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AN ADAPTIVE TRANSCEIVER DESIGN FOR DUPLEX VISIBLE LIGHT COMMUNICATION

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Master of Science

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AN ADAPTIVE TRANSCEIVER DESIGN FOR DUPLEX VISIBLE LIGHT COMMUNICATION

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DEDICATION

At first I would like to thank God for this blessing. I would like to dedicate this work to my father, Engineer Sameer sadeq abd, who supported me with his spirit despite everything, to my teacher, my mother, Dr. Madiha Saleh Mahdi, who was everything, and my wife, Engineer Russell, who always faithfully supported me in overcoming all difficulties in my work, my brothers and sisters who supported me with their hearts, and I would like to thank my sister Dear Ayşegül KARGIN, who supported me in Turkey and made me feel the absence of my family and friends who never left me alone. thank you all.

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ABSTRACT

AN ADAPTIVE TRANSCEIVER DESIGN FOR DUPLEX VISIBLE LIGHT COMMUNICATION

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The Visible light communications (VLC) become an attractive subject for many researchers recently the reason why is that the VLC has many benefits that couldn't be observed in any of the RF communication systems; many of the researches have been done in the field of the VLC that focusing on how to reach to the high data rates for communication and handful of very little research gave interest on how to design a transceiver for VLC step by step to be utilised for short-range in an indoor environment application. In this study, a transceiver system design is proposed for a short distance and indoor communications that are utilise the VLC technique. The proposed system comprises two principal blocks (i.e. Block #1 and Block #2) each block is able to send the visible light data or receive the same data form. Block #1 comprises ATmega328P, Light Emitting Diode (LED), Liquid Crystal Display (LCD), and photo-sensor; this block is able to transmit the visible light data through the LED as well as receive the visible light data that is

transmitted by the laser beam. While block #2 comprises ATmega328P, laser module, LCD, and LDR; this block is able to transmit the visible light data through the laser beam as well as receive the visible light data that is transmitted by the LED. Each block utilised the Ps2 keyboard to initialisation the data (i.e. numbers or letters) after that the Arduino microcontroller receive the character form the keyboard and transmit it as a bitstream via the LED or the laser beam. A good performance is achieved after the practical test applied and a communication range that is up to 30cm.

Keywords: Photo-Sensor, Laser Diode, Arduino Microcontroller, VLC, LCD .

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LIST OF ABBREVIATIONS

ASK : Amplitude Shift Keying
BER : Bit Error Ratio
CMOS : Complementary Metal Oxide Semiconductor
DMT : Discrete Multi-Tone Modulation
IoT : Internet of Things
ITS : Intelligent Transportation System
IR : : Infra Red
IT : Information Technology
IM-DD : Intensity Modulation - Direct Detection
LED : Light Emitting Diode
LDR : Light Dependent Resestor
LOS : Line of Sight
Li-Fi : Light Fidelity
LCD : Liquid Crystal Display
LDR : Light Dependent Resistor
MIMO : Multiple Input Multiple Outputs
NRZ : None Return to Zero
OWC : Optical Wireless Communication
OOK : On Off Keying
OFDM : Orthogonal Frequency Division Multiplexing
OCC : Optical Camera Communications
OSI : Open Systems Interconnection
PD : Photo Diode
PD : Photo Diode
PSD : Power Spectral Density
PWM : Pulse Width Modulation
PPM : Pulse Position Modulation
PHY : physical layer physical layer

PDU	:	Protocol Data Unit
RF	:	Radio Frequency
RGB	:	Red Green Blue
R	:	Receiver
SNR	:	Signal to Noise Ratio
TCP	:	Transmission Control Protocol
TX	:	Transmitter X
UDP	:	User Datagram Protocol
VLC	:	Visble Light Communication
V2V	:	Vehichle to Vehicle
VCC	:	Visible Camera Communications
WSN	:	Wireless Sensor Network
WDM	:	Wavelength Division Multiplexing

1. GENERAL INTRODUCTION

This chapter contains many sections that cover the VLC, fading and path loss for VLC, time synchronization, noise analysis, VLC for the vehicle-to-vehicle system, underwater VLC communication, VLC standardization, VLC challenges, and systems hardware.

1.1 INTRODUCTION

The invention of Light Emitting Diode (LED) brings back the concept of utilising Visible Light Communication (VLC) a long time after the failed experiment of Alexander Graham Bell at the time he first produced the idea of using visible light in communication. The communication with light is basically communication with optical light it could be classified as a kind of free space optical wireless communications. The transmission of information by the use of light is obtained by the presence of light-medium. The blinking source is deactivated and activated in respectively represent a high logic signal and a low logic signal. The main advantage of visible light communication in which it provides higher connectivity at information transfer speed because it has a wide bandwidth and the unorganized spectrum about 1600 times the OWC bandwidth and radio frequency, unlike radio frequencies that cannot pass through objects [1]. This is required for security because the signal is limited in a confined area, so another advantage of optical communication is the lack of multi-path fading. The LED's are utilised as a transmitter in VLC so its ability to rapidly switching OFF and on which couldn't be noticed by human eyes. The visible light spectrum transmission medium. Photodiodes are utilised as a receiver for the light that could easily detect blink light signals quickly. The advantage of visible light communication is that it does not interfere with Radio Frequency (RF) signals and could be used safely in RF restricted areas such as hospitals, aircraft, underwater communication and a lot of other applications. Visible light communication can be used to create a secure wireless network because they have a good level of security [2]. During the implementation of the visible light communication system, there are some factors that must be taken into consideration because the communication system is the first to be considered second Transmitter and receiver distance - these are important information to consider when designing a VLC system. The free-range license for VLC gives preferences for use in some different applications. High-power, low-cost LEDs which can be switched at high frequency these are the technological key features that make visible light communication possible. Furthermore, visible light communications infrastructure already exists. All needs are exchange regular bulbs to smart and powerful LED lights [3].

1.2 PROBLEM STATEMENT

With the recent increase in the network active devices connections and in order to achieve a high data transfer speed, the network operators have developed wireless communications toward the fifth generation, which includes the use of the higher frequencies to increase data transfer speed. In recent years the Li-Fi technology has become popular for indoor applications, which provided us with very fast data transfer through using the visible light at a low cost in terms of equipment and design.

1.3 THESIS OBJECTIVES

The main objectives than can be obtained from this study can be summarised by the design and implement a visible light communication transceiver that must be able to transmit/receive data through the light with a data transmission range within 30 Centimeters. The proposed design is capable to operate in several indoor applications. This study will provide a good idea, basis, and a serene understand of the implementation as well as the design of the visible light communication transceiver. Additionally, will be a beneficial beginning spot for everyone who wants to pursue research and development in this field.

1.4 LIMITATIONS

It can be utilised in an indoor environment only, where the fundamental restrictions of the proposed design are the distortion of the sunlight which accrues when the distance between transmitter and receiver is large the likelihood of data loss increases. Line-of-sight is an essential limitation of VLC systems.

1.5 LITERATURE REVIEW

Several studies have been designed and studied in the literature, some of which can be presented as follows:

a. In [4] the researchers has been the design and implementation of a visible light One-sided transmitter and receiver based on an ATmega328P microcontroller chip. The designed system utilised two microcontrollers one of them for the transmitter side while the second is for the receiver side, the LEDs were also used in the transmitter side as the transmission unit. The practical test for the designed system presents that the design achieves visible light data transmission for short distances indoors and verifies a reliable transmitter/receiver for communicating with visible light.
b. In [5] the researchers have been the design of VLC receiver for On-Off Keying (OOK) modulation is proposed. The design is based on the cancellation of the minimum offset voltage of the received OOK signal, using a novel minimum-voltage detection circuit. The design is based on the cancellation of the minimum offset voltage of the input OOK signal, in order to remove the interference from ambient lights. Experiments show that the proposed VLC receiver is insensitive to sunlight and indoor fluorescent lights.
c. In [6] the researchers have been presented the bi-directional VLC testbed design. Also, the implementation process utilising the Universal Software Radio Peripheral (USRP) software-defined radios (SDR) and the open-source software was introduced. The VLC design utilises LED light sources for wireless communications purposes. The testbed combines light, infrared and radio frequencies as wireless media to be utilised in a hybrid wireless communication system. The idea was to design/implement a bi-directional VLC testbed for providing a platform to test and research the subject in the future. The testbed was designed to use software-defined radio. To predict the results, a bi-directional communication at a 12.5 Mbps bit rate was successfully achieved in the testbed limited by a sample rate of the system.
d. In [7] the researchers introduced a hybrid Wi-Fi-VLC system utilising a unidirectional VLC channel as a downlink and reserving the Wi-Fi back-channel as an uplink. The asymmetric solution resolves the optical uplink challenges and benefits from the full-duplex communication based on VLC. To further enhance the robustness and increase throughput, the Wi-Fi and VLC aggregated in parallel by leveraging the bonding technique operating system so two heterogeneous systems incorporating Wi-Fi and VLC was evaluated. The goal of the work was to provide a proof of concept for the coexistence between these two communication bands. Within a short distance between

the transmitter and the receiver, the hybrid VLC could perform much better than the Wi-Fi system in the crowded wireless environment. As a complementary technique, However, Wi-Fi may outperform VLC in the case of long-distance data transmission.

e. In [8], the researchers studied the needs to be done to replace the current light bulbs with intelligent and efficient bulbs capable of data transmission. The running on the single-board computer using LED for transmission and a photodiode for the reception. The implemented system was capable of the full-duplex communication atabitrateo roughly 25 Kbit/s. Also, is capable of compensating for errors that occur during transmission to achieve reliable communication. Due to only having built one transmitter-receiver pair, the transmissions in the other direction is performed via a copper wire. The system is built to retransmit a packet until it has arrived successfully. The system can perform half- or full duplex transmissions. The system can perform full duplex transmissions by using a wire for transmission in one of the directions, and light in the other.
f. In [9], the researchers have been designed a system for the Indoor communication application system based on the visible LED light. The system can modulate the original signal one or more times, move to a specific frequency band, transmit on the power line, use this module to decode the LED terminal. The introduced design applies to the simplicity of LED visible light communication applications, which provide a premise and guarantee for the construction of a smart home network. A smart home hardware and software integration system based on a visible local area wireless communication network is being developed recently.
g. In [10], the researchers have been designed a new technique for the VLC. The designed system based on the transmission of light pulses that presence in the visible spectrum. The VLC employs a part of the electromagnetic spectrum that is currently unused for transmission purposes. This technology is based on LEDs and photodiodes at first, the researchers were made a study to understand what the level of technology reached until now. In general, the VLC systems could be divided into two macro-categories: indoor systems and outdoor systems. Later, study the VLC from a physical point of view half of the blocks of the VLC physical layer: the transmitter LED, receiver photodiode, channel and modulating block. From this, the general idea of the current state of VLC

applications was introduced and the most commonly used modulation schemes to be OOK as well as pulse position modulation.

1.6 THESIS OUTLINE

The outline of this thesis can be listed as follows:

a. ***Chapter Two:*** In this chapter, the VLC, fading and path loss for VLC, time synchronization, noise analysis, VLC for the vehicle-to-vehicle system, underwater VLC communication, VLC standardization, VLC challenges, and systems hardware parts will be presented.

b. ***Chapter Three:*** In this chapter, an overview of the design and implementation requirements of the proposed system. Also, the software requirements and the required components that utilise to construct this work will be presented.

c. ***Chapter Four:*** In this chapter, the proposed system BER results, hardware simulation, and the simulation result will be presented and discussed as well.

d. ***Chapter Five:*** In this chapter, the conclusion and the future work that can be used to develop this work will be presented.

2. OVERVIEW FOR VISIBLE LIGHT COMMUNICATION

In this chapter, an overview of the visible light communication systems, and visible light communication in the wireless sensor networks will be discussed and presented.

2.1 VISIBLE LIGHT COMMUNICATION

As previously discussed in the introduction, most research activities have been focused on the VLC over the last decade especially at universities most of these researches focused on how to reach high-speed communication because of the license-free spectrum of visible light which starts from 380 nanometers to 780 nanometers visible light communication technology uses optical sources to transfer information such as LED. At the receiver, section photo-sensors are used to detect the modulated information such as photo-diode and cameras or imaging sensors. The LED can also work as a photo-sensor but with lower sensitivity. Many sensors in wireless sensors network can connect with each other to obtain information such as environmental conditions. The core of the technology is a wireless sensor module that integrates sensor with wireless information signal receiving and transmitting circuit the communication methods for information exchange can be mainly classified into two kinds wireless and wired. the sensor device is mainly mobile, and in this situation, it is impossible to install wired communication. Wireless sensor networks are wireless node with sensors coordinates with other sensors to obtain a wireless network of environmental conditions and physical data [11].

2.1.1 Wireless Sensor Networks in the Core Technology

a. Information Technology (IT): Data accumulation analysis and management.
b. Sensing Technology: convert various situations into Information instead of humans.
c. Communication Technology: can separately build and rebuild communication ways between nodes.

2.1.2 Fading and Path Loss for VLC

The VLC systems don't subject to fading, so the visible light communication system has a certain path loss to some extent, unlike omnidirectional antennas in the common wireless systems, visible light communication has directional “antennas”, which means it's irrelevant when the angle light enters the corner or there is a device Send or visible light communication receiver. The real issue is the entry and exit. An angle of the light beam between nodes that can be placed randomly and randomly oriented [12]-[14]. Two nodes form a default line, the slope of this line could be expressed like an angle using equation (2.1):

$$\theta_0 = \tanh(\frac{y_2 - y_1}{x_2 - x_1}) \tag{2.1}$$

Where x_n and y_n are Coordinates corresponding to nodes (2.1) and (2.2).

$$\Psi = |360^0 - \theta_0 - B_d| \tag{2.2}$$

Where ψ is entry angle between the light beam and its nature on the surface of the photodiode sensor, carry the destination node. Bearing angle between direction and x-axis.

$$\varphi = |\theta_0 - B_s| \tag{2.3}$$

Where φ is exit angle between the light rays and their nature on the surface of the LED beam towards the receiving node; BS is bearing of the source node.

2.2 INDOOR LOCALIZATION

It is important to know the sensor position for most wireless network sensors responsible for decision-making functions. Visible light can connect to uniquely detect nearby devices by acting as a visual marker. Internal localization system that helps the visually impaired person to locate, LED indicator on the ceiling, the smartphone is suspended with the geomagnetic sensor in the user's neck, the smartphone is connected to the earpiece. The mobile phone receives the identifier information that the LED indicator sends over the visible light connection and obtains the direction of the light source and the positioning data. The track is improved and the result is transferred to the headset to guide the infantry. The test results show that the laboratory can accurately locate and move within (1 to1.5) meters and could achieve direction correction within (59 °) to (69 °). The VLC navigation system was developed in conjunction with the LED light source of the wall signal panel: the system is designed with filters to reduce background light interference. Through visible light communication, the user's mobile phone receives navigation data from the LED signal panel. Navigation information includes location data for the signboard and the optimal point at which the visually impaired person accesses downloadable data information. In this system, the data transfer rate of the navigation signal is 62.5 kb / s, and the data transfer rate is 1 MB / s. In the test, the visually impaired persons could be receiving the navigation signal transmitted by the LED light on the signal board about 5 meters through the earpiece. While walking to the signal about 1 meter away, the visually impaired receiver could operate automatically when the light intensity is sufficient. Download and store text data [15].

2.3 TIME SYNCHRONIZATION

It's a service that allows the devices to share the idea of time in a consistent way to create a collaborative service. VLC-based synchronization bindings are more energy-efficient than RF bindings [16].

2.3.1 Smart House

This type of system is used in indoor and home environments in order to monitor and finding some parameters such as room temperature, humidity, gas leak, and other data [17].

2.3.2 VLC Physical Layer Characterization

The key element that determines the performance of the communication system and the corresponding transceiver design techniques is the link between the transmitter and receiver. This correlation includes several parts, such as transmitter and receiver characteristics, propagation channel characteristics, uplink characteristics, and typical noise sources. In this part, the basic internal visible light communication connection properties are discussed. The International Organization for Standardization defines the Open Systems Interconnection (ISO/OSI). Model the ISO/OSI separates the communication systems in a seven-level hierarchical form, as shown in Table 2.1[18].

Table 2.1: Open Systems Interconnection Model

OSI Model			
Layer		Protocol data unit (PDU)	Function
Host layers	7. Application	Data	High-level Apis, including resource sharing, remote file access
	6. Presentation		Translation of data between a networking service and an application; including character encoding, data compression, encryption/decryption
	5. Session		Managing communication sessions, i.e. continuous exchange of information in the form of multiple back-and-forth transmissions between two nodes
	4. Transport	Segment(TCP) /Datagram(UDP)	Reliable transmission of data segments between points on a network, including segmentation, acknowledgement and multiplexing.
Media layers	3. Network	Packet	Structuring and managing a multi-node network, including addressing, routing and traffic control.
	2. Data link	Frame	Reliable transmission of data frames between two nodes connected by a physical layer
	1. Physical	Bit	Transmission and reception of raw bit streams over a physical medium

The first and lowest levels of the physical layer structure are the levels that this thesis focuses on. The physical level includes modulation/modulation definitions, channel, receiver and transmitter. The Four elements could be selected:

a. Transmitter

b. Recipient

c. Channel

d. Demodulation/ Formation

The Transmitter is a device that takes a modified signal and converts it into something which could be sent over the channel and for the VLC systems transmitter are usually LED lights. The receiver is the opposite of the transmitter these devices take a signal from the channel and convert them into signals that can be processed by a demodulator. A channel is physically how the signal actually interacts and spreads to the environment. The channel receives the signal from the transmitter and calculates emulates how the signal reaches the receiver. The channel is not connected to a device it describes how the signal passes through the environment, for example, an empty room or from one building to another. Modulation and demodulation are two opposing masses: the first one takes the logical signal and converts it into something that can be sent over the transmitter. For example, in VLC, the modification converts the logical input signal into an existing signal that can drive the LED to characterise the physical level a person must be able to draw the block diagram shown in Figure 2.1 [19].

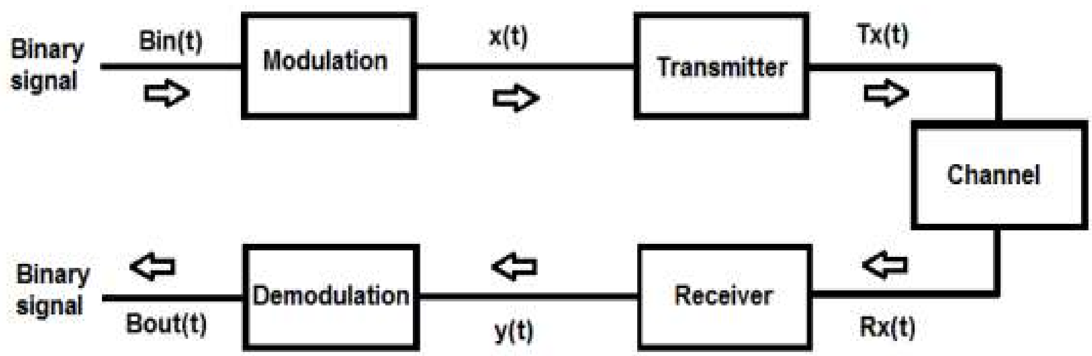


Figure 2.1: Block Diagram for Physical Level.

2.3.3 Link Characterization for LOS

Push channel response to LOS link is a delta time delay that given by the following equation:

$$h(t) = \delta(t - \tau) \tag{2.4}$$

where $\tau = D/c$, D is referred to the distance between transmitter and receiver and c is the speed of the light in the free space.

The line of sight can be completely distinguished by the loss of its path. We model a general line of sight visible light communication scenario in Figure 2.1 and Evaluate the identical path loss to be utilised to study the performance of the communications receiver. Some parameter is defined to follows. The receivers distance to the sources is D and the radius of the receiver aperture is r. the α is the angle from the source to the receiver line and the normal receiver and to the source beam axis is β (viewing angle). Ωr is the solid angle of the receiver that the transmitter sees s and Ar is the receiver. It meets the relationship Archos (α) $\Omega D2\Omega r$ [20].

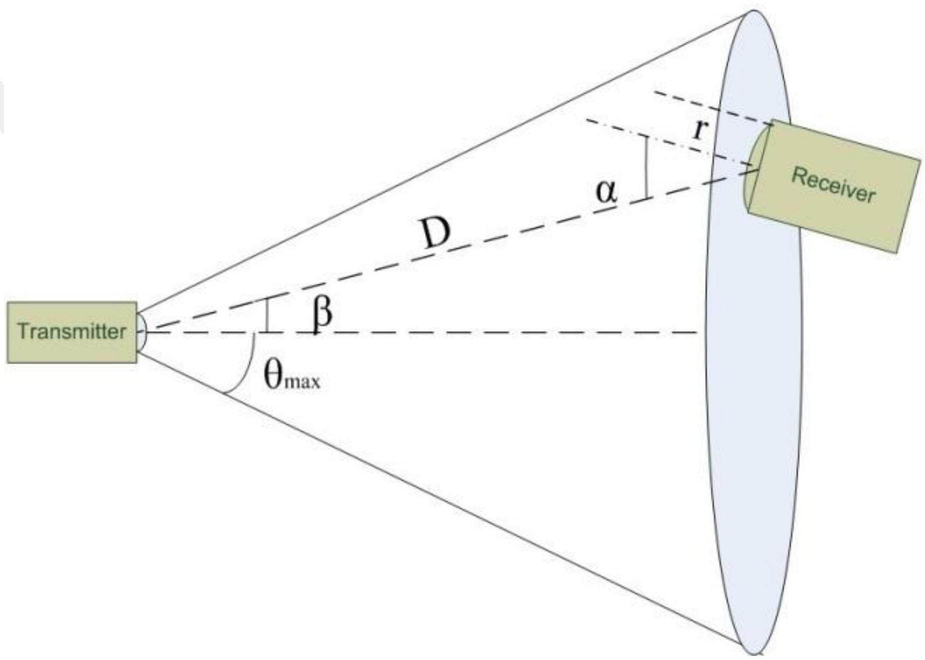


Figure 2.2: Model LOS Link.

2.3.4 Noise Analysis

Noise limiting the performance of the communication system is mainly provided by the receiver and channel. Figure 2.3 shows six major contributors to channel and receiver noise. Here each noise sources present in an internal VLC system will be analysed to determine the spectral density of the corresponding noise power (PSD). Background noise could be considered with constant respect to the received light energy because it changes very slowly, and the second noise can bring the background noise closer to the shot as a white Gaussian for a large number of events equation (2.5) [21].

$$SNR = \frac{(RP_r)^2}{\sigma_q^2+\sigma_d^2+\sigma_{qbg}^2+\sigma_{th}^2} \xrightarrow{only\ back\ ground} \frac{(RP_r)^2}{\sigma_{bg}^2} = \frac{(RP_r)^2}{2qRI_{env}\Delta f} \qquad (2.5)$$

Where R is the response of the photodiode, P_r is the received power and a very 2 represents a different a type of noises.

For an internal visible light communication system that uses a white LED as a light source and a photodiode to detect the flickering of the noise sources to consider.

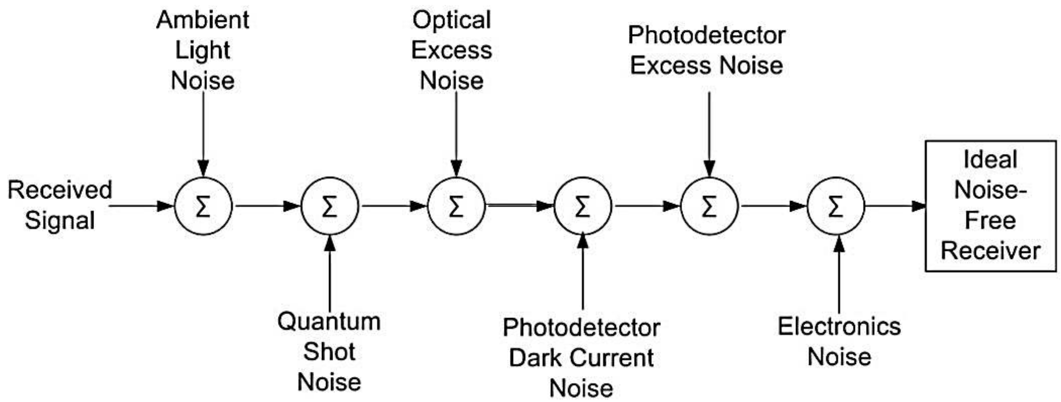


Figure 2.3: Different Types of Noise.

2.3.4.1 Light Noise for External

External light noises ambient light contains radiation from different sources, such as sunlight in the background through windows and light from some common artificial lighting sources such as fluorescent lamps and incandescent, as mentioned previously in Figure 3.2. The incandescent taillights of the sun's rays represent uncontrolled primary sources and produce a DC current output current. This noise has little power at high frequencies and therefore could be easily eliminated by a high-speed filter [22]. The unmodulated PSD of the noise (A2/Hz) could be represented as in the equation (2.6).

$$S_b(f) = \left[\frac{e}{hc}\int_{\lambda_{rL}}^{\lambda_{rH}} \eta(\lambda)\lambda S_b(\lambda)R_f(\lambda)d\lambda\right]^2 \delta(f) \qquad (2.6)$$

Where $S_b(\lambda)$ represents the PSD, $\eta(\lambda)$ represents the detector quantum efficiency, e represents the electron charge, and the combination of $RD\,(\lambda) = e\eta(\lambda)\lambda/hc$ represent the detector responsivity (A/W) at wavelength λ.

2.4 VLC FOR VEHICLE TO VEHICLE COMMUNICATION

LED lamps have been adopted by automobile manufacturers over the past decade now, with these developments, car manufacturers are looking for a way to share information on driving condition and other necessary data between vehicles. Vehicle-to-vehicle (V2V) communication is an application that aims to provide a safer driving experience and utilise roads more efficiently, Figure 2.4 exhibits the method of utilising LEDs in cars to connect to V2V [23].

Figure 2.4: V2V for The VLC Communication.

Intelligent Transport Systems (ITS) reduce traffic accident, traffic congestion and fuel consumption by obtaining information on traffic conditions and timely transportation. photo processing could be used to helping drivers identify with traffic lights, vehicle and vehicle, detect obstacles, and capture data between road facilities and vehicles. Key technology for intelligent transportation systems. High-speed data photo sensors along with visible light communication has wide application opportunities for intelligent transport systems. The vehicle test verified which system could accurately receive information transmitted from 256 light-emitting diode arrays in 35m for a speed at a range of 30km/h. At the moment, there have some technical issues to be solved in the application of high-speed photosensors in visible light communication if installation facilities are expensive, complex technology for real-time image processing is required, and a camera frame rate has lower than the speed of the LEDs reaction, limiting the connection speed Literature reports in the application of the new develop optical communication photo sensor in OWC. The newly developed optical photosensor with CMOS photosensor technology has two advantages: 1-bit signal output for fast and accurate LED detection and communication pixels to receive high-speed signals (CPx). The OWC is the world's first-pixel communication system with a 16.6ms delay and 20Mbps transfer rate. in this field has resulted in the development of a V2V communications system for visible light using LED lights of 10 kbps and 30 meters in daylight when the recent study from Korea the find the Reverse pulse position adjustable 4 ppm. Utilised in the system because this type of modulation scheme provides a high data rate and gives a high opacity to modify the PWM [24].

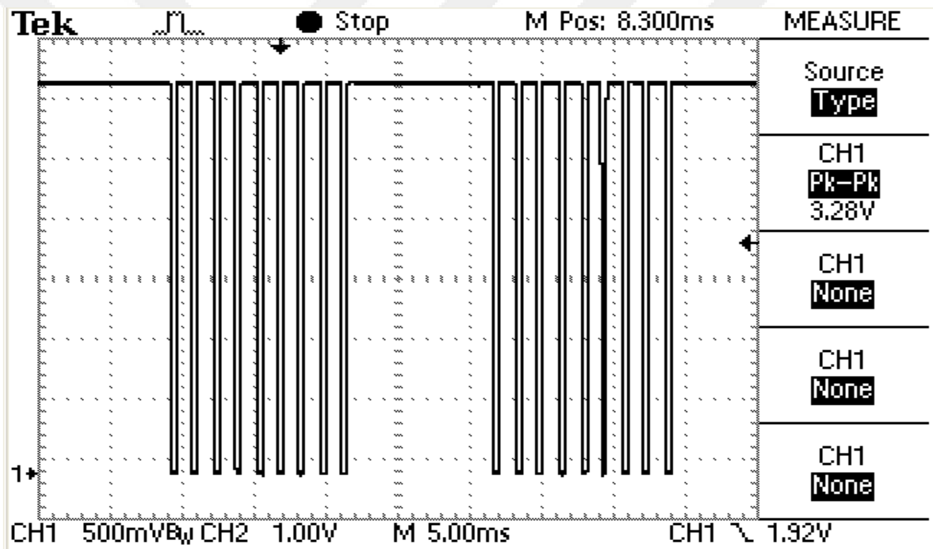


Figure 2.5: Position Modulation for Inverse Pulse.

2.5 UNDERWATER FOR VLC COMMUNICATION

Underwater communications have become an interesting dot for some researchers and the scientifical community because of their wide applications. Inability underwater due to the radio frequency waves communication due to attenuation. Underwater communications that utilise the VLC technology have many of the disadvantages and advantages. Underwater communications play an important part in the military, scientific fields and Industrial. The communications underwater rates requirements start from some megabits to tens of megabits or higher. Seawater in the radio waves is very light sound waves travelling at 1,500 m / s in the ocean with long delays. Limited BW and high bit error rates. Sound waves can also interfere with marine life such as whales and dolphins. visible light communication can be overcome the problems with electromagnetic interference and attenuation rate underwater [25]. About the development of the visible light communication system between the underwater transport vehicle and the controller: The transmitters in this system consists of 70 of the LEDs sources, Support information transmission in the viewing angle range of 120 degrees, the transfer rate up to 20Mb / s. The underwater teleport is equipped with video signal transmission and control between the camera and a remote station 20 meters away. At present, the main challenge of underwater VLC systems which is hard to achieve long-range communications because of underwater nature, especially turbidity. For such a problem, due to the 1.2 MB / s underwater optical communication system at a distance of 30 meters. The National University of Singapore and the Massachusetts Institute of Technology conducted research and presentations. light waves have better directional properties than RF waves and high information rates could be achieved in visible light communication systems for short and medium distances [26]. Figure 2.6 and 2.7 illustrates the block diagram for the underwater VLC receiver and transmitter.

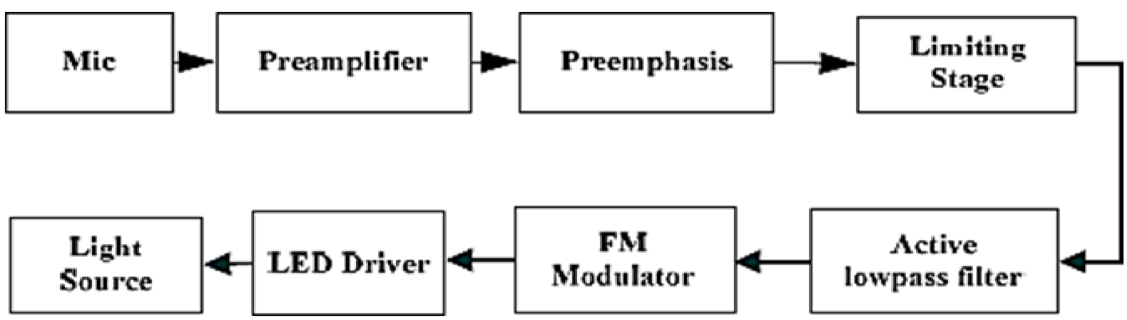


Figure 2.6: The Block Diagram of The Underwater Communication Ttransmitter.

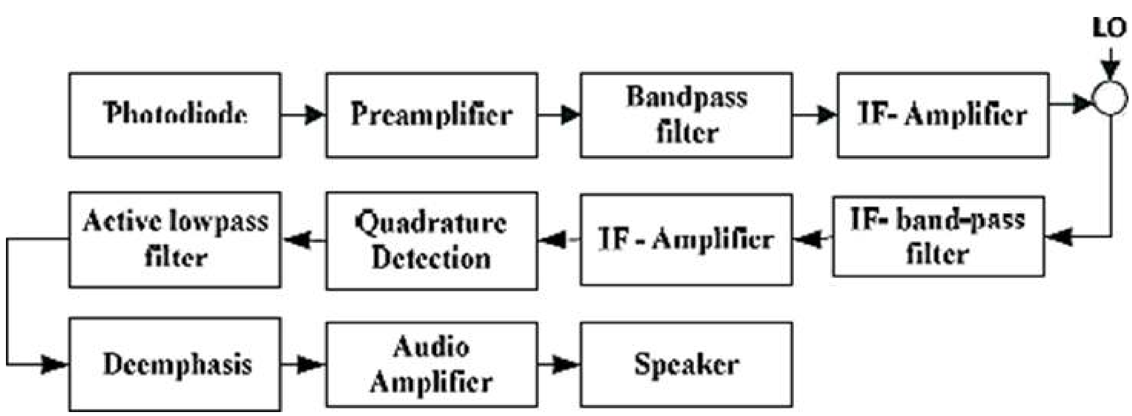


Figure 2.7: The Block Biagram of The Underwater Communication Receiver.

2.6 HIGH-SPEED DATA TRANSMISSION FOR VLC

Access to data like HD video streaming, high-speed streaming and high-speed information backup has become an integral part of modern life. The light beam can be used to transmit visible light at a small spacing angle, and the loss of its low transmission path makes it possible to download and transfer secure information flows at high speeds [27]. In Tables 2.2 and 2.3 practical the VLC systems demonstrations.

Table 2.2: Practical Demonstrations for VLC

Year	Transmitter	Receiver	Modulation	Data Rate	Distance
2017	Blue LD	Ultrafast photodiode(UPD)	UFMC additive 16-QAM OFDM	17.6 Gb/s	16 m
2017	RYGB LDs	Imaging Diversity Receiver	OOK	10 Gb/s	/
2017	NUV LD+ RGB phosphors	APD	OOK-NRZ	1.25 Gb/s	15 cm
2017	μ-LED	PIN	OFDM	7.91 Gb/s	/
2017	μ-LED	APD	PAM(spatial)	7 Gb/s	0.5 m
2017	RGB LED	PIN	OFDM(adaptive bit loading)	6.36 Gb/s	1 m
2017	Red LED	silicon PN	OOK	600 Mb/s	6 m
2016	LD	/	OOK	1 Gb/s	/
2016	Red RC-LED and blue and green μ-LEDs	PIN	OFDM(WDM)	10 Gb/s	1.5 m
2016	μ-LED	/	DCO-OFDM	5 Gb/s	
2016	μ-LED	/	PAM	3.5 Gb/s	
2016	μ-LED	APD	PAM	2 Gb/s	0.6 m
2016	RGB-LED	APD	QAM-OFDM	1 Gb/s	100 m
2016	ps-LED	PIN	OFDM (adaptive bit and power loading)	2.08 Gb/s	1 m

The European OMEGA project has developed VLC information data transmission through 4 high-resolution 100MB / s data streams. Data transfer on a photodiode detector is performed within $10m^2$ by 16 LED light source using orthogonal frequency division multiplexing (OFDM) technology. Demonstration system for high-quality audio and video transmission (5 × 5 × 3) meters by adding a focus lens between visible light communication receiver and transmitter: Nd LoS link have a network compareda LoS network. The node has good mobility and strong tracking, but the are loss of correlation leads to a lower transmission rate. for the conducted research on this problem, a typical internal OWC system with a transmission rate of 2M and 400

Mb / s and a bit error rate $BER < 10^{-8}$ (IR is an uplink visible LED light source is achieved as a source Transfer downlink data. RGB LEDs utilise WDM to achieve higher information transfer rates. The document record for the first VLC system based on DMT/WDM wavelength section multiplexing/discrete multi-tone modification technology, that modulates a single white LED RGB and reach 803 Mb/s data communication.

Table 2.3: Practical Demonstrations for VLC

Year	Transmitter	Receiver	Modulation	Data Rate	Distance
2016	ps-LED	PIN	OFDM (bit-loading)	1 Gb/s	0.6 m
2015	RGB LDs	PIN	OFDM(WDM)	14 Gb/s	2.8 m
2015	RGB LDs	APD	OFDM(WDM)	4.4 Gb/s	0.2 m
2015	Blue LDs	APD	OFDM	9 Gb/s	5 m
2015	Blue LD + phosphor	/	OFDM (adaptive bit and power loading)	6.52 Gb/s	0.35 m
2015	Blue LD + phosphor	APD	OFDM	5.2 Gb/s	0.6 m
2015	Blue LD + phosphor	APD	OFDM	4 Gb/s	0.5 m
2015	Blue LD + phosphor	APD	OOK	4 Gb/s	/
2015	μ-LED + polymer color converter	APD	DCO-OFDM (WDM)	2.3 Gb/s	/
2015	RYGB LED	PIN	CAP(WDM)	8 Gb/s	1 m
2015	RYGB LED	APD	OFDM(WDM)	5.6 Gb/s	4 m
2015	RGB LED	PIN	CAP	4.5 Gb/s	2 m
2015	RGB LED	APD	QAM-OFDM	750 Mb/s	/
2015	LED	PIN	OFDM(Spatial)	1.4 Gb/s	2.5 m
2015	ps-LED	APD	OFDM(adaptive bit and power loading)	2 Gb/s	1.5 m
2015	ps-LED	PIN	OFDM	1.6 Gb/s	1 m
2015	ps-LED	APD	QAM-OFDM	1.4 Gb/s	0.8 m
2015	ps-LED	APD	OFDM(Spatial)	1.3 Gb/s	0.4 m
2015	ps-LED	PIN	PAM	1.1 Gb/s	/
2015	ps-LED	PIN	QAM-OFDM	682 Mb/s	1 m
2014	μ-LED	PD	OFDM(adaptive bit and power loading)	3 Gb/s	5 cm
2014	μ-LED + polymer color converter(white)	APD	OFDM	1.68 Gb/s	3 cm
2014	RGB LED	APD	QAM (Wavelength)	4.22 Gb/s	/
2014	RGB LED	APD	CAP(WDM)	1.35 Gb/s	0.3 m
2014	RGB-LED	APD	16-QAM (Polarisation)	1 Gb/s	/
2014	Blue-LED	APD	4-QAM(Spatial)	500 Mb/s	0.3 m
2014	ps-LED	PIN	OOK-NRZ	550 Mb/s	0.6 m
2014	ps-LED	PIN	OOK-NRZ	340 Mb/s	0.43 m

2.7 FUTURE AND DIRECTIONS FOR VLC

The VLC systems which take advantage of LED advances has been considered one of the most promising technologies the LED lighting market has grown steadily in response to global policies like electricity saving and green growth, While the price is reduced by 50%, the technology more than doubled light visual communication technology is the high value-added and local speciality, expect to be the source of technology for entering the global market VLC is a technology which is fused with LED lighting and could create a mutual growth industry new convergence service can be created using visible light characteristics of VLC have a very high Loss that it can communicate only in a certain area, it could be used for physical communications to protect data, it could be used in the places where there is no interference, and has the advantage of no permission now, for the era of internet of things the LED for communication has evolved to be “smart lighting”. It can control the lightness and colour of light according to the people presence and the atmosphere of the interior, and it is also effective in reducing the efficiency of the energy in large building and cities [28]. Along with intelligent lighting, the expansion of light-emitting communications technology is moving fast. Assigned to LED-ID technology is capable of sending and receiving unique data through LED smart cameras and displays. The Samsung Electronics a VLC system that uses LED lighting as a transmitter to complete the IEEE 802.15.7 standard in November 2011. Despite continued R&D and standardization, commercialization process of VLC system based for smart devices like smartphones was hard because of the necessity of additionally the usage of VLC Photodiodes and hardware changes IEEE 802.15 IG-LED works in May 2012 to solve this problem, and (IEEE 802.15.7a,2018) OCC (visible Camera Communications) began a recent study focusing mainly on systems receiving signals and patterns of LED displays, LED displays, LED digital signage, or LED lighting using smart device cameras (image sensors) instead of IEEE 802.15.7, that deals with image detectors (PDs). After the final approval of the IEEE 802 EC, the OWC TG Task Force has been formally operation since IEEE 802.15 Extension meeting held on January 2015. TG wireless communications will primarily focus on OCC technology and further consolidate LED-ID and Li-Fi high-speed OWC technology [29].

2.8 VLC STANDARDIZATION

According to the information of the national statute, the "Standing Technology" technical Committee - proposed the state administration to supervise, manage and issue the market. The data information technology system the remote communication and data exchange VLC media access controls, the gross requirements of the standard and physical layer number: GB/T 36628.1-2018 was officially achieved. It shows that GB / T 36628 remote ICT system and information exchange visible light is divided into four parts The first part is to control media access and the physical layer requirement, while the second part relies on positioning technology in VLC .the third Part: Access control of high-speed video communication media and physical layer specifications. The fourth Part: Controlling access to low speed narrowband flexible light communication media and physical layer specifications. This time, the first part, consisting of a high-quality electronics semiconductor technology research institute to liberate the Liberation Army Engineering Army and Tsinghua University, also outlines high-speed VLC requirements, Low-speed VLC, physical layer requirements for indoor positioning based on VLC and general media access control layer requirements, also apply to the development and used VLC systems and equipment [30].

2.9 VLC CHALLENGING ISSUES

VLC systems have some difficult issues despite a large number of their benefits some of the issues and challenges are [31]:

a. Range Limitation: Due to LoS requirements, this technology is fitting for indoor and short distances communication.
b. Higher data rate: Because of the limited bandwidth of LEDs, this creates another big challenge issue for getting higher data rates.
c. Extreme noise in the environment: Artificial and natural lights are other challenges for VLC, a major problem for external VLC applications that reduce or overcome the impact of artificial and natural lights is a difficult problem.
d. Uplink supply: Making light sources naturally suitable for transmission and broadcasting applications will be a problem.

e. The difficulty of modulation: The simplest and the most useful modulation method based on the modification of direct intensity detection is insufficient to solve many of the problems and challenges required by the modulation method to support desirable and efficient data delivery.
f. Parallel Communications (MIMO): An interesting setup idea for VLC. Although, in theory, it's maybe achievable, the hard part is the implementations part.
g. Receiver complexity: Some studies have suggested that use the equation will a receiver complexity.
h. Regulatory Issues: VLC regulations such as eye safety standards and safety standards.

2.10 BACKGROUND

In this section, the basic background about the devices utilised in the implementation of this work and information regarding the modification methods utilised in the design will be presented.

2.10.1 Arduino UNO Microcontroller

Arduino was employed in many projects, it is an easy tool for prototyping and utilised in many applications and projects. Its open sources platform, the Arduino microcontroller is based on ATmega328P possess 14 pins of digital input/ output and 6 analogue inputs Its also have a USB port to connect it to the computer in order to program it. Figure 2.8 illustrates the Arduino Uno kit with the configuration of the input-output pins and ports [32].

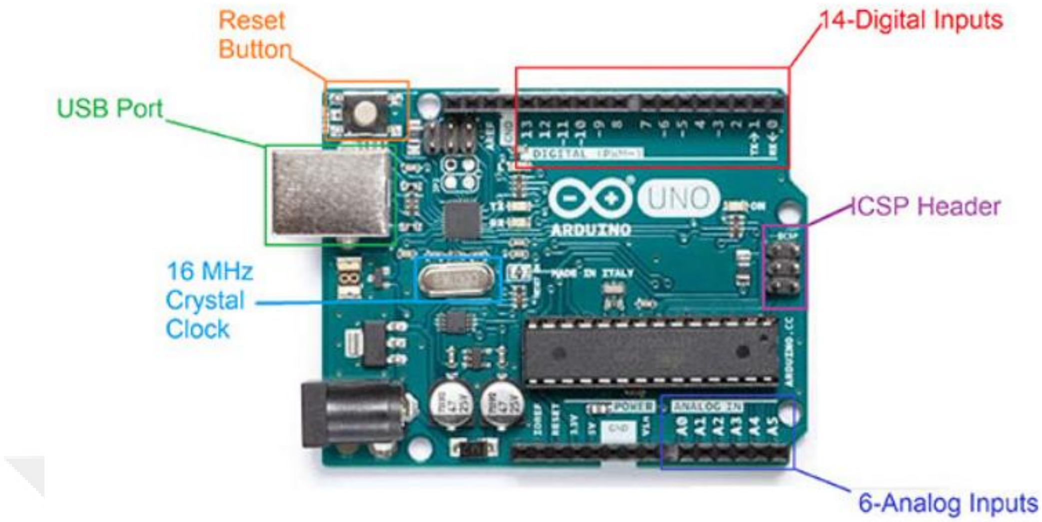


Figure 2.8: Arduino UNO Board

Arduino microcontroller can be programmed via utilising the Arduino IDE which represents the integrated development environment in which this program works on the computer that gives the ability to write codes and load them on the board. The markup language utilised in the IDE for programming an Arduino microcontroller is C / C ++. Table 2.3 shows the technological information for the Arduino Uno kit.

Table 2.4: Technical Information on Arduino Uno.

SPecifications	Arduino Uno R3
Microcontroller	Atmega328P
Clock Speed	16MHz quartz crystal
Flash Memory	32KB
SRAM	2KB
EEPROM	1KB
Analog Input Pins	6KB
Digital I/O Pins	14 pins

2.10.2 Laser Diode

A laser diode is a semiconductors device that resembles LED. The p-n junction is used to produce a coherent light in which all waves are at the same frequency and phase. This interconnected light is produced by a laser diode using a process called amplification of light by activated radioactive emissions which is shortened by laser. Due to the use of the p-n junction to produce laser light, this device will be named a laser diode [33], Figure 2.9 illustrates the laser module.

Figure 2.9: The Laser Module

2.10.3 Light Emitting Diode

The LED could be defined as a semiconductor device that works like a diode and consists of two types of N-type and P-type semiconductors. The atoms travel to the intersection of P-N when the current is applied where they give their electrons to the atoms of the P region containing holes in the forward bias. Indirectly polarizes the diode. Figure 2.10 when the electrons travel from the N region to the P region where they combine with the holes in the P region, the P-N junction releases energy in the form of light. This phenomenon called electro-luminescence. Figure 2.11 shows the architecture of the LED [34].

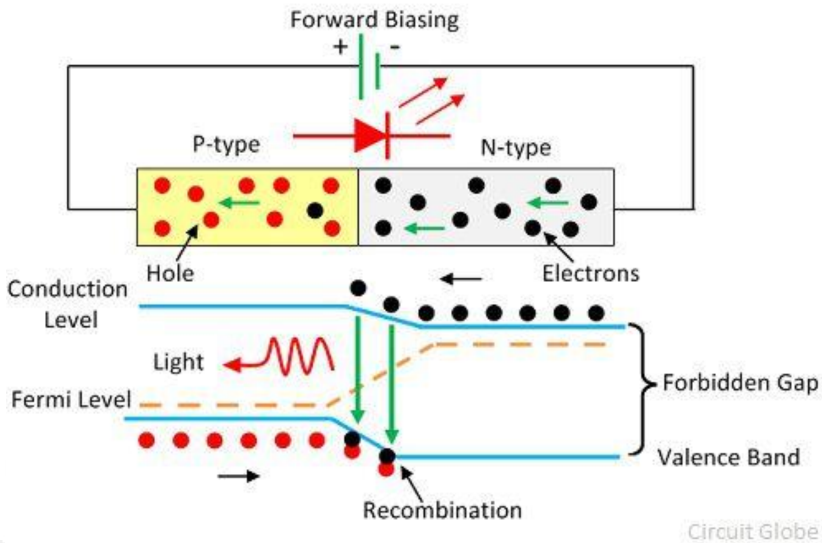


Figure 2.10: The Forward Biased LED P-N junction.

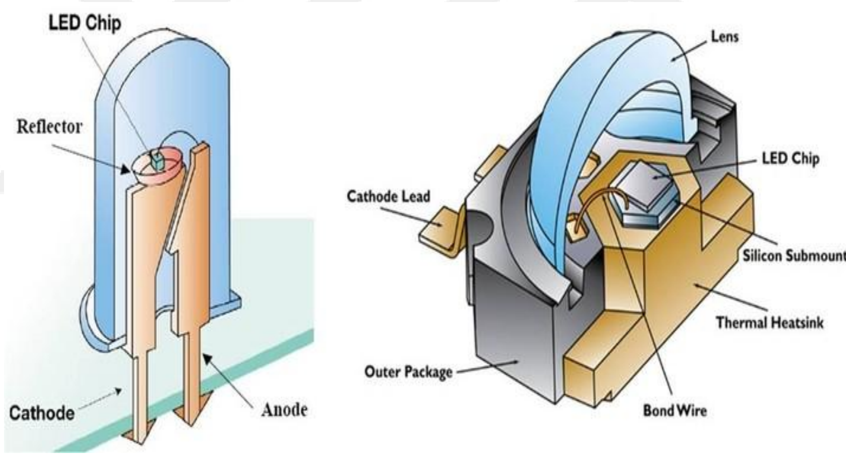


Figure 2.11: LED Architecture

2.10.4 Light Dependent Resistor (LDR)

LDR is a sensor that uses light-sensitive elements to convert light signals into electrical signals. Sensitive wavelengths are located near the wavelength of visible light, including infrared wavelengths and ultraviolet wavelengths. The light sensor isn't limited to detecting light. It could also be used to detect other sensors. It could detect many nonelectrical amounts, as long as these nonelectrical amounts are converted into light signal changes. The electronic simplest device a photosensor is a photoresist that senses light and darkness in the light; it outputs a weak electrical signal which could be controlled by the simple electronic circuit to control the automated switching of the LED. Lamp The LDR has a resistance to change which varies according to the amount of visible light exposure. LDR resistance becomes low by increasing light intensity, as illustrated in Figure 2.12. These sensors are usually made of cadmium sulfide. Light-based resistors used in many different applications, the most common use of LDR is the control of street lighting [35].

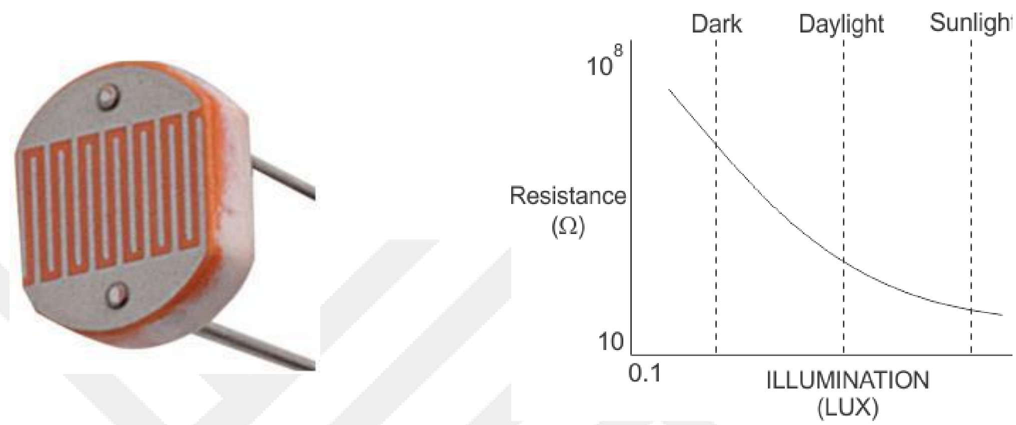


Figure 2.12: LDR with its Light Response.

2.10.5 Photoconductive Mode

In the operation mode, the diode diverted reversely by applying an external DC voltage The depletion area is increased which leads to good conductivity and this mode is preferred for high-speed operations due to rapid response. For the photovoltaic mode for this operating mode, there is no external DC voltage applied to the photodiode and this mode is used in the low response applications required due to the low conductivity in this mode.

2.10.6 Photo Detectors

The photodetector is an optical receiver that converts light to electricity and converts the exposed light signal into a current or voltage. This principle is called photoelectric. Unlike the principle of photodetectors, LEDs are working in an inverse way the photo converters convert light into energy. Optical transistors could be also used as optical switches and light detectors and other applications, Figure 2.13 below show ST-1KLA phototransistors [36].

Figure 2.13: Phototransistor ST-1KLA Model.

2.10.7 Photodiodes

The optical diodes are semiconductors capable of absorbing photons and generating current flow in the photodiode circuit used to convert the optical signal into an electrical signal. They are also used to detect electrical signals that have designed optical diodes to operate in reverse bias these photodiodes are P-N junction diodes but are usually manufactured as a PIN junction, as illustrated in Figure 2.14 for the purpose of the interior region is to increase the speed of photodiode response [37].

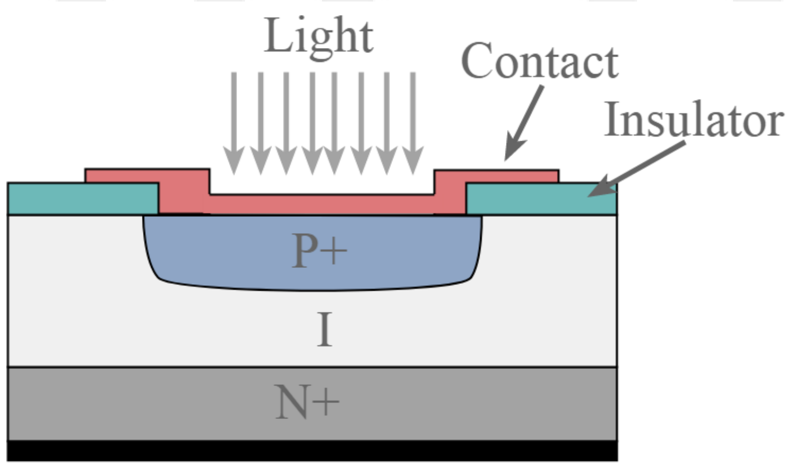


Figure 2.14: PIN Photodiode.

The OSRAM BPW21 Silicon Photodiode shown in Figure 2.15 below is utilised in the project and many other photodiodes to get the most suitable sensor that gives a higher bit rate and better sensitivity for long distances.

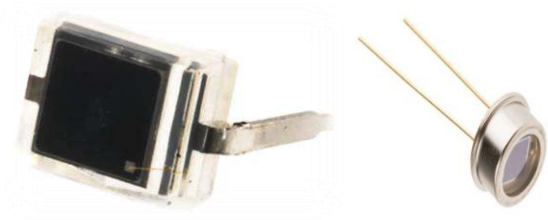


Figure 2.15: Silicon Photodiode OSRAM BPW21 and BPW34.

2.10.7.1 Operation Modes of Photodiodes

The two basic operating modes of the photodiodes are the photovoltaic and photoconductive modes; this two work principle of a photodiode depend on the bias method according to the applications used.

2.11 AMPLITUDE SHIFT KEYING

The Amplitude Offset Key (ASK) has a special case known as on-off-keying (OOK), a type of digital modulation method. In the on and off switches, data will be sent with and without a network operator where Logic 1 displays the presence of the bus and Logic 0 shows no carrier signal. Modified user OOK in many applications because of its simplicity and requires a low implementation cost [38]. Figure 2.16 displays the different formats of modification on-off for the data sequence {10111001101}.

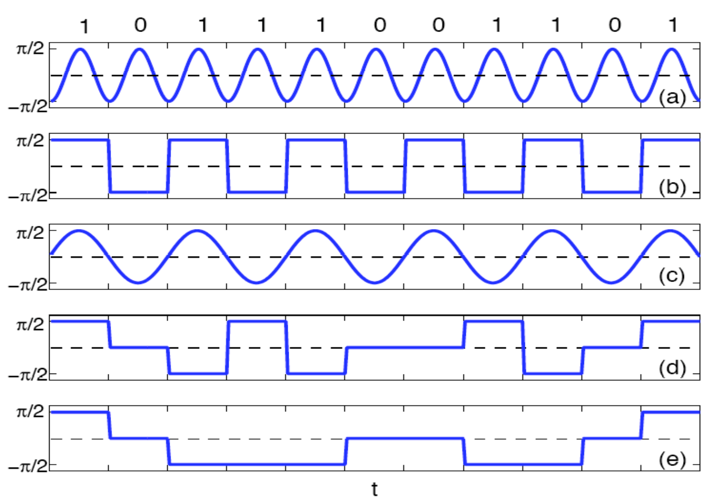


Figure 2.16: Off-On Modulation of Different Formats.

2.12 PULSE WIDTH MODULATION AND PULSE POSITION MODULATION

To send information or data through a channel you must modify the information. The modification method is reliable and simple enough. For VLC systems is the modulation of pulses. A kind of digital communication transmission systems is pulse modulation technology. The advantages of digital transmission are good noise resistance to the different analogue transmission which has lower noise resistance. Message signals in digital transmission are represented in a different time format and capacity form. Pulse Position Modulation (PPM) and Pulse Width Modulation (PWM), are the most popular pulse modulation technique Both PPM and PWM They are capable of modulating the analogue information or data. Figure 2.17 illustrates the principle of working for different configuration kinds [39].

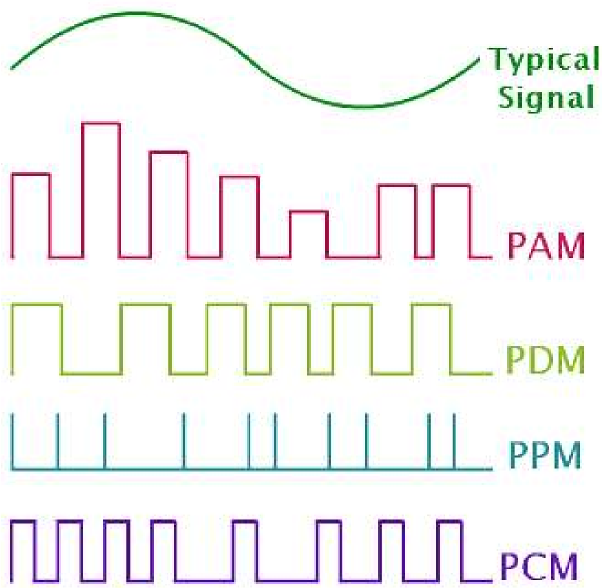


Figure 2.17: Different Modulations Types.

3. IMPLEMENTATION AND REQUIREMENT OF DESIGN

This chapter present an overview of the design and implementation requirements of the proposed system. Also, presents the program requirements and the required components that utilise to construct the this work.

3.1 HARDWARE

The electronics components utilised with the microcontroller boards implement the physical layer which can be summarised as follows:

a. LED and a laser module is utilised in the proposed transmitter side system to transmit data over visible light, in other words, they are utilised as a light source to carries the data.
b. For the receiver side, the photodiode is utilised for the purpose of receiving information that transmitted as light. Further, the photodiode converting the signal of the visible light into a digital electrical signal (i.e. 0 and 1). After that, the digital electrical signal is redirected to the Arduino microcontroller board to analyse it and extract the data. For the purpose of testing, different types of LEDs were utilised to find out which type is suitable for designing the transmitter that provides a higher range of connections. To design a silicon BPW21R receiver, a dual photodiode and BPW34 resistor was employed.

3.2 TRANSMITTER

The VLC transmitter is employed to converting the electrical signal into visible light by the utilisation of the LED, the linearity properties of LED makes it suitable for data transmission also because of its ability to flicker OFF and ON rapidly.

3.3 RECEIVER

A VLC receiver is employed to converting the visible light signal into a digital electrical signal by using optical diodes. The design of the VLC receiver device is important in order to guarantee high-performance to receive and analysed the transmitted data. The existence of noise in the channel and the low-level signals considered as additional disturbing factors that should be taken into account in the design of the receiver.

3.4 SOFTWARE

The next subsections comprise a description of the utilised softwares that have been utilised to simulate and programming the proposed design of the VLC transceiver

3.5 ARDUINO IDE

An Arduino microcontroller board can be programmed via the called Arduino IDE which represents the Integrated Development Environment. Through the Arduino IDE, the user can communicate with the Arduino board by the USB cable and program its own board, where the written Arduino code is called usually "Sketch". The markup language that is utilised in the development of the Arduino IDE is the C and C ++ programming languages [40].

3.5.1 Autodesk Circuits

Autodesk Circuits is a designing software utilised for circuit simulation based on the programming of the Arduino board (autodesk.com).

3.5.2 Matlab

Matlab created a modified environment for the design processes and iterative dissection. Assign arrays and math expressed directly with the programming languages (mathworks.com).

3.5.3 OptiSystem

Optiwave is a leader tool in innovative software which are utilised to simulate, evaluate and optimise systems, networks, and components for the growing field of optical applications, optoelectronics as well as optical networks (Optiwave.com).

3.6 IMPLEMENTATION AND DESIGN

The designing steps of the prototypes will be presented and explained in this chapter. The software employed for the purpose of simulation and implementation after designing the prototype are MATLAB and Optisystem software is used to design and simulate the transmitter as well as the receiver. The main description of the design for the proposed system is summarised by the selection of electronic parts, the software simulation with Optisystem for the visible light communication system, and the results of the simulation.

3.7 DESIGN OF THE VLC SYSTEM

The system design includes the VLC system structure, the design of the VLC transmitter, and the receiver design of the VLC.

3.8 VLC SYSTEM STRUCTURE

The VLC system designed was proposed for short distances communication as an indoor visible light text information transmitting system. The system consists of two main blocks (i.e. block #1 and block #2) each of the blocks can transmit or receive the data that embedded by the visible light, in other words, each block act as a transceiver. Two microcontroller boards based on ATmega328P were employed in the design of the proposed system as the main microcontroller which responsible on the processing of the receiving/ transmitting the data. The block #1 comprises of Ps2 keyboard, the Arduino microcontroller, LED, photo-sensor, Liquid Crystal Display (LCD), and power supply (i.e. 9V battery). The block #2 comprises of Ps2 keyboard, the Arduino microcontroller, laser module, LDR, LCD, and power supply (i.e. 9V battery).

3.8.1 Design Block #1

This block has been based on the hardware parts mentioned previously in section 3.4.1. Block #1 is responsible for transmitting the data by the LED and at the same time this block is able to receive the data that transmitted by the laser. Figures 3.1 and 3.2, respectively, illustrate the circuit diagram and the implemented system of the block #1.

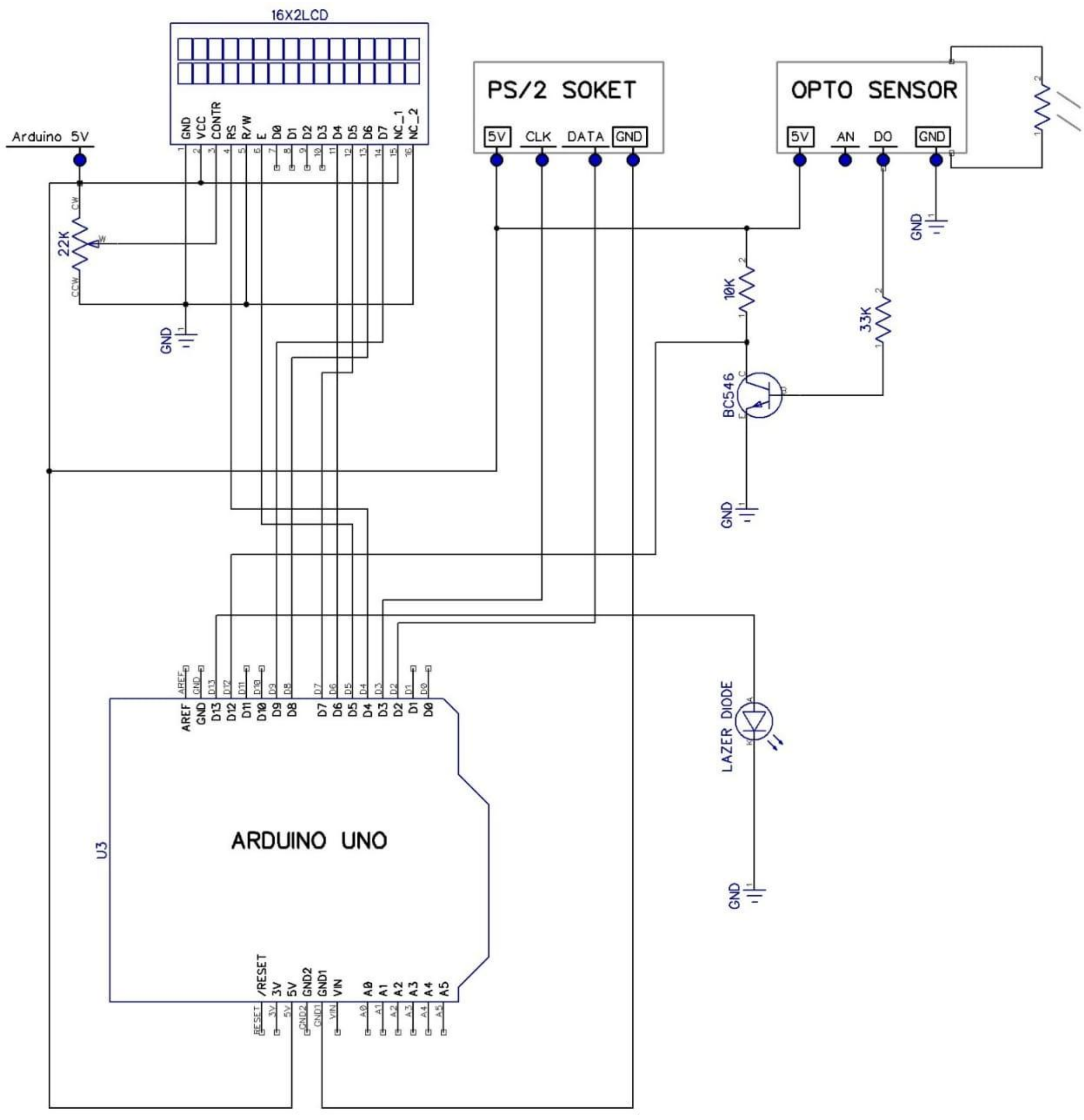


Figure 3.1: Circuit Diagram of The Block #1

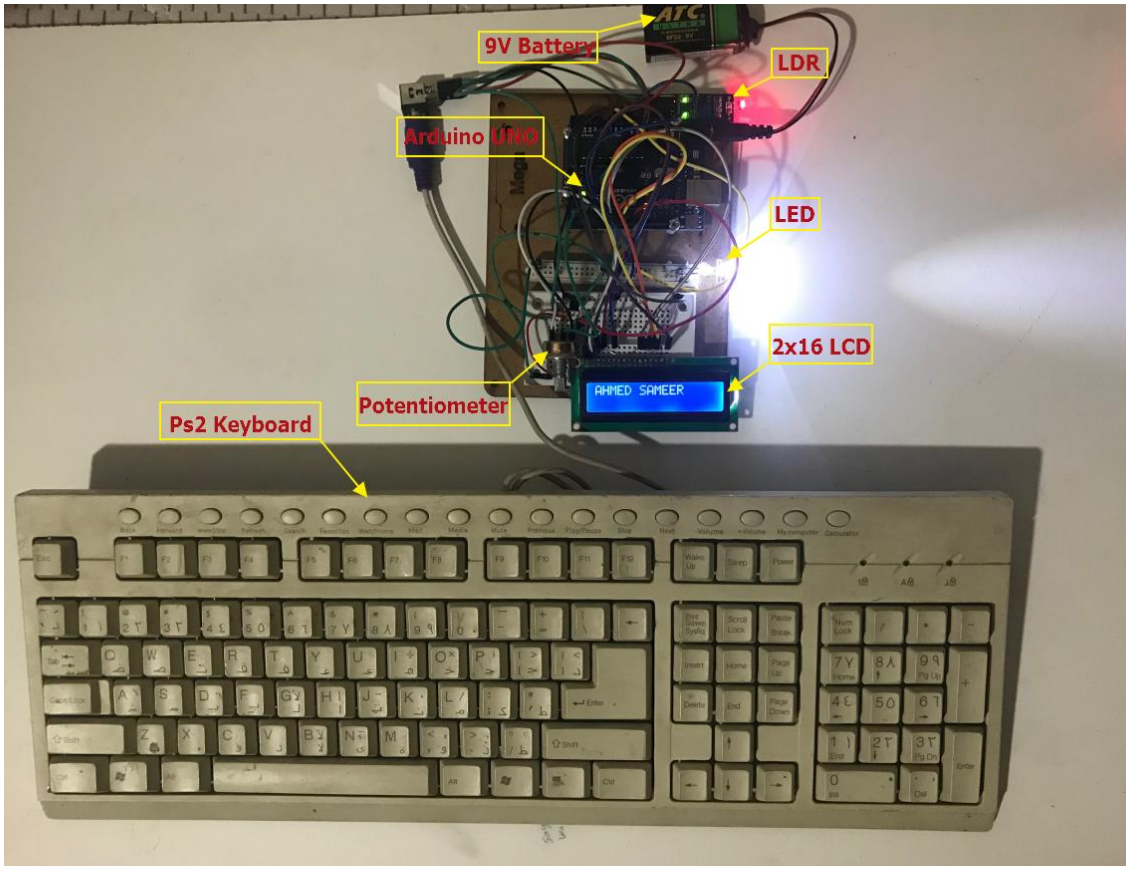


Figure 3.2: The Implemented System for The Block #1

When press any button form the Ps2 (letter or number) the microcontroller recognises the pressed button as a stream of bits; after that Arduino microcontroller turning ON/OFF the LED according to the received bits that related to a specific button. The Photo-sensor responsible for receiving the data transmitted through the laser beam as a stream of bits; after that transfer theses bits to the Arduino microcontroller board for processing purpose and display the received character on the LCD.

3.8.2 Design Block #2

In the same procedure that is done in the previous section, block #2 is responsible for transmitting the data by the laser beam and at the same time this block is able to receive the data transmitted by the LED through the LDR. Figures 3.3 and 3.4, respectively, illustrate the circuit diagram and the implemented system of block #2.

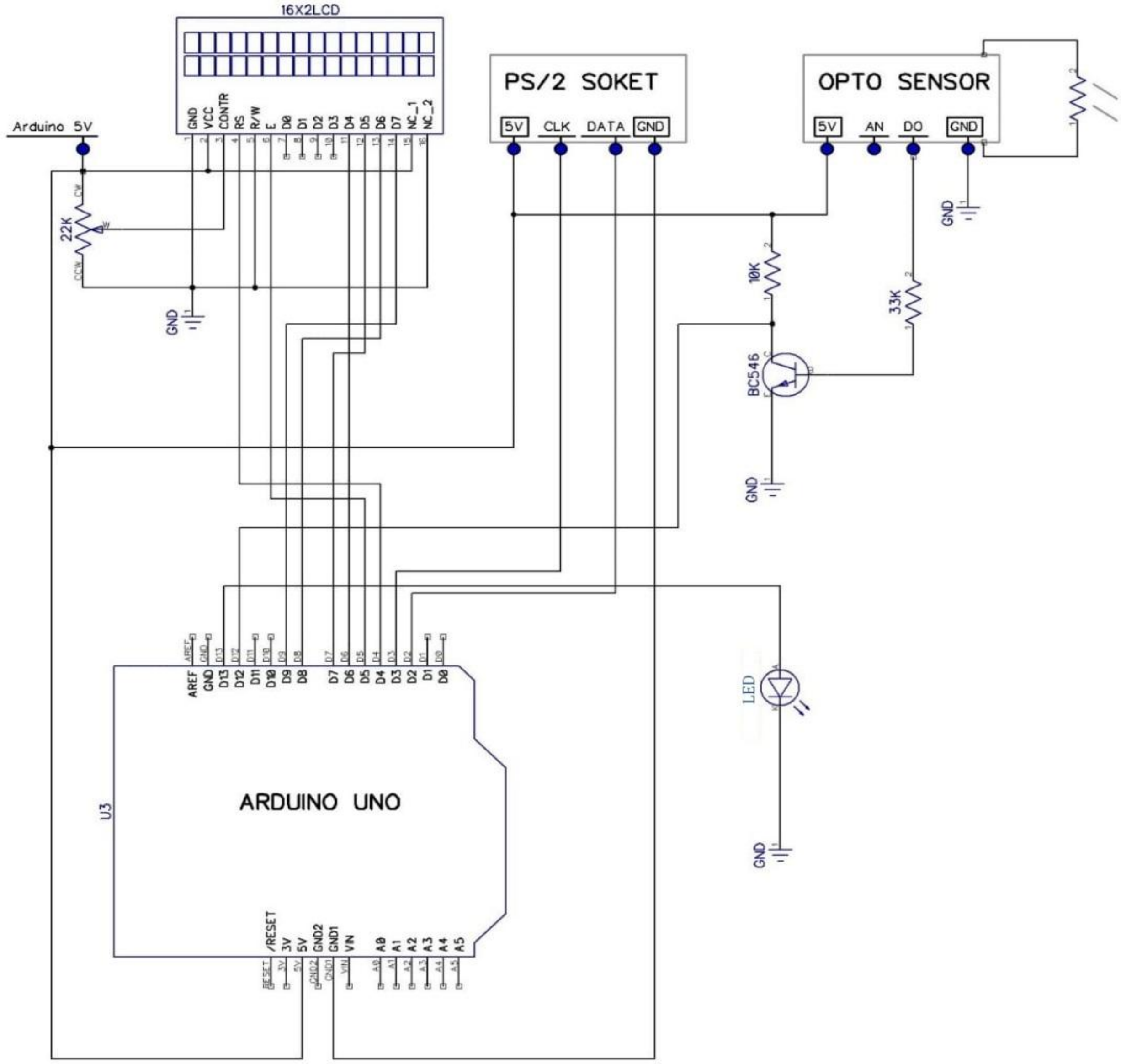


Figure 3.3: Circuit Diagram of The Block #2.

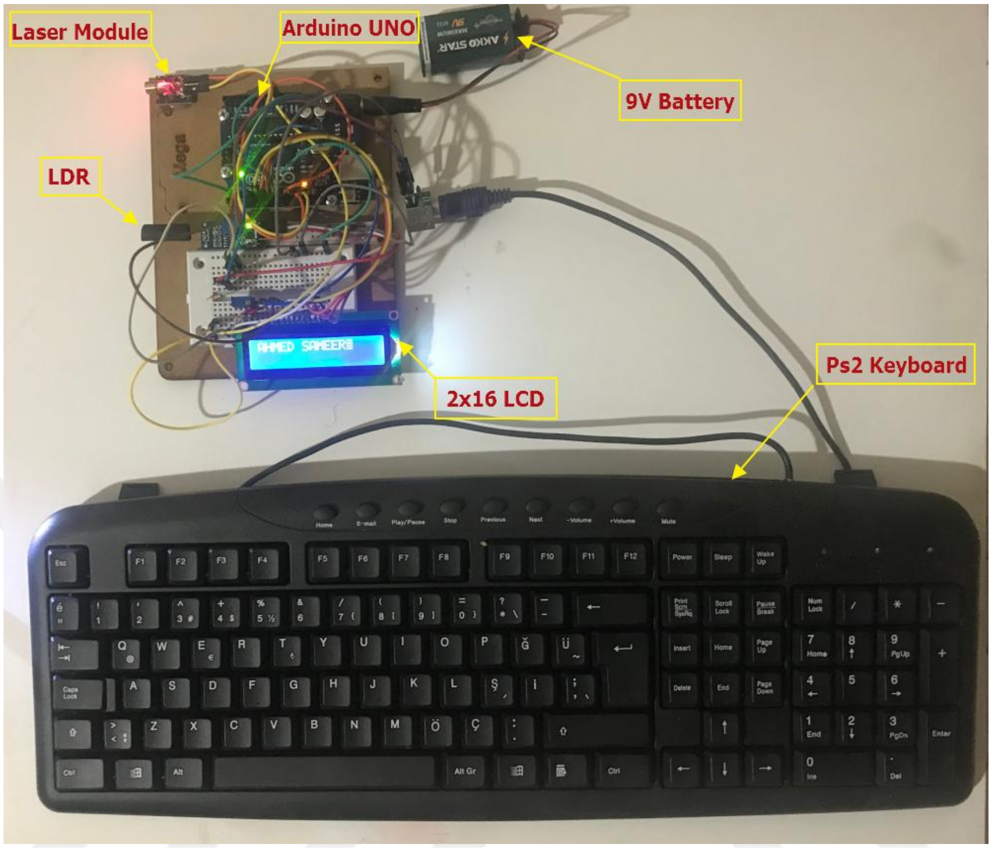


Figure 3.4: The Implemented System for The Block #2

3.9 SYSTEM DEBUG

The main challenge in the proposed VLC system can be summarised as the connection distance between block #1 and block #2 because the LoS arrangement is required. So it is important to arrange the blocks correctly to debug the hardware before the examination of the system performance, Figure 3.5 illustrates the alignment of the block #1 and block #2 during the practical test.

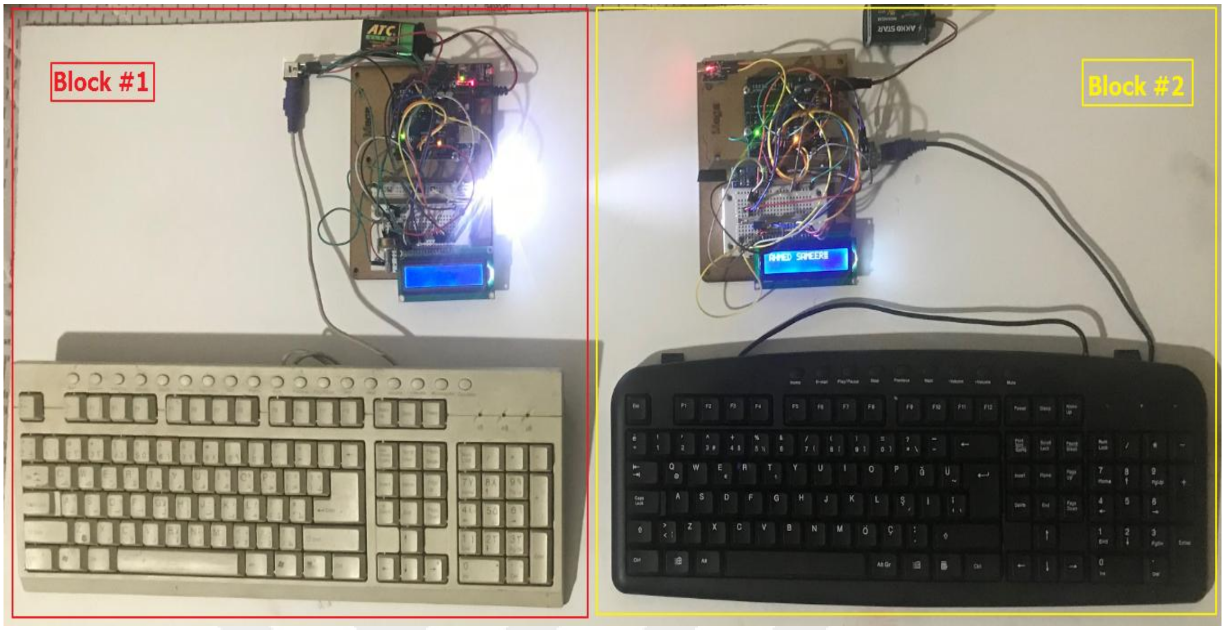


Figure 3.5: Implemented Ttransceivers Systems.

4. SIMULATION AND RESULTS

4.1 INTRODUCTION

In this chapter, the proposed system BER results, hardware simulation, and the simulation result will be presented and discussed as well.

4.2 SYSTEM EXAMINATION

The proposed system has been examined practically and good performance was achieved. During the test of the proposed system notes that the communication distance up to 30cm, once this distance increased the distortion effect dominates this due to the presence of the natural light of the system installation environment. Also, note that when the angle between LED and LDR up 30 degrees the communication is done well but when the angle more than 30 the receiving errors appear. Figures 4.1 and 4.2, respectively, shows the BER curves obtained by Optisystem software for the LED and laser.

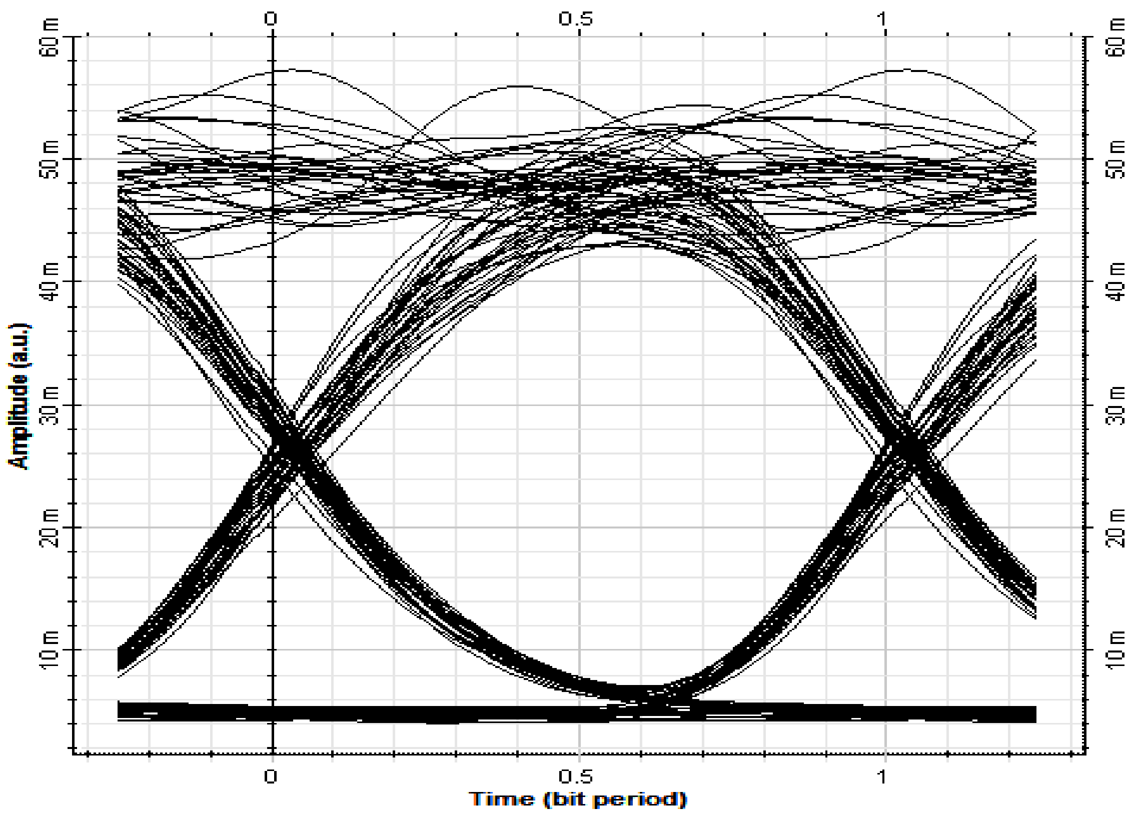


Figure 4.1: BER Results for the LED.

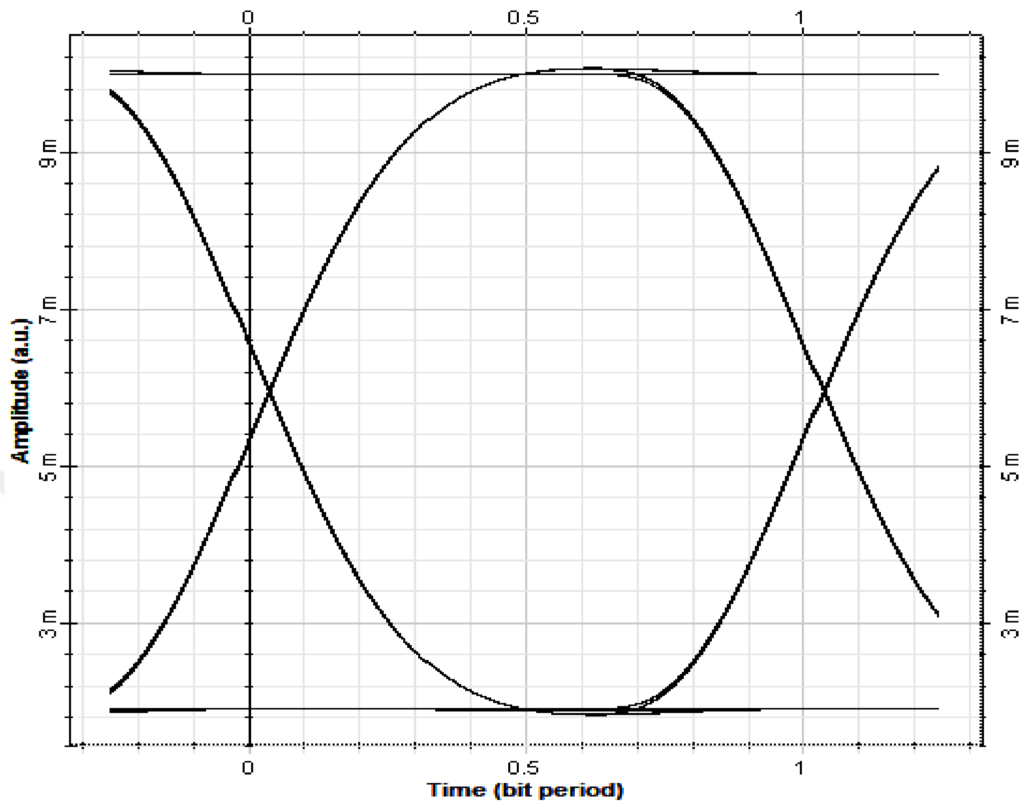
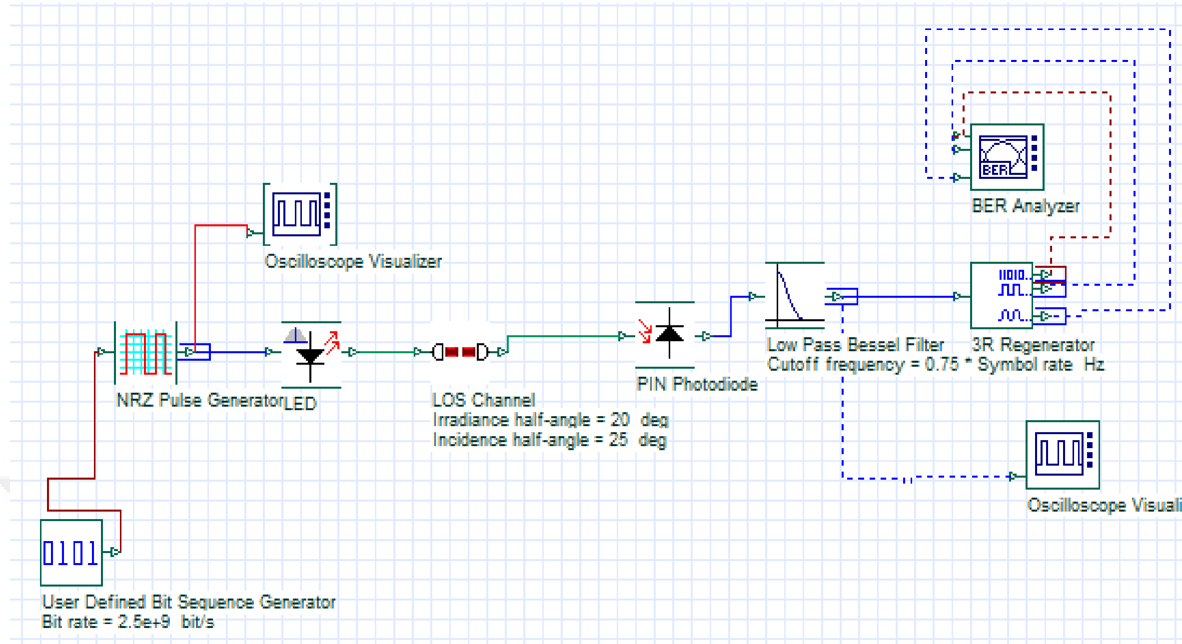


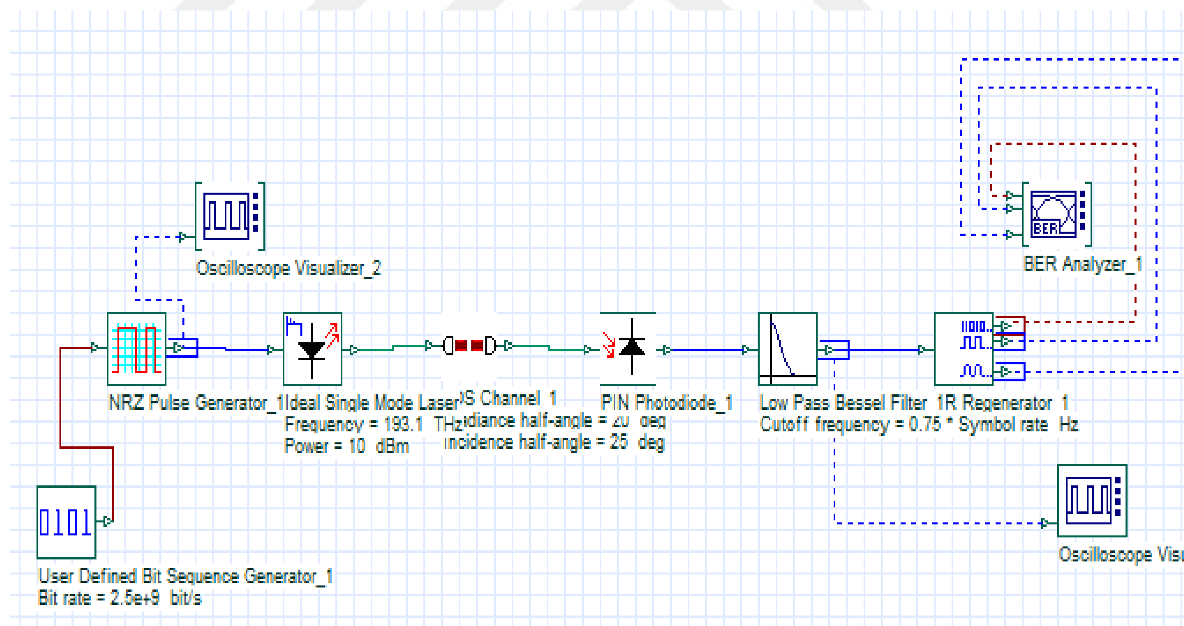
Figure 4.2: BER Results for The Laser.

4.3 VLC SYSTEM SIMULATION

Optisystem software is also can be employed to simulate the proposed VLC system. Figure 4.3 shows the proposed VLC transceivers (i.e. Block #1 and Block #2) circuit diagram inside the Optisystem software environment and Figure 4.4 presents the input signal of the blocks.

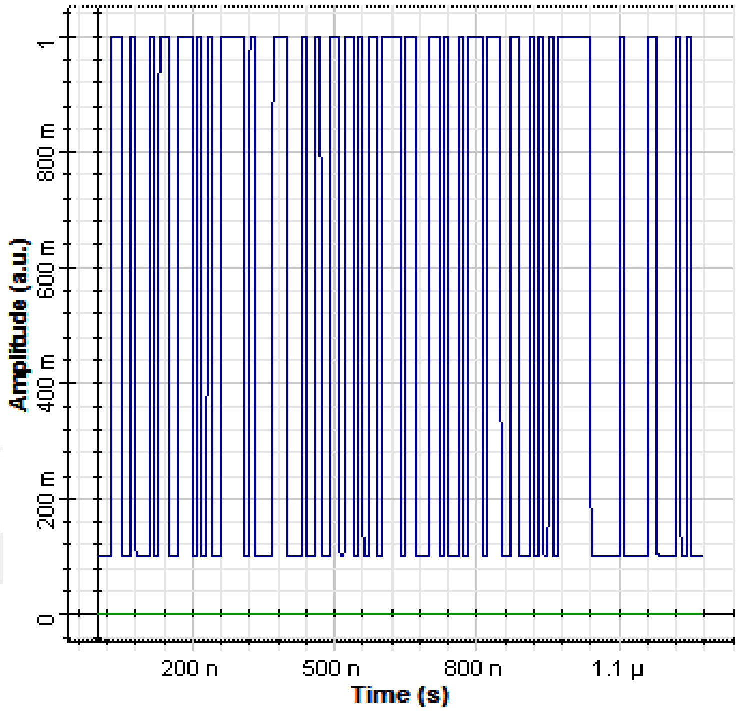


(a) Block #1

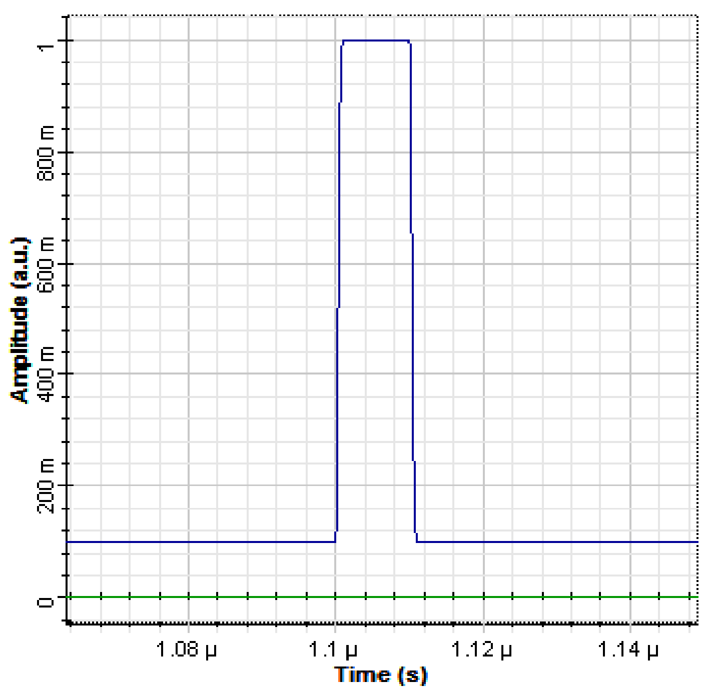


(b) Block #2

Figure 4.3: The Simulated Proposed system inside the Opisysem.



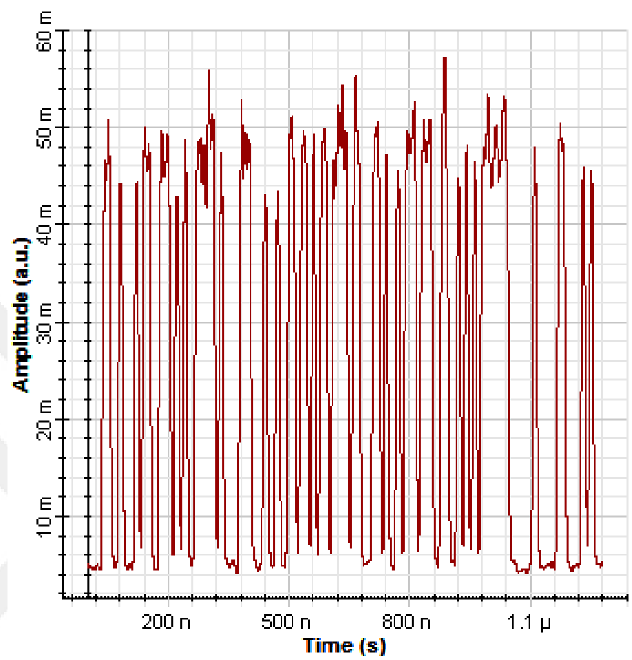
(a) Input Signal



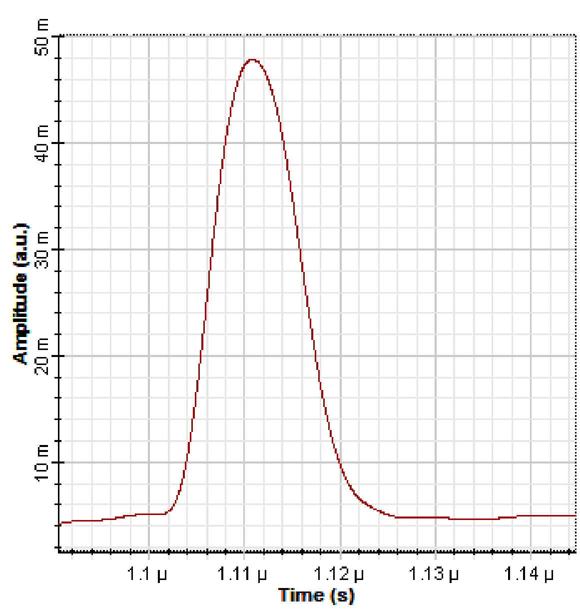
(b) Zoomed View of The Input Signal

Figure 4.4: Input Ssignal for LED and Laser.

Figures 4.5 and 4.6, respectively, illustrates the received signal (i.e. bits stream), received data by the LDR that trasmitted via the LED, and the received data by the photo-sensor that trasmitted via the laser beam.

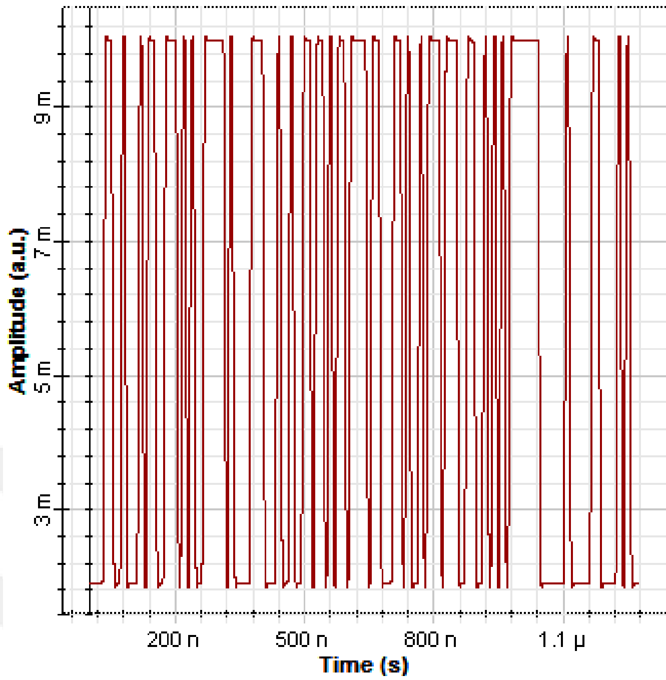


(a) Received Data by The LDR

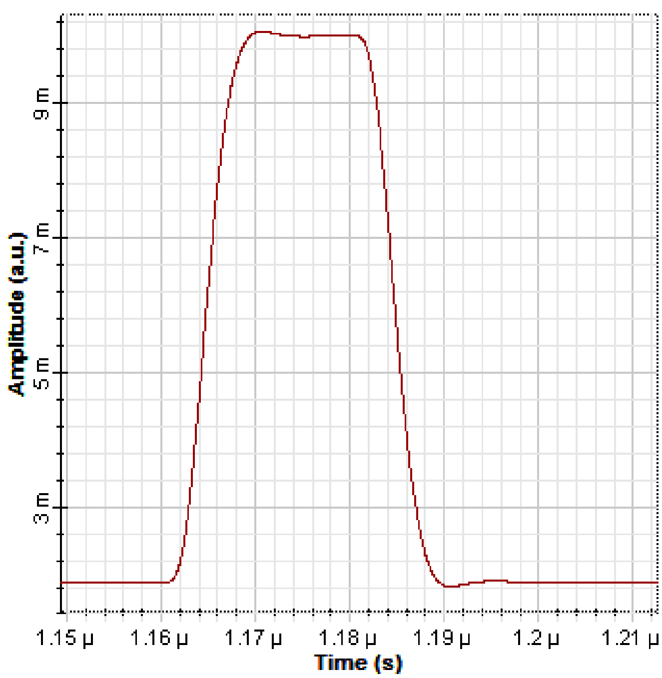


(b) Zommed View for The Received Data by The LDR

Figure 4.5: Received Data by The LDR.



(a) Received Data by The photo-Sensor



(b) Zommed view for the received data by the photo-sensor

Figure 4.6: Output Simulation Signal for Leaser.

5. CONCLUSION AND FUTURE WORK

5.1 CONCLUSION

In this study, VLC transceivers systems have been successfully proposed, designed in implemented. Two transceivers blocks were proposed in this work to send the data through the LED and laser beam based on the basis of the VLC technique. Where the first block (i.e. block #1) able to transmit the data through the LED and received the transmitted data through the laser beam by the photo-sensor; while the second one (i.e. block #2) able to transmit the data through the laser as well as received the transmitted data through the LED by the LDR module. The Arduino microcontroller that is based on the ATmega328P chip was employed in the preparation of the data that comes from the Ps2 keyboard (i.e. character or a number) and convert them into a bitstream to be transmitted via the LED or the laser beam. Also, the Arduino can be received such data by the LDR or the photo-sensor and processing such data to be converted into a useful data form. Each transceiver block contains in its structure a 2x16 LCD to presents the received data; where the transmitted data via the LED from block #1 can be received by block #2 through the LDR module; while the transmitted data from block #2 by the laser beam can be received by block #1 through the photo-sensor. The implemented transceiver blocks have been successfully tested and a good communication performance was achieved within a distance of up to 30cm wirelessly.

5.2 FUTURE WORK

The proposed transceiver systems can be enhanced in future developments by doing many of the additions, some of which can be listed as follows:

a. Increase the communication distance
b. Develop the system to be able to receive the multimedia
c. Employed the Field-Programmable Gate Array (FPGA) instead of the Arduino microcontroller to ensure the best data processing
d. Employed the solar cells to feed the microcontrollers by the DC voltage

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APPENDIX (A)

- **Source code of the Receiver side**

```
#include <SoftwareSerial.h>
#include <LiquidCrystal.h>
#include <PS2Keyboard.h>
const int DataPin = 2;
const int IRQpin =  3;
SoftwareSerial GSerial2(10,13);
PS2Keyboard keyboard;
LiquidCrystal lcd(4, 5, 6, 7, 8, 9);
SoftwareSerial GSerial(11, 12);
char rec = 0;
char com_buffer [32] ;
int com_buffer_nb_bytes = 0 ;
void setup()
{
  keyboard.begin(DataPin, IRQpin);
    GSerial2.begin(400);
  Serial.begin(9600);
  GSerial.begin(400);
  lcd.begin(16, 2);
    lcd.setCursor(0, 0);
    lcd.print(" ISTANBUL ");
    lcd.setCursor(0, 1);
    lcd.print(" COMMERCE  ");
    delay(100);
    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print(" UNIVERSITY  ");
    lcd.setCursor(0, 1);
    lcd.print("  ");
    delay(100);
    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("  ISTANBUL  ");
    lcd.setCursor(0,1);
    lcd.print("    TURKIYE   ");
    delay(100);
  lcd.clear();
}

void loop()
{

   if (keyboard.available()) {

    // read the next key
    char d = keyboard.read();
    Serial.print("Key=");
```

```
    Serial.println(d);
  GSerial2.print(d);
   }
  if (GSerial.available() != 0)
  {
//    rec = GSerial.read();
    int c =   GSerial.read();

    char a = c;
    lcd.print(a);

//    com_buffer[com_buffer_nb_bytes] = rec ;
    com_buffer_nb_bytes ++ ;
        if (   com_buffer_nb_bytes == 16) {
      com_buffer_nb_bytes = 0;
      lcd.clear();
        }
////         Serial.println( String(com_buffer_nb_bytes));
//int y = atoi(rec);
// Serial.println(y,DEC);
    if (   c ==13) {
      com_buffer_nb_bytes = 0;
      lcd.clear();
    }

//      lcd.setCursor(0, 0);
//      for ( int x = 0; x < 16; x++) {
//        lcd.print(com_buffer[x]);
//        Serial.print(rec);
//      }
//      lcd.setCursor(0, 1);
//      for ( int x = 16; x < 32; x++) {
//        lcd.print(com_buffer[x]);
//        Serial.print(rec);
//      }

 Serial.println(c,DEC);
//Serial.println(rec);

//      Serial.println();


//    }



  }

}
```

APPENDIX (B)

- ## Source code of the Transmitter side

```
#include <SoftwareSerial.h>
#include <LiquidCrystal.h>
#include <PS2Keyboard.h>
const int DataPin = 2;
const int IRQpin =  3;
SoftwareSerial GSerial2(10,13);
PS2Keyboard keyboard;
LiquidCrystal lcd(4, 5, 6, 7, 8, 9);
SoftwareSerial GSerial(11, 12);
char rec = 0;
char com_buffer [32] ;
int com_buffer_nb_bytes = 0 ;
void setup()
{
  keyboard.begin(DataPin, IRQpin);
    GSerial2.begin(400);
  Serial.begin(9600);
  GSerial.begin(400);
  lcd.begin(16, 2);
    lcd.setCursor(0, 0);
    lcd.print(" ISTANBUL ");
    lcd.setCursor(0, 1);
    lcd.print(" COMMERCE  ");
    delay(100);
    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print(" UNIVERSITY  ");
    lcd.setCursor(0, 1);
    lcd.print("  ");
    delay(100);
    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("  ISTANBUL  ");
    lcd.setCursor(0,1);
    lcd.print("    TURKIYE   ");
    delay(100);
  lcd.clear();
}
void loop()
{
   if (keyboard.available())
    // read the next key
    char d = keyboard.read();
    Serial.print("Key=");
     Serial.println(d);
  GSerial2.print(d);
   }
```

```
  if (GSerial.available() != 0)
  {
//    rec = GSerial.read();
    int c =   GSerial.read();
        char a = c;
    lcd.print(a);
 //    com_buffer[com_buffer_nb_bytes] = rec ;
    com_buffer_nb_bytes ++ ;
        if (   com_buffer_nb_bytes == 16) {
      com_buffer_nb_bytes = 0;
      lcd.clear();
        }
Serial.println( String(com_buffer_nb_bytes));
//int y = atoi(rec);
// Serial.println(y,DEC);
    if (   c ==13) {
      com_buffer_nb_bytes = 0;
      lcd.clear();
    }
//      lcd.setCursor(0, 0);
//      for ( int x = 0; x < 16; x++) {
//        lcd.print(com_buffer[x]);
//        Serial.print(rec);
//      }
//      lcd.setCursor(0, 1);
//      for ( int x = 16; x < 32; x++) {
//        lcd.print(com_buffer[x]);
//        Serial.print(rec);
//      }
 Serial.println(c,DEC);
//Serial.println(rec);
//      Serial.println();
//    }
  }
}
```