Araştırma Makalesi

AN ADAPTIVE TRANSCEIVER DESIGN FOR VISIBLE LIGHT COMMUNICATION

Sayf Albayati[†], Serhan Yarkan[††]
[†] İstanbul Ticaret Üniversitesi, Fen Bilimleri Enstitüsü, İstanbul, Türkiye
[††] İstanbul Ticaret Üniversitesi, Mühendislik Fakültesi, İstanbul, Türkiye
swmajeed.bayati@istanbulticaret.edu.tr, syarkan@ticaret.edu.tr

ABSTRACT

Wireless Visible light communication has been attracting many researchers attention recently the reasons are that visible light communication have some advantages which does not exist in radio frequency communications. Many researches done in visible light communication fields the most of these researches focused on how to achieve higher communication data rates and much less focused on the designing steps of the visible light communication transceiver to be utilized for indoor applications within short ranges. In this thesis designing and implementing of a visible light communication transceiver is successfully accomplished. The designed system composed of two main sections the transmitter section and the receiver section. The system uses two ATmega328P chip microcontrollers. Light emitting diodes used at the transmitter section as the transmitting module. The light emitting diode illumination light wave acts as the carrier of the transmitted signals. At the receiver section a photo detector and an LCD display are used to realize the signal reception. The final tests of the system showed that the design realizes indoor visible light short distance data transmission and verifies a reliable transceiver for visible light communication.

Keywords: Visible light communication, light emitting diode, photo detector, photodiode, microcontroller

Geliş/Received : 23.05.2019
Gözden Geçirme/Revised : 30.05.2019
Kabul/Accepted : 26.06.2019

1. INTRODUCTION

The LED invention in 1927 brought back the idea of using visible light for communication many years after Alexander Graham Bell's failed experiment in the year 1880 when he first introduced the idea of using visible light for communication. The communication with visible light is essentially communication through optical light it can be classified as a type of free space optical communications. The transmission of data through the light is achieved by the existence of light source. The flickering source is activated and deactivated to respectively represent a high logic signal and a low logic signal (Komine and Nakagawa, 2004).

The main advantage of visible light communication is that it provides high speed communication because it has large bandwidth capacity and unregulated spectrum approximately 1600 times wider than the bandwidth of the radio and optical wireless communication (OWC) unlike radio it cannot pass through objects (Ziad et al, 2015). This is desired for security terms because the signal will be limited for a confined area. Another advantage of optical wireless communications is that multipath fading does not exist.

LED's are used as the transmitter in visible light communication (VLC) because of its ability of rapidly switching on and off which cannot be noticed by human eye. Transmission medium is the visible light spectrum. Photo diodes are used as the receivers of the light which can easily detect the rapidly flickering light signals.

The advantage of visible light communication (VLC) is that it does not interfere with radio frequency signals (Uysal, 2014) and can be used safely at radio frequency restricted areas such as airplanes, hospitals, underwater communication and many other applications. VLC can be used to establish a secure wireless network because it has a good level of security.

There are some parameters to be considered while implementing visible light communication system line of sight is the first thing to be considered secondly the distance between the transmitter and receiver these are important parameters to be considered when designing visible light communication system. The license free band feature gives the visible light communication the preferences to be used in some different applications. The high powered and low cost LEDs that can switch at high frequencies are basic technological features that make VLC possible. Moreover, the VLC infrastructure already exists. All the needs are to replace ordinary light bulbs with the smart and powerful LED lights.

1.1. Problem Statement

Designing and implementing an advanced transceiver for visible light communication since there is no enough available resources that describe the implementation and design of visible light communication system in step by step and detailed form because VLC is a new area most researches in this field focusing on how to achieve high speed visible light communication. So the problem statement of this thesis is designing and implementing a visible light communication transceiver and providing detailed information on designing the VLC system. Reflection paths and underwater communication test were taken into account in this design.

1.2. Problem Objectives

The objective of this project is the designing and implementation of VLC transceiver which should be able to send and receive data over visible light and data transmitting range over 1 meter distance it should be able to work in different indoor environments. This project provides a good overview and clear understanding of the design and implementation of the VLC transceiver and it will be a good starting point for anyone wishing to pursue R & D in this area.

1.3. Limitations

The limitations of the proposed design are that it can be used in an indoor environment only because of the distortion of sunlight. When the distance between the transmitter and receiver is increased the probability of data loss is increased. Line of sight is mainly considered as a limitation of visible light communication systems.

2. BACKGROUND

Light emitting diode (LED) can be defined as a semiconductor device which works like a diode it consist of two types of semiconductors N-type and P-type when the current is applied the atoms move to the P-N junction they give their electrons to the P-region atoms which have holes in forward biasing (Figure 1) When the electrons travel from N-region to the P-region where it recombine with the holes in P-region the P-N junction release energy in form of light and this phenomena called electroluminescence. (Figure 1) also shows the led architecture.

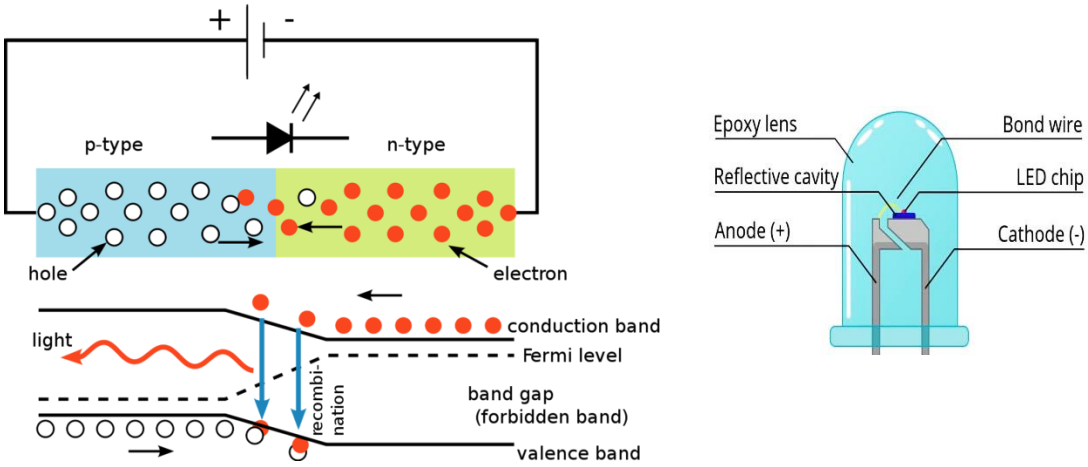

Figure 1. Forward biased P-N junction of LED and LED architecture.

To calculate the energy band gap and wavelength of a led the following equations can be used.

$$hv = E_g \tag{1}$$

$$\frac{hc}{\lambda} = E_g \tag{2}$$

$$\lambda = \frac{hc}{E_g} \tag{3}$$

Where (h) Represents Plank's constant, (c) represents the light speed and (E_g) represents the energy band gap. The band gap determines the LED color for example a 2 eV band gap emits red color light at about 620 nm. A 3 eV band gap emits violet color light at 414 nm. To calculate the dissipated powe in LEDs also to find the total power the following equation can be used

$$P_{led} = I_f \cdot V_f \tag{4}$$

where (I_f) represents forward currint of the LED and (V_f) represents the forward voltage of the LED.

Photo detectors are an optical receiver which converts light into electricity it converts the light signal that exposed to the junction to a current or voltage this principle called photoelectric effect. (Komine, 2003). LEDs work in an inverse principle unlike photo detectors working principle it converts energy to light while photo detectors converts light into energy. Phototransistors also can be used as light detectors and optical switches and in many other applications (Figure 2) below show ST1KLA phototransistor.

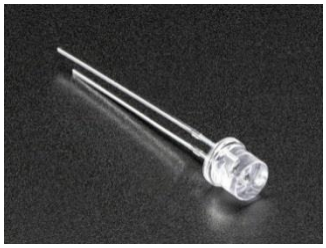

Figure 2. The ST1KLA phototransistor.

Photodiodes are semiconductors capable of absorbing photons and generates flow of current in an external circuit photodiodes used to convert optical signal to electrical signal also used to detect electrical signals the photodiodes are designed to operate with reverse bias (Boubezari et al, 2016). These photo diodes are P-N junction diodes but usually manufactured as PIN junction photodiode the purpose of intrinsic region is to increase the response speed of photodiode.BPW34 and BPW21 Silicon Photodiodes shown in (Figure 3) below are used in the project and many other photodiodes to find the most suitable sensor that gives better sensitivity and higher bit rate for longer distances.

Figure 3. BPW34 and BPW21 silicon photodiode.

The photodiode conductivity can be calculated by the equation as following:

$$\sigma = \sigma_{th} + \sigma_{pd} \tag{5}$$

where σ_{th} represents the thermal conductance also known as dark current when there is no light falling to the junction and σ_{pd} represents the photodiode conductivity.

There are two basic operating modes for photodiodes which are photoconductive and photovoltaic modes this two working modes depends on the biasing method according to the application used.

In Photoconductive operating mode the diode biased reversely by applying an external DC voltage also the depletion region is increased which results in good conductivity this mode is preferred to use in high speed operations because of its fast response where In Photovoltaic operating mode there is no applied external DC voltage to the photodiode this mode is used in low response needed applications due to the low conductivity of this mode.

Light dependent resistor (LDR) is a sensor that uses light-sensitive elements to convert optical signals into electrical signals. The sensitive wavelengths are near the wavelength of visible light, including infrared wavelengths and ultraviolet wavelengths. The light sensor is not limited to the detection of light. It can also be used as a detector element to form other sensors. It can detect many non-electric quantities, as long as these nonelectric quantities are converted into changes in the optical signal. The simplest electronic device in a photo sensor is a photo resistor that senses light and dark changes in light, outputs a weak electrical signal, and can be controlled by a simple electronic circuit to control the automatic switching of the LED fixture. Light dependent resistor (LDR) has a changeable resistance which varies according to the amount of exposed visible light on it. The LDR resistance becomes decreased by increasing the light intensity. These sensors usually made from cadmium sulphide. Light dependent resistors used in many different applications the most common use of LDRs is street light controlling.

3. DESIGN REQUIREMENT

This section will present and overview the requirements for the design and implementation of VLC system including the required components used in the design. It will also include the software requirements.

3.1. Hardware

The electronic components used between the microcontroller boards are implimenting the physical layer. light emitting diodes used at the transmitter side for the purpose of data transmitting through visible light. And for the receiver side a photodiode used for the purpose of data receiving by converting the visible light signal into electrical signal and then it forward the electrical signal to the arduino board to be processed as data.

For the test purpose different types of LEDs was used to find out which type is suitable for the transmitter design that gives higher range for communication. For the receiver design BPW21R Silicon photodiode, BPW34 Photodiode and light dependent resistor was used.

The transmitter of visible light communication is a device which converts the electrical signals into visible light by the use of light emitting diodes the linearity properties of light emitting diodes makes it suitable for data transmission because of its ability to flicker on and off rapidly a 5mm red green blue white LEDs used and tested to find out which one is suitable for larger distances.

The receiver of visible light communication is a device which converts the visible light signals into electrical signal by the use of photodiodes. The sucsessful design of VLC receiver device is important in order to guarantee high performance VLC receiver. The Presence of noise interference and low level signals are Other worrying factors to be considered in the receiver design.

As mentioned in unit 2. Light dependent resistor (LDR) is a sensor that uses light-sensitive elements to convert optical signals into electrical. The simplest electronic device in a photo sensor is a photo resistor that senses light and dark changes in light, outputs a weak electrical signal, and can be controlled by a simple electronic circuit to control the automatic switching of the LED fixture. Light dependent resistor (LDR) has a changeable resistance which varies according to the amount of exposed visible light on it. The LDR resistance becomes decreased by increasing the light intensity. Photodiodes are semiconductors capable of absorbing photons and generates flow of current in an external circuit photodiodes used to convert optical signal to electrical signal. OSRAM BPW21R Silicon Photodiode and BPW34 Photodiode are used and tested in the receiver design.

3.2. Software

Software implementation was also used for the VLC transceiver design for the purpose of simulation all the used software mentioned below.

Arduino IDE: The arduino microcontroller is programed by the use of software called arduino IDE which stands for integrated development environment this software works on computer which gives the capability of writing codes and uploading it to the board. The coding language used in IDE to program the arduino microcontroller is C/C++ language.

Autodesk Circuits: Autodesk Circuits is a simulation and design software that provides circuit simulation capabilities based on the Arduino programing board.

Matlab: Matlab create an environment adjusted for design processes and iterative analysis. array mathematics and matrices directly expressed with programming language.

OptiSystem: Optiwave is an emerging leader in the innovative software tools that is used in simulation, optimization, and design of systems, networks, and components for the growing field of optical networks, photonic applications, and optoelectronics.

4. DESIGN AND IMPLEMENTATION

The prototype designing steps will be illustrated in this section software implementation used after designing the prototype. Optisystem and matlab software was used to simulate the transceiver. First a general description of the implementation for the system is given and details on the selection of electronic components, followed by optisystem software simulation for the VLC system and the simulation results.

4.1. VLC System Design

The VLC system is designed as an indoor short distance visible light character information transmission system. It consists of two parts transmitting and receiving part. The VLC system mathematically represented as in the following equation

$$y(t) = R(x(t) * h(t)) + n(t) \quad (6)$$

Where $y(t)$ the system output, R represents the photodiode response, $h(t)$ is the impulse response of the channel, $n(t)$ represents AWGN. The SNR of the system can be defined by the following equation

$$SNR = \frac{{R^2}_r \times {P^2}_r}{{\sigma^2}_{shot\ noise} + {\sigma^2}_{thermal\ noise}} \quad (7)$$

Where (R_r) is the photo receiver responsivity and (P_r) average optical power received. The system uses two microcontroller board based on ATmega328P as the main microcontrollers of the transmitting and receiving boards. Character input keys from the transmitter board, the microcontroller, LED lighting module of the receiving module by the photo receiver module, a microcontroller, and an information display (16x2 LCD). (Figure 4) shows the overall system structure of visible light communication system.

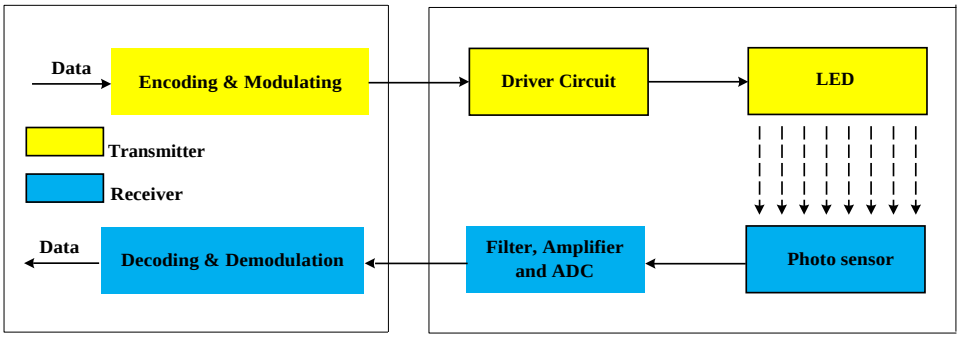

Figure 4. The VLC Overall system structure.

4.2. VLC Transmitter Design

VLC systems transmitter section consist of a set of keypad character keys, the microcontroller section, the light emitting diode illumination section, information modulation section, the power section and etc. The microcontroller part of the system transmitter module uses the ATmega328P chip (Figure 5) shows the VLC transmitter block diagram and (Figure 6) shows the VLC transmitter prototype. When any button is pressed, the numbers of digits of the characters is input into the transmitter circuit, and the number of characters in the circuit controls the operating of the blinking completion signal of the LED lamp by controlling the on and off status.

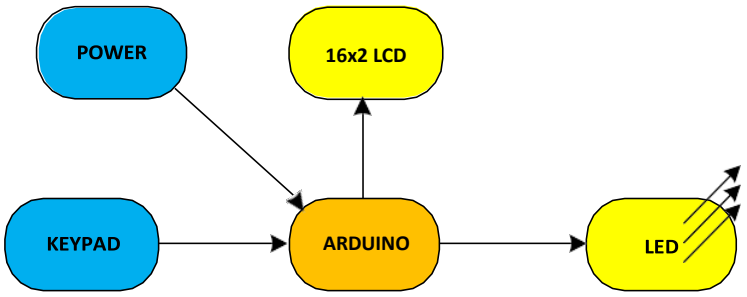

Figure 5. The VLC transmitter block diagram.

When the (A) button is pressed, the system recognizes the number of characters (A) and transmits the number (01100001B) of (A) to the circuit when the output is (0) the LED illumination is turned on. And the LED illumination is turned off when the output (1) is output, that is, the high-frequency flicker formed by the LED light is used to complete the information transmission.

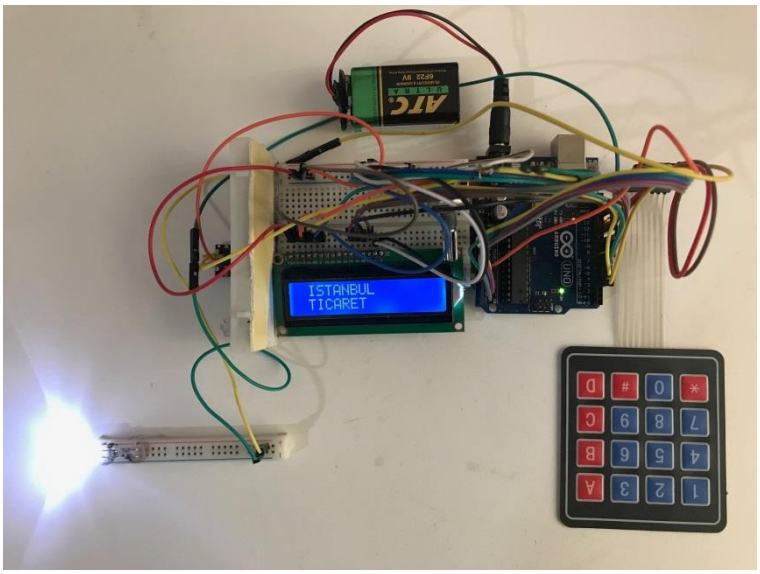

Figure 6. The VLC transmitter prototype.

The lighting specification of the transmitting module determines the range of the communication distance of the visible light communication system. The power supply part provides the required voltage or current to the LED lighting and transmitting circuit by using the USB interface or 9V batterers. When the LED lamp size is determined, the magnitude of the power supply voltage determines the distance that the LED illumination reaches and the system signal can travel whenever the voltage in the circuit is kept stable the maximum voltage is selected as much as possible to achieve a large transmission distance. Therefore the illumination lamp selected in the transmitter section is composed of an LED lamp which has high brightness, low energy consumption, small volume, and stable brightness.(Figure 7) schematic of the VLC transmitter Prototype.

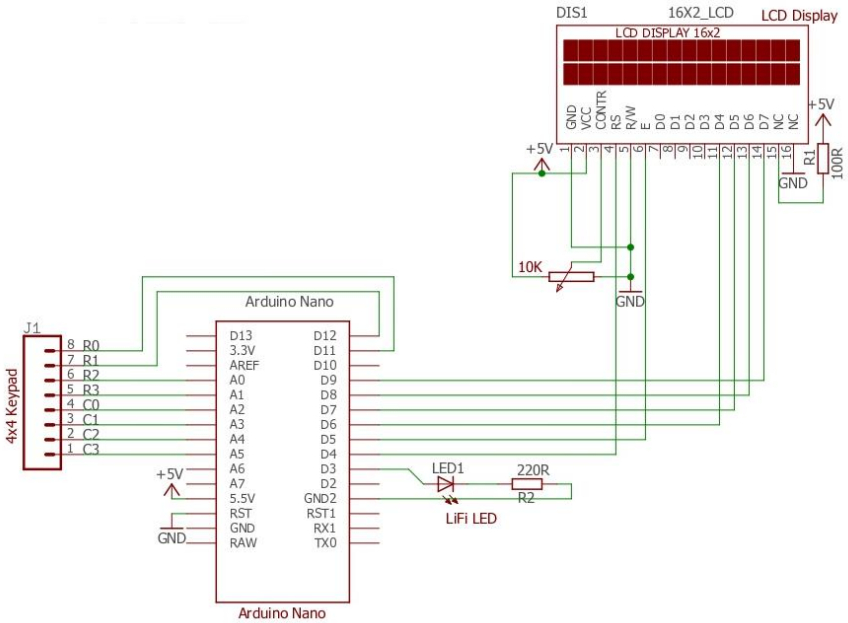

Figure 7. Schematic of the VLC transmitter prototype.

4.3. VLC Receiver Design

VLC systems receiver section consists of the microcontroller section, the photo detector section, information demodulation section, the power section and etc. The microcontroller part of the system receiver section uses the ATmega328P chip. The photodiode converts the light flickering signal sent from the transmitting section into an electrical signal when the light is high level the output is (1) and the output is (0) when the light is low level that is how the photodiode output is received the binary number of the information is obtained by decoding in order to obtain the original transmission information and the original character is displayed on the LCD screen through

the circuit. When the power is turned on the display screen lights up and begins to prepare to receive information signal. The information display of the system receiver part is composed of one liquid crystal display screen (16x2 LCD) and a photodiode (Figure 8) shows the VLC receiver block diagram.

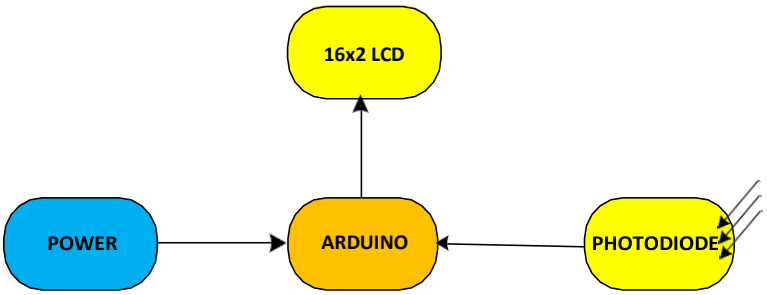

Figure 8. The VLC receiver block diagram.

The program of the liquid crystal display screen initializes the liquid crystal display function at the beginning so that part of the content is displayed when the power is turned on and can be displayed after the information is transmitted and corresponds to the previous display. The (VO) pin of the liquid crystal display is connected to the adjustment resistor to adjust the display contrast appropriately to achieve a better display effect. (Figure 9) shows the VLC receiver prototype.

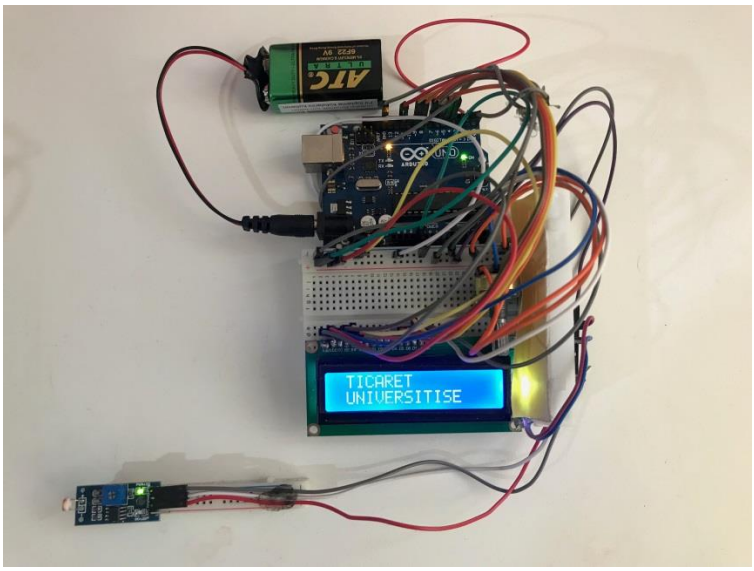

Figure 9. The VLC receiver prototype.

Light dependent resistor (LDR) with an adjustable indication part also used In order to determine whether the communication area has the influence of other light sources on the receiver section the part is composed of a regulator, a photodiode and an indicator lamp the sensitivity can be adjusted so that the external ambient light does not interfere with the device or with the received signal then adjust the regulator so that the indicator light does not turn on then the receiver should operate normally the information is transmitted between the transmitter and the receiver and the transmitted information can be seen on the display screen. (Figure 10) shows the schematic of the VLC receiver Prototype.

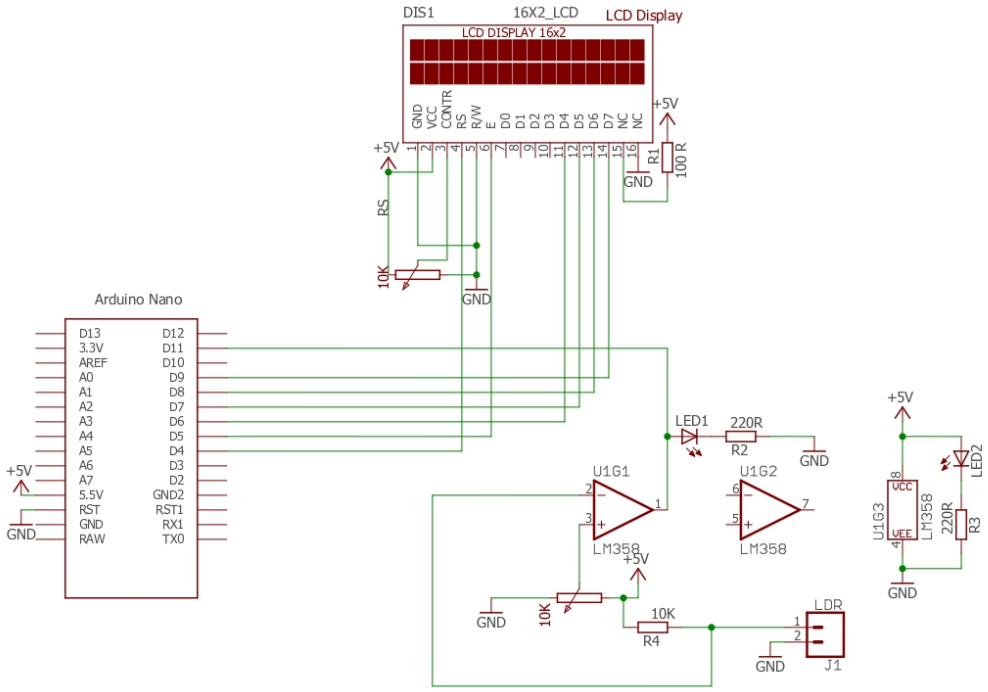

Figure 10. The schematic of the VLC receiver prototype.

4.4. System Debugging Detection

In the construction of the entire VLC system the connection between the transmitter and receiver is the most important so it is necessary to debug the hardware before the entire system is operated in order to better verify and understand the functions of the system and to prepare for a better upgrade of the system.

4.4.1. VLC Hardware Debugging Detection

Since the indoor short range visible light communication design is completed the line of sight between the transmitter and the receiver is not too long and it is kept within 1.5 meters in the experimental tests moreover since it is an indoor visible light communication transceiver other light sources will affect it so it is used only in an environment away from high intensity light sources.

After turning on the receiver board the display will turn on, and the indicator will flash and then turns off indicating that the receiving module is running normally. And after the transmitter power is turned on the LED lamp isilluminated and the receiver indicator is illuminated, indicating that the transmission channel is operating normally. When a character key is pressed the LED light starts flickering the transmitted character appears on the display at the receivers display

5. RESULTS AND EXPERIMENTAL SETUP

In the test the whole system works well the LED lamp of the transmitter and the photodiode of the receiver the information can be transmitted relatively quickly even when the angle between the LED and photodiode reaches more than 60 degrees. The communication distance can be reaches 1 meter. The more serious problem at larger distances is the distortion and interference of external ambient light especially in indoors. (Figure 12) shows the designed transceiver and (Figure 11) below shows the bit error ratio (BER) curves calculated by matlab.

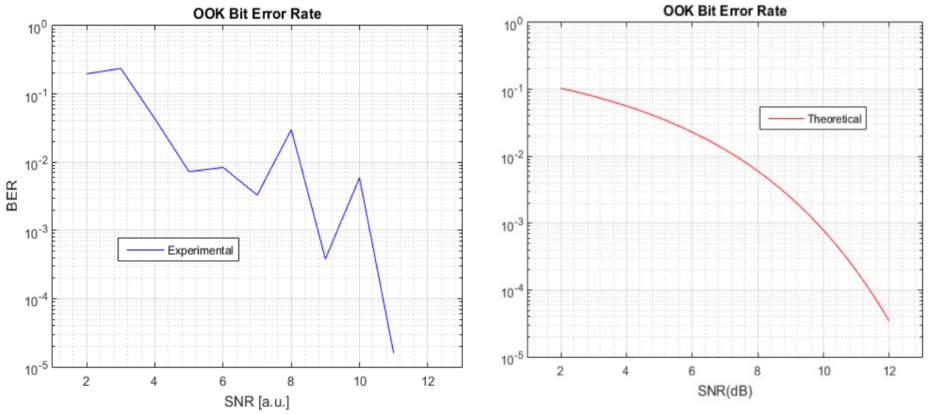

Figure 11. The experimental and theoretical BER.

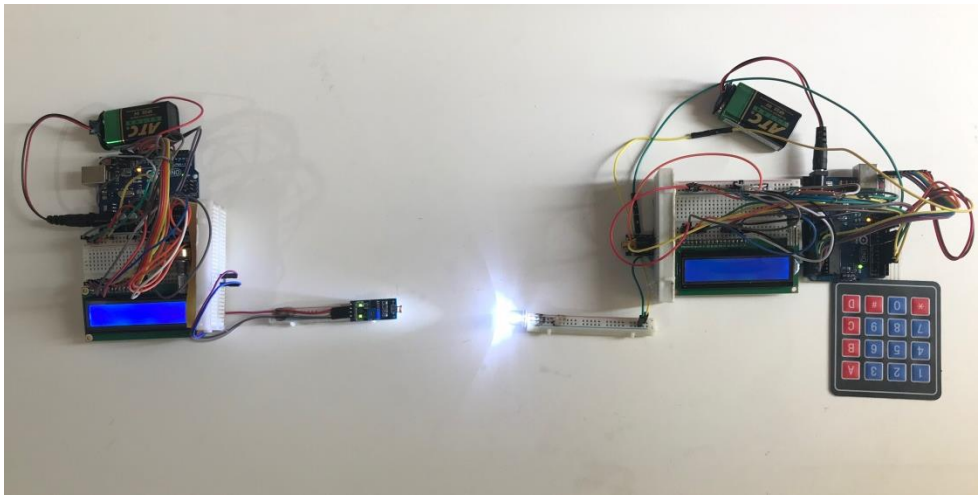

Figure 12. The designed transceiver.

6. CONCLUSION

In this project a VLC communication system transmitter and receiver is designed. Two ATmega328P chips are used as a microcontroller of the transmitting and receiving sections of the system the light emitting diode's white light is used and represented as the carrier to realize the transmission of character information. The signal transmission is relatively stable. The designed VLC system test results showed that the dynamic limit of visible light brightness is variable the utility is high the operation principle is simple the anti-interference ability is good the LED achieves its goal in illumination and the signal transmission at the same time. The shortcoming is that the transmission distance is short. VLC communication has many difficulties to achieve long distances it is necessary to improve the modulation bandwidth technology and further optimization of signal coding techniques.

KAYNAKLAR

Komine, T., and Nakagawa, M. (2004). Fundamental analysis for visible light communication system using LED lights. IEEE Transactions on Consumer Electronics, Vol. 50, No. 1, 100-107.

Komine, T., and Nakagawa, M. (2003). Integrated System of White LED Visible Light Communication and Power-Line Communication, IEEE Transactions on Consumer Electronics, Vol. 49, No. 1, 71-79.

Boubezari, R., Le, H., Ghassemlooy, Z., and Bouridane, A. (2016). Smartphone Camera Based Visible Light Communication. Journal of Light wave Technology, Vol 34, No. 17, 4121 – 4127.

Moon, H., and Jung, S. (2012). Multi coded variable PPM for high data rate visible light communications, Optical Society of Korea, Vol. 16, No. 2, 107-114.

Uysal, M. (2014). Survey on free space optical communication. Communication theory perspective in IEEE Communication Surveys, Vol. 16, No. 8, 2231-2258.

Yoo, J., Jang, J., Kim, H., and Jung, S. (2016). Demonstrations of vehicular visible light communication. International Journal of Automotive Technology, Vol. 17, No. 2, 347-352.

Sewaiwar, A., Tiwari, S., and Chung, Y. (2017). VLC practical demonstrations. Visible light communication networks, Vol. 23, No. 10, 13015–13024.

Chun, H., Rajbhandari, S., Faulkner, G., Tsonev, D., Xie, E., Mckendry, D., Dawson, D., Obrien, C., and Haas, H., (2016). LED Based Wavelength Division Multiplexed 10 GB/s visible Light Communications. Journal of Light wave Technology, Vol. 34, No. 13, 3047–3052.

Haigh, P., Bausi, F., Hoa, L., Popoola, W., Burton, A., and Cacialli, F. (2015). Wavelength Multiplexed Polymer LEDs towards 55 Mb/s Organic Visible Light Communications. Selected Areas in Communications. IEEE Journal , Vol. 33, No. 9, 1819-1828.

Dimitrov, S., and Haas, H. (2015). Principles of LED Light Communications towards Networked Li-Fi, Cambridge University Press, United Kingdom, TJ International Ltd.

Ziad, T., Al Dahan, S., Al Dabagh, Y., and Asmahan, A. (2013). Design and Implementation of Under Water Optical Communication System. International Journal of Application or Innovation in Engineering and Management, Vol. 2, No 6, 104 – 109.

IEEE 802.15WPANTM15.7 Amendment. Optical Camera Communications Study Group (SG 7a). Retrieved from http://www.ieee802.org/15/pub/SG7a.html

Arduino IDE Software https://www.arduino.cc/

Autodesk Circuits. Autodesk https://circuits.io

Matlab Software https://www.mathworks.com/products/matlab.html

Optiwave Photonic Software https://optiwave.com/