Design and performance analysis of visible light communication system with noise mitigation

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CERTIFICATE

It is certified that the dissertation report entitled **"Design and performance analysis of visible light communication system with noise mitigation"** has been successfully completed and submitted by **Vikram Maurya** of Second year, IV semester in partial fulfillment of degree of **Master of Technology** in **Electronics and Communication** during the academic year **2017-2019** to the best of my knowledge and belief that this work has not been submitted elsewhere for the award of any other degree.

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DECLARATION

I, **Vikram Maurya**, declare that this Dissertation titled as **”Design and performance analysis of visible light communication system with noise mitigation”** and the work presented in it is my own and that, to the best of my knowledge and belief.

I confirm that major portion of the report except the refereed works, contains no material previously published nor present a material which to be substantial extent has been accepted or the award of any other degree by university or other institute of higher learning. Wherever I used data (Theories, results) from other sources, credit has been made to that source by citing them (to the best of my knowledge). Due care has been taken in writing this thesis, errors and omissions are regretted.

Date: **Vikram Maurya**

”Dedicated to my family” for their sacrifices, endless support,

encouragement, guidance

and love

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List of Abbreviation

• VLC	Visible Light Communication
• FSO	Free Space Optics
• OWC	Optical Wireless Communication
• BER	Bit Error Rate
• QF	Quality Factor
• LED	Light Emitting Diode
• LOS	Line Of Sight
• RF	Radio Frequency
• IR	Infrared
• NRZ	Non Return to Zero
• OOK	On Off Keying
• APD	Avalanche Photo Diode
• PIN	Positive Intrinsic Negative
• RZ	Return to Zero

Abstract

An NRZ-OOK visible light communication (VLC) system is constructed and simulated, with and without noise using a LED of wavelength 450 nm as a optical source and a Photo-detector as a receiver. Here PIN photo-diode is used as a photo-detector. Another white light source having power of 6W which affects the performance and quality of the visible light communication system.

For this noise rectangle optical filter is used before the photo-diode at receiver side, it reduces the ambient light noise, improves the BER, Q-factor and clear eye diagram is achieved. This proposed design of VLC helps to analyze the effect of distance on eye height, electrical power, Max. Q-factor and Min. BER. This thesis also discuss the effect of LED wavelengths on Q-factor and eye height.

This simulation is done on optisystem-7 software. In this thesis, performance analysis of this system is achieved by using the values of Q-factor and BER also check its eye diagram for better communication and also separate two bit sequences from two bit generator, at receiver side when they are using same free space optics (FSO) channel at same time by using rectangular optical filter and polarizer.

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Chapter *1*

Introduction

The concept of using light waves as a communication medium was introduced in the year 1880 by Alexander Graham Bell with the invention of photo phone. It is a tool that is employed to transmit a voice signal on a beam of sunshine. Bell targeted daylight with a plane mirror then talked into a mechanism that vibrated the plane mirror. The moving beam was accumulate by the receiver at the receiving finish so decoded into the voice signal. In present identical procedure because the phone did with electrical signals. However Bell couldn't generate or apply a helpful carrier frequency, nor was he able to transmit the sunshine beams from purpose to point. Obstacles in nature like fog, dust, mud and rain which could interfere with the photo phone made Bell stop any more analysis into his invention. With invention of light emitting diode (LED), the thought of exploitation light rays as a communication medium has started once again because LED is best for optical source and photo diode is used as the detector.
The first visible light communication (VLC) started at Nakagawa laboratory in Keio University, Japan in 2003. This was followed by a growing analysis and development interest at a worldwide scale. In recent time, there are nice advancements within the producing method attributable to lucent potency, thermal style, brightness and management associated with the light emitting diode that makes it best suited for providing each illumination and communication. After these two experiments lots of scientist and researchers show their attention on this field and achieved many results which is helpful for this communication.

