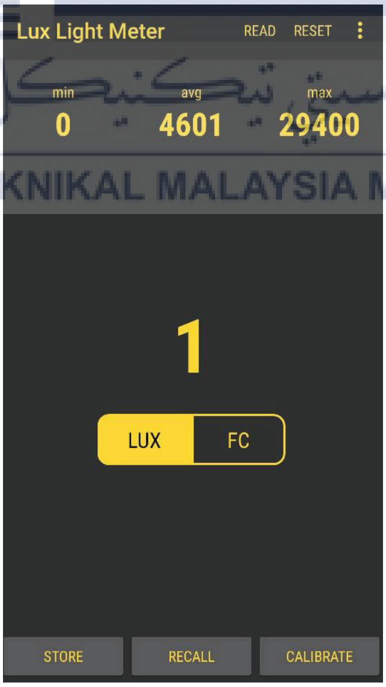

Figure 4.28: Lux Light Meter apps

4.5.1 Comparison result for distance between LED to sensor for Single LED and LED Array

Table 4.6: Comparison of distance between of LED to sensor and total Lux for single LED and LED array

Distance between LED to sensor (cm)	Single LED	LED Array
	Total LUX (Lux)	Total LUX (Lux)
10	3020	5566
20	1156	5090
30	414	2377
40	290	1469
50	125	918

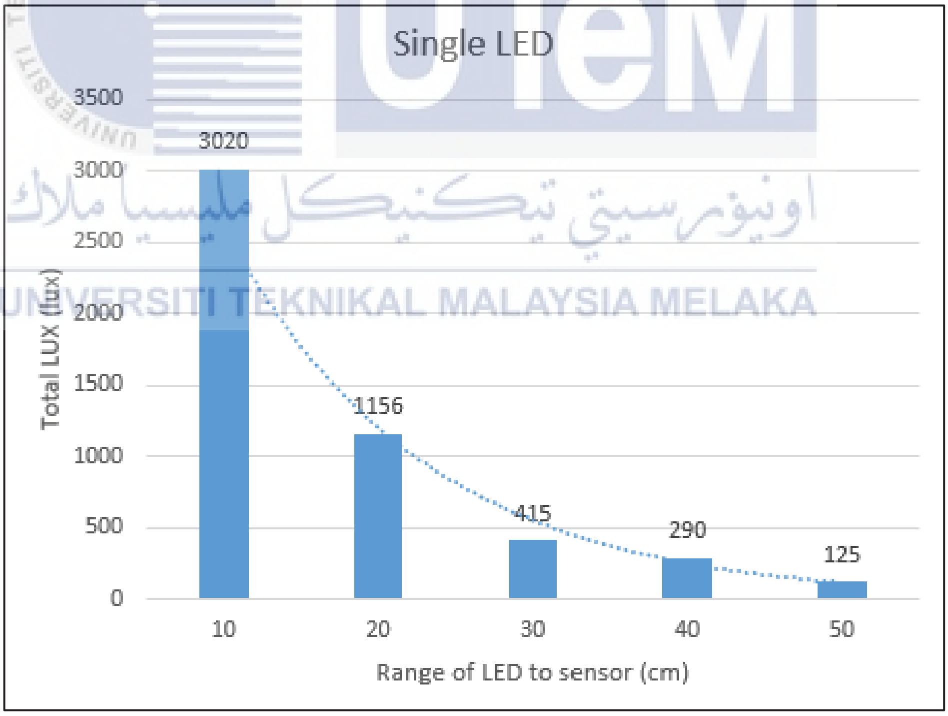

Figure 4.29: Distance between LED to sensor and total lux for single LED

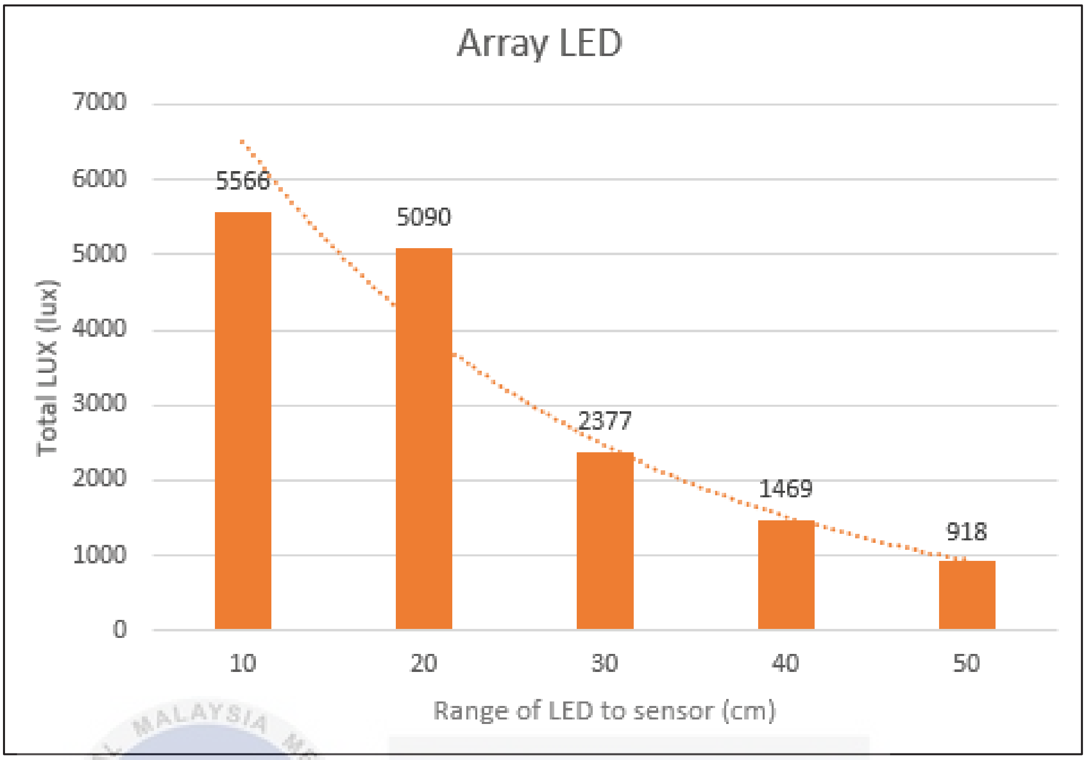

Figure 4.30: Distance between LED to sensor and total lux for LED array

Lux Light Meter apps was used for measure the brightness of LED within a different distance. The apps will show the result value lumen of LED. The light sensor in the handphone was used to measure the brightness. So the light LED must direct to the sensor for get accurate value of the brightness. When the distance between LED to sensor increases, the total lux decreases. From the above comparison, it can be concluded that the total lux for LED array is more than single LED.

4.6 Discussion

Based on this project, the main objective was to design and construct a VLC system consists of the transmitter unit and receiver unit. The second objective was to analyze data transmission of VLC using a single LED and LED array such as distance between LED to LDR, power received of LDR, and brightness of LED. According to the objective, the VLC system was successfully designed, constructed and tested. Firstly, the optical part of the project was designed separately in a software Optisystem, several simulations were done and the simulation show that the more distance of FSO channel, more power are required to used depend on the total of LED uses. Even the LED array is bright, the power transmit are not stable compared to the single LED. So, the suggestion to get stable power transmit is by using a single LED with high power to improve the distance of FSO.

For electrical part of the project was designed separately in a software Proteus. The design was tested before a finalized design of transmitter circuit and receiver circuit were selected. The transmitter circuit was mainly used a single LED and LED array for data transmission, keypad and LCD as a display. Next the receiver circuit mainly used an LDR as sensor which function to capture the light. The transmitter circuit and receiver circuit was design at the breadboard. The transmitter circuit board was connected to the Arduino UNO and the receiver circuit also connected to the different Arduino UNO. The prototype transmitter and receiver was designed and constructed in the different box. Keypad function as instruction that will give the message data to Arduino UNO, then the LCD will display the message at the same time LED flickering. The message also displays at the LCD on the receiver part. This message is being transmitted through visible light communication. When the LDR was block, the message cannot be received.

According to second objective, the constructed VLC was tested on the single LED and LED array at the distance between LED and LDR, power received of LDR, and brightness of LED. The comparison of distance and power received of LDR for single LED and LED array was analyze by using formula P = V^2/R. The power received is inversely proportional to the resistor value. So, as the resistor value increases, the power received will decrease. For single LED, the distance between LED to LDR affect the power received of LDR as the distance is in rising state, the power gained by LDR is declining in uniform pattern. On the other hand, based on the graph in Figure 4.24 until Figure 4.27, power gained for the LED array also declining but in irregular pattern as the LED array have distortion in terms of the other conditions such as shadow, external light source, and light intensity. Secondly, the brightness of LED was measure using a Lux Light Meter apps. The total lux of LED was measured by increase the distance between LED to sensor of hand phone. The light LED must be positioned vertically with LDR to get an accurate lux value. The Figure 4.29 and Figure 4.30 show the more distance between LED to sensor, the less total lux was measured. The comparison show, the LED array has more total lux than single LED because LED array used many LED so the light will brighter.

Since the results obtained in this project were in both simulation and actual system, a comparison has been done for the distance of LED to LDR. In the simulation, the results were obtained in signal waveform and power measure. In actual system, results for power measure have been determine by using a multimeter. The result of actual system is different from simulation result. This is because in actual system, due to surrounding situations, the signal interference is higher when more light sources are present. Many problems were faced during the completion this project. For the simulation Arduino IDE part, many coding was used to make the successful.

4.7 Environment and Sustainability

Environmental care is a responsibility everyone should feel responsible for. This project proposed a data transmission system via LED lights, which could be used for both lighting and networking. LED illumination offers many environmental advantages. Firstly, it is energy efficient whereby it draws less power. Less use of energy reduces power plant demand and reduces greenhouse gas emissions. Besides, LED lights are free of toxic elements and have better light distribution quality. This means less LED lights are needed to achieve the same level of brightness given off by fluorescents or incandescent lights. Fewer lights will reduce the energy consumption. LED has a longer life span as it has lower carbon emissions. LED lights can last longer than other types of lights, thereby reducing frequent replacement requirements.

CHAPTER 5

CONCLUSION AND FUTURE WORKS

5.1 Conclusion

This project is about Visible Light Communication which also known as VLC, a new research area in the technology of wireless communication. The concept is on modulation of the white LEDs broadcasting electromagnetic waves. The idea of this project is referred to the existing VLC system which uses a single LED to transfer data with different coverage in a space. The data transfer by a single LED is limited in space for each of the LED with a certain radius length.

Therefore, this project title 'Single LED vs LED-Array VLC System Performance Analysis' is carried out by designing, simulating and constructing VLC system of transmitter unit (consist of single LED/LED array) and also VLC system of receiver unit (consist of LDR sensor). The performance of the complete system and data transmission of single LED/LED array are also analysed. This project consist of two objectives that is to design a VLC system that consist of transmitter and receiver unit and also to analyze data transmission of VLC using single LED and LED array such as distance between LED to LDR, power received of LDR and brightness of LED. As per mention in chapter 4, the VLC system was successfully designed, constructed and tested. The constructed VLC are also has been tested towards the single LED and LED array at the distance between LED to LDR. Based on the data gained, a hypothesis is obtained that is the higher the distance between LED to LDR, the less power are received. Although LED array uses higher power, the total lux is higher compared to the single LED. This shows that there are pros and cons in both single LED and array LED.

To be conclude, there are advantage and disadvantage from both single and array LED. The analysis has been carried out and obtained the total power received of LDR and also total LUX from both of LEDs. Power received of LDR at single LED has received a low power and the single LED produce a low brightness while power received of LDR at LED array accept a high power and produce higher brightness. This shows that, LED array preferable to be use on transferring data because of the higher brightness (total LUX). However, single LED has lower in cost as the power used is lesser than LED array.

5.2 Future Work

Both of the objectives of this project is achieved. Based on the results, the VLC system was successfully designed, constructed and tested. The constructed VLC are also has been tested towards the single LED and LED array at the distance between LED to LDR. However, there is always rooms for improvement.

As the project is carried out, there are few issues and complication has occurred. One of them is limitation of use of tools. With limitations of tool used, this project has slightly deficient of outcomes. Another issues is the data is not continuously transferred. This is because the data is transferred by using keypad, as the keypad can only be transferred one data at a time with every click. Results shows that with the uses of the LED array, the total lux is higher compared to single LED. Although it is one of the advantages of LED array, the power used is higher which means high in cost.

With these issues and complication faced, there's always a solution for it. So, for the future researchers, there is some improvement that can be made to improve the result of the project. The improvement is:-

- To use oscilloscope, optical spectrum analysis modules and optical power meter to obtain the waveform graph for an accurate data and better vision and perspective as a strong evidence of the paperwork.
- To be able to control on transferring data continuously.
- To reduce the power used of LED array so it benefits both in data transferred and reduce in cost.

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APPENDICES

Appendix A: Coding for transmitter

```
#include <Keypad.h> //The keypad and LCD i2c libraries
#include <Wire.h>
#include <LCD.h>
#include <LiquidCrystal_I2C.h>
#include <SoftwareSerial.h>
#define I2C_ADDR 0x27 //defining the LCD pins

#define En_pin 2
#define Rw_pin 1
#define Rs_pin 0
#define D4_pin 4
#define D5_pin 5
#define D6_pin 6
#define D7_pin 7
LiquidCrystal_I2C lcd(I2C_ADDR,En_pin,Rw_pin,Rs_pin,D4_pin,D5_pin,D6_pin,D7_pin);

const byte ROWS= 4; //number of rows on the keypad
const byte COLS= 4; //number of columns on the keypad
//keymap defines the key pressed according to the row and columns just as appears on the keypad
char hexaKeys[ROWS][COLS] = {

{'1', '2', '3', 'A'},
{'4', '5', '6', 'B'},
{'7', '8', '9', 'C'},
{'*', '0', '#', 'D'}
};
byte rowPins[ROWS] = {9,8,7,6}; //Rows 0 to 3 //If you modify your pins you should modify this too
byte colPins[COLS]= {5,4,3,2}; //Columns 0 to 3
//initializes an instance of the Keypad class
 SoftwareSerial GSerial(11,12);
Keypad customKeypad = Keypad( makeKeymap(hexaKeys), rowPins, colPins, ROWS, COLS);
char keycount=0;
char code[5];
void setup() {
          // initialize the lcd
  lcd.backlight();
  delay(1000);
  Serial.begin(9600);
  Serial.println("Keyboard Test:");
  GSerial.begin(400);
  lcd.begin(16, 2);
  // Print a message to the LCD.
  lcd.setCursor(0, 0);
  lcd.print(" SYAZWAN BAHADOR");
  lcd.setCursor(0, 1);
  lcd.print("   B02160113    ");
  delay(3000);
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print(" VISIBLE LIGHT  ");
  lcd.setCursor(0, 1);
  lcd.print(" COMMUNICATION  ");
  delay(3000);
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("  TRANSMITTER  ");
```

```
  lcd.setCursor(0,1);
  lcd.print("    CIRCUIT    ");
  delay(3000);
  lcd.clear();
  GSerial.print('&');
}

void loop()
{
  char customKey = customKeypad.getKey();
  if(customKey && (customKey !='='))
  {
    if (customKey == '#')
    {
      GSerial.print('^');
      lcd.setCursor(0, 1);
      lcd.print("                ");
      lcd.setCursor(0, 1);
    }
    else if (customKey == '*')
    {
      GSerial.print('&');
      lcd.clear();
    }
    else
    {
      // otherwise, just print all normal characters
      Serial.print(customKey);
      GSerial.print(customKey);
      lcd.print(customKey);
    }
  }
    }
```

Appendix B: coding for receiver

```
#include <Wire.h>
#include <LCD.h>
#include <LiquidCrystal_I2C.h>
#include <SoftwareSerial.h>
#define I2C_ADDR 0x27 //defining the LCD pins

#define En_pin 2
#define Rw  pin 1
#define Rs_pin 0
#define D4_pin 4
#define D5_pin 5
#define D6_pin 6
#define D7  pin 7
LiquidCrystal_I2C lcd(I2C_ADDR,En_pin,Rw_pin,Rs_pin,D4_pin,D5_pin,D6_pin,D7_pin);
SoftwareSerial GSerial(11,12);
char rec=0;
void setup()
{
  Serial.begin(9600);
  GSerial.begin(400);
  lcd.begin(16, 2);
  lcd.setCursor(0, 0);
  lcd.print(" SYAZWAN BAHADOR");
  lcd.setCursor(0, 1);
  lcd.print("    B02160113   ");
  delay(3000);
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("  VISIBLE LIGHT ");
  lcd.setCursor(0, 1);
  lcd.print(" COMMUNICATION  ");
  delay(3000);
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("   RECEIVER    ");
  lcd.setCursor(0,1);
  lcd.print("    CIRCUIT    ");
  delay(3000);
  lcd.clear();
}

void loop()
{
  if(GSerial.available() != 0)
  {
    rec = GSerial.read();
    if(rec=='^')
    {
      lcd.setCursor(0, 1);
      lcd.print("                ");
      lcd.setCursor(0, 1);
    }
    else if(rec=='&')
    {
      lcd.clear();
    }
    else
    {
      Serial.print(rec);
      lcd.print(rec);
    }
  }
}
```

Appendix C: LM358 Datasheet

Product Folder | Order Now | Technical Documents | Tools & Software | Support & Community

Texas Instruments

LM158, LM158A, LM258, LM258A
LM358, LM358A, LM358B, LM358BA, LM2904, LM2904B, LM2904BA, LM2904V

SLOS068X – JUNE 1976 – REVISED JUNE 2020

Industry-Standard Dual Operational Amplifiers

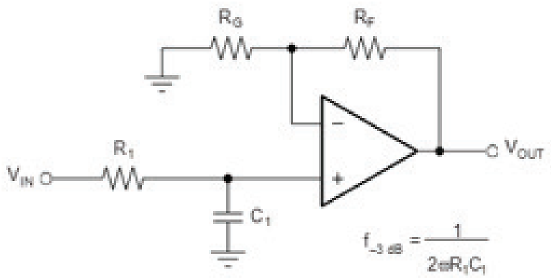
1 Features

- Wide supply range of 3 V to 36 V (B version)
- Quiescent current: 300 µA per amplifier (B version, typical)
- Unity-gain bandwidth of 1.2 MHz (B version)
- Common-mode input voltage range includes ground, enabling direct sensing near ground
- Low input offset voltage of 3 mV at 25°C (A and B versions, maximum)
- Internal RF and EMI filter (B version)
- On products compliant to MIL-PRF-38535, all parameters are tested unless otherwise noted. On all other products, production processing does not necessarily include testing of all parameters.

2 Applications

- Merchant network and server power supply units
- Multi-function printers
- Power supplies and mobile chargers
- Motor control: AC induction, brushed DC, brushless DC, high-voltage, low-voltage, permanent magnet, and stepper motor
- Desktop PC and motherboard
- Indoor and outdoor air conditioners
- Washers, dryers, and refrigerators
- AC inverters, string inverters, central inverters, and voltage frequency drives
- Uninterruptible power supplies
- Programmable logic controllers
- Electronic point-of-sale systems

Single-Pole, Low-Pass Filter



$$\frac{V_{OUT}}{V_{IN}} = \left(1 + \frac{R_F}{R_G}\right)\left(\frac{1}{1 + sR_1C_1}\right)$$

3 Description

The LM358B and LM2904B devices are the next-generation versions of the industry-standard operational amplifiers (op amps) LM358 and LM2904, which include two high-voltage (36-V) op amps. These devices provide outstanding value for cost- sensitive applications, with features including low offset (300 µV, typical), common-mode input range to ground, and high differential input voltage capability.

The LM358B and LM2904B op amps simplify circuit design with enhanced features such as unity-gain stability, lower offset voltage of 3 mV (maximum at room temperature), and lower quiescent current of 300 µA per amplifier (typical). High ESD (2 kV, HBM) and integrated EMI and RF filters enable the LM358B and LM2904B devices to be used in the most rugged, environmentally challenging applications.

The LM358B and LM2904B amplifiers are available in micro-sized packaging, such as the SOT23-8, as well as industry standard packages, including SOIC, TSSOP, and VSSOP.

Device Information[1]

PART NUMBER	PACKAGE	BODY SIZE (NOM)
LM358B, LM2904B, LM358, LM358A, LM2904, LM2904V, LM258, LM258A	SOIC (8)	4.90 mm × 3.90 mm
LM358B, LM2904B, LM358, LM358A, LM2904, LM2490V	TSSOP (8)	3.00 mm × 4.40 mm
LM358B[2], LM2904B[2], LM358, LM358A, LM2904, LM2904V, LM258, LM258A	VSSOP (8)	3.00 mm × 3.00 mm
LM358B[2], LM2904B[2]	SOT-23 (8)	2.90 mm × 1.60 mm
LM358, LM2904	SO (8)	5.20 mm × 5.30 mm
LM358, LM2904, LM358A, LM258, LM258A	PDIP (8)	9.81 mm × 6.35 mm
LM158, LM158A	CDIP (8)	9.60 mm × 6.67 mm
LM158, LM158A	LCCC (20)	8.89 mm × 8.89 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

(2) Package is for preview only.

Appendix D: Light Dependent Resistor (LDR)

Data pack F | *Issued March 1997* **232-3816**

RS
Data Sheet

Light dependent resistors

NORP12 RS stock number 651-507
NSL19-M51 RS stock number 596-141

Two cadmium sulphide (cdS) photoconductive cells with spectral responses similar to that of the human eye. The cell resistance falls with increasing light intensity. Applications include smoke detection, automatic lighting control, batch counting and burglar alarm systems.

Guide to source illuminations

Light source	Illumination (Lux)
Moonlight	0.1
60W bulb at 1m	50
1W MES bulb at 0.1m	100
Fluorescent lighting	500
Bright sunlight	30,000

Circuit symbol

Light memory characteristics

Light dependent resistors have a particular property in that they remember the lighting conditions in which they have been stored. This memory effect can be minimised by storing the LDRs in light prior to use. Light storage reduces equilibrium time to reach steady resistance values.

NORP12 (RS stock no. 651-507)

Absolute maximum ratings

Voltage, ac or dc peak	320V
Current	75mA
Power dissipation at 30°C	250mW
Operating temperature range	-60°C to +75°C

Dimensions