1.1 Visible light communication

Visible light communication is a short range optical wireless communication (OWC) technology which is acknowledged as the future in green lighting as it acts as a twin role for illumination and data/electronics communication. VLC uses the spectrum of visible light from 380 nm to 780 nm [1]. The name itself indicate that it is a wireless communication that uses light for transmitting data from one point to another for different propose. That means an optical source and a photo-detector is major components for this visible light communication [1]. The simple block diagram of VLC uses white LEDs because the optical supply, free space channel because the medium and exposure detector at the receiver. VLC is basically a communication technology that uses the visible light supply as a sign transmitter, transmission medium (according to us) and also the acceptable photo diode as a sign receiving part. Free space channel is advantageous over the conventional fiber optic cable as there is no requirement for cable, the installation cost is less, faster transmission and no RF interference [26]. This made visible-light communication to be used at hospitals and space stations. Security, simple implementation procedures and license free band characteristics also increase the usage of VLC for different applications. Figure 1.1 shows the VLC that how can we use this technology in our daily life applications [23].

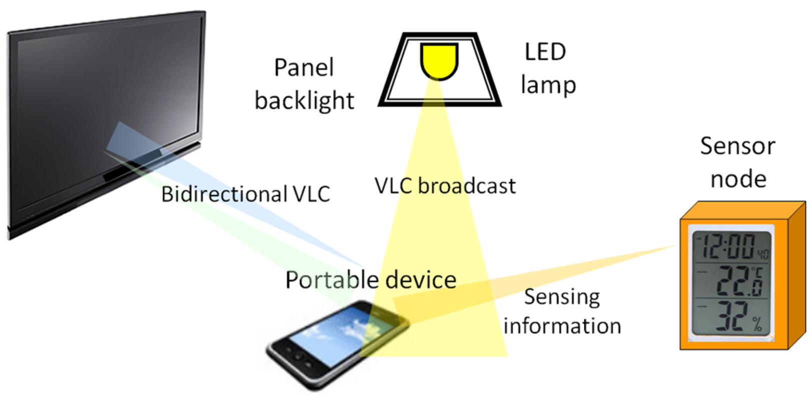


Figure 1.1: visible light communication [23]

1.2 Visible light spectrum

VLC uses only visible spectrum in whole electromagnetic spectrum, that is named visible light spectrum. All electromagnetic radiation is light, however we are able to only see a tiny low portion of this radiation—this part is called visible light. The visible light spectrum is the section of the electromagnetic spectrum that is visible to the naked human eye. Visible light takes place between infrared and ultraviolet in EM spectrum. We know the relation λ = c/f between frequency and wavelength, where c is speed of light. This relation shows that wavelengths and frequencies are inversely proportional to each other.

It has frequencies of about 4.3 $\times$ 10^{14} Hz to 7.5 $\times$ 10^{14} Hz and wavelengths of about 750 nanometer to 380 nanometer. Figure 1.2 shows all the electromagnetic spectrum starting from radio waves to gamma rays and in between infrared and ultraviolet their is visible light spectrum [28].

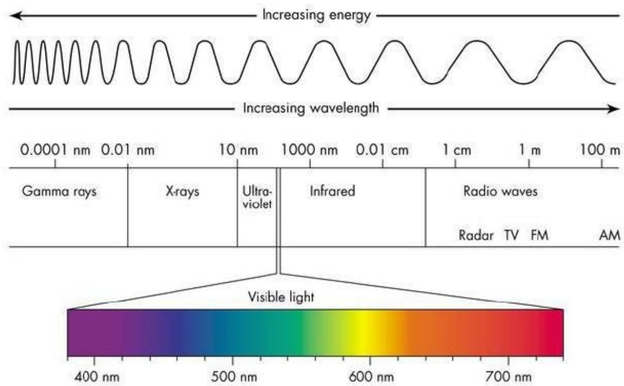


Figure 1.2: visible light spectrum [28]

1.3 characteristics of VLC

VLC have many characteristics because of light which makes it more comfortable in the field of communication. Light have a character of reflection, refraction, polarization and many more. Some of the important characteristics of VLC are as follows which is very much helpful for making this communication better, safe and efficient compare to the other:

1.3.1 Spectrum availability

VLC uses visible light spectrum, that is 10,000 time wider than established communication. The frequency band for visible light is 4.3 $\times$ 10^{14} Hz to 7.5 $\times$ 10^{14} Hz and for RF it is 3 $\times$ 10^{9} Hz to 300 $\times$ 10^{9} Hz . Thus VLC is the best answer to fill the gap between user demand and network capability. It provide large network capacity to user.

1.3.2 Safety

VLC uses light waves as a carrier. Light rays is that the supply of life. Hence, there has no health risk. We have to take care about the power of the light sources. In RF communication it generates higher frequencies waves that is creating problem for human and mainly dangerous for birds. So VLC does not cause health problem. High power LASER light is harmful for human eyes.

1.3.3 Efficiency

VLC provides economical manner of communication because of diode that need negligible power and fewer quality. It is cheap as a result of the employment of already offered visible light sources. We just need a modulation technique after that using the available free light we can do the communication process. We also know RF communication is very costly and its system is complex. Installation is also difficult in RF communication. So in VLC we can either use sun light which is free or we can use LED which is not so costly and if light have proper power to reach at the photo diode then efficiency of the VLC is enough for communication.

1.3.4 Unlicensed spectrum

VLC has no licensing issue because VLC uses visible light spectrum which is free in environment. Hence, it has no licensing issues and also light propagate in Free space channel which is also free. So in the case of VLC there is no licensing problem.

1.3.5 Security

VLC is very much secure because of line of sight communication and in VLC we can encode the transmitted data at sender side and at the receiver side we easily decode our data. By using polarizer at both the side we easily secure our data or signal. LOS communication provide a straight path to signal so there is less chance that the signal gets distorted.

1.3.6 High data rates

VLC acquires high data rate from optical communication because light travels in free space very fastly. If there is no any obstacle between source and destination then light travels freely and then rate of data transferring is more.

1.3.7 No Electromagnetic Interference

This communication uses visible lights so it has no electromagnetic interference.

1.4 Problem formulation

VLC is a new research and developing area in wireless communication technology. There are many important parameters that must be considered while implementing a VLC system. Some of the main parameters are, high data rate, optical source(LED) bandwidth, distance between source and destination, line of sight communication and photo-diode responsivity. These parameters play an important role when designing a VLC system. Types of optical source, types of photo-diode and types of filter which we are using for designing of VLC system also effect the communication process. Execution of the VLC system is depends on these parameters. The main problems in the implementation of an improved data rate VLC system are the range and cost of the system. If we increase the range of the communication channel then data rate and performance will decreases [19]. For high data rate VLC the transmitter and receiver must be compatible. Designing a high data rate transmitter and receiver is very complex and expensive. This project proposes simulation model of high data rate VLC system and evaluation of the relationship between the data rate, delay spread, signal distortion, BER performance and also check its performance by using eye diagram also find some way for mitigating the noise and differentiating two or more signal at receiver side.

1.5 Problem Identification

VLC have many characteristics which makes it important in many applications but VLC remains within the early stage that there are several severe issues or limitations required to be resolved because it is a new research and developing ares. Some of the problems are as follows-

1.5.1 Line Of Sight (LOS)

LOS may be a definite advantage as a result of the signal are going to be stronger as well as secure and VLC required line of sight communication. In LOS communication the sender and the receiver which receives the light are in same line. If the sender and receiver of the VLC system are not in same line then there are possibilities that communication may be done but the quality, efficiency and performance of the VLC system is definitely degraded [20]. So in VLC line of sight is important. This characteristic can be also considered as a disadvantage of VLC.

1.5.2 High data rate

This is the common problem or challenge in any type of communication because every communication system is designed for a fixed or some limited range and if we want to increase the range of the communication system then we have to change some parameters and some devices. If a system is designed to communicate for some range and without changing any parameters if we change its range then performance of the VLC system is degraded.
In VLC there is some basic parameters like optical source power and LOS which takes major role for limiting the data rate value.

1.5.3 Duplex Transmission

There are three main types of communications: Simplex, Half duplex and Full duplex. Duplex communication is a problem in case of visible light communication because the side which works as a transmitter is always transmit data, not able to receiving data and the side which works as a receiver is always receiving data, not able to transmit the data. So duplex transmission is a limitation for VLC system.
Mainly VLC is useful for broadcasting the information from one place to another. For two way communication in VLC we can use transmitter as well as receiver in both the side.

1.5.4 Interference from sunlight

The problem of interfering from sunlight is very common in VLC. In this communication, this problem is more critical because the ambient light noise could be very stronger than source light, so the resulting signal to noise ratio is low [2]. It is comparatively easy to eliminate the overwhelming majority of interference from sunlight and artificial sources using rectangle optical filter [27]. After the PIN photo-diode, low pass bessel filter is present to ensure remaining interference is negligible.

1.5.5 Range

Range also effect the performence of the VLC system because after increasing the length of the medium, the required power of the LED gets reduced at the receiver side by which the efficiency and the quality of the communication gets degraded. After increasing the length of the medium their is a possibility that noise may be added and for that case we have to add some circuit in this VLC system to mitigate this noise.

1.6 VLC vs RF communication

VLC stands for Visible Light Communication and RF stands for Radio Frequency. Both VLC and RF communication technologies are used for wide variety of applications for wireless communication. VLC uses light as medium for communication where as RF uses Electromagnetic waves. Basic comparison between VLC communication and RF communication are as follows:
1- EM sources is not able to affect the VLC where RF communication is affected with the EM sources.
2- Less Power utilization in visible light communication as compared to RF communication.
3- VLC is a power efficient system but RF is power faulty system.
4- Bandwidth is high in VLC and low in RF.
5- VLC provides secured communication because of LOS and RF does not provide secured communication.
6- In VLC based wireless communication there is no health risks involved but in the case of RF communication high power is used for transmission so it is harmful for health.
7- Installation is easier in VLC system compared to the RF communication.
8- Underwater communication is easy in VLC as compared to the RF communication.

1.7 VLC vs IR communication

In VLC we can easily increase the data rate by changing some parameters without any health issue but in the case of IR communication the data rates can not be increased beyond a prescribed level as it poses serious threat to human eye so in IR communication the date rate is limited.

1.8 Application of VLC

VLC is in early stage and a very fast developing research field but at present there are so many field which uses this technology and in future their are some important field in which VLC play a very important role. some of the major applications are as follows:-

1.8.1 Aviation

All radio frequency functioning gadget or device is not allowed in traveler aircraft. So in this case light rays will perform a twin operation lighting as well as data transferring. Here LED can play important role like lighting as well as communication.

1.8.2 Vehicle transportation

All vehicles have back and front LED lights with different power and wavelengths and traffic light also have light rays, with different color. These lights can act as a light source and using this we can transmit the information [13]. Just use some extra receivers for receiving and displaying the informations. By using this technique accidental cause may reduced. Traffic control also becomes easier. Figure 1.3 shown how VLC is helpful for controlling the traffic and reduces the accidental cause [24].

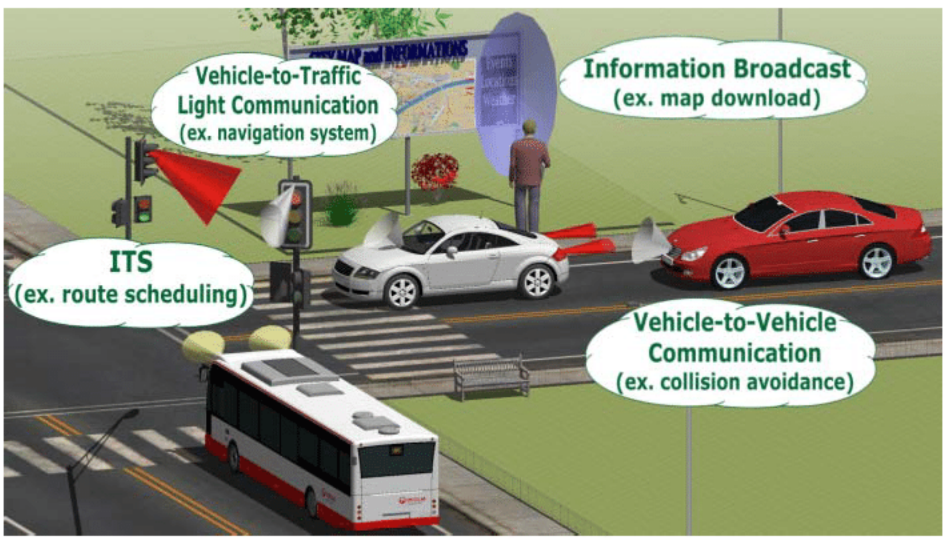


Figure 1.3: Use of VLC in traffic controlling

1.8.3 Broadcasting of the information

By using VLC technique we can easily transmit data form one point to another and it is safe, secure and fast. But the only problem is the source and the receiver must be in line because VLC needed line of sight communication. In VLC there are so many modulation technique so according to our data we choose appropriate modulation technique for modulating the signal. We can transmit bit sequence data, voice data, video data etc. with the help of this VLC system.

1.8.4 Underwater communication

Underwater communication is very easy when we are using VLC. Underwater RF communication is extremely difficult because installation is very difficult and costly. That's why VLC is best for underwater communication [17]. In underwater visible light communication firstly we have to take care about which type of the water it is because quality of the water decides the attenuation between transmitter and receiver and this will effects the whole communication process. Like pure sea water and clean ocean these are two water types and both have different different attenuation value so performance of the communication in it are also different [8].

1.9 Problem Statement and Objectives

The objective of this project is to design and analyze the VLC systems to investigate the possibilities of improvising the performance of the system in noisy environment [5] [11]. Also check some parameters which effect the performance of this VLC system also by using rectangular filter and polarizer try to differentiate two or more signal or data which are merge in the medium at the time of transmitting [7]. The purpose of this study is to analyze the main parameters in visible light communication that how these parameters changes the value of quality factor. Using the optisystem simulation tool it is easy to design and in optisystem it is simple to check VLC performance by using BER and Q-factor [1] [4]. With the help of eye diagram analyzer in optisystem achieving the eye pattern and find the distortion in the communication process.

1.10 Limitations

The proposed basic VLC system only can be used in indoor environment means environment where no other lights are present. The system cannot be used outdoor since the distortion from sunlight is very high because sunlight is like a noise for this visible light communication so we have to take care about it [26]. But in case of outdoor environment we can use this VLC system with some optical filter. When distance of the channel is increases, the data loss is high because more distance more noise will added and less power will reach at the receiver side. Another limitation is the LOS condition. The transmitter and the receiver of visible-light communication must be in line condition, otherwise data transmission is not possible. High data rate is always a limitation for any communication system so here also when for a system data rate increase then we have to change some parameters value for better communication. The complexity of the system design increase when we add some other devices for mitigating the noise which add with signal at the time of transmission. Noise with different frequency with respect to main signal's frequency can be easily removed with the help of rectangular filter but the noise whose frequency is same as signal frequency will not be remove by using rectangular filter so it is a limitation for this system. Another limitations is we can not increase its data rate beyond the designed VLC system limits.

Chapter *2*

Literature survey and Review

Today, many researchers are working on the development of LED lighting and VLC systems. An LED lighting system can achieve reduced power consumption and has a better life span compared to other illumination systems. That's why in VLC system most of the time LED will be used and most of the writer writing on LED in the field of VLC. This literature review is conducted to understand the various aspects of visible light communication and to develop a VLC system model for analysis and checks its performance. In this literature review, there are some papers which describe how some optical parameters effects the performance of the VLC system and how we can improve communication quality. This literature review involves understanding the fundamental concepts of visible-light communication, applications, performance parameters, VLC system modal and challenges faced by VLC. For the literature review 8 papers related to visible-light communication were considered.

K.Sindhubala and B.Vijayalakshmi designed and simulated an NRZ OOK visible light communication system in 2015. The title of this paper is Design and performance analysis of Visible Light Communication system through simulation. So in this study a simple visible light communication system is designed and here non return to zero on off keying modulation is used. Also introduce Ambient light noise source, in opti system white LED is act like a noise source and so for this paper this is used as a noise. After adding noise in the signal performance and quality of the VLC system is degraded. At the receiver side in this paper they use rectangular filter for removing the noise but this is only helpful in the case of different frequency. In this paper, VLC system have a optical source LED whose wavelength is 450nm and a photo detector at the receiver side for detecting transmitted signal. For removing the noise at the receiver side they are using rectangular optical filter after the channel and before PIN photo-diode. In this system they use rectangular filter because the noise frequency and the optical source frequency are not same. This filter reduces the ambient noise, improve the quality factor and low bit error rate is achieved. In this analysis, performance of optical power to electrical power conversion, Min. BER value, Threshold value, eye height is achieved with respect to distance between the source and destination. This paper is helpful for designing the suitable VLC system for better communication also describe noise effect and how to remove noise by using rectangular filter. In this paper, they also observed some outputs like Oscilloscope visualizer output of the signal, spectrum of the rectangular optical filter using Optical Spectrum Analyzer etc [1] [5].

In 2004, T. Komine and M. Nakagawa describe the Fundamental analysis for visible-light communication system using LED lights. With the help of this paper it is fix that suitable optical source for the VLC system is LED because LED have many important characteristics which makes it perfect in this work. Here basic introduction of visible light communication system and also introduce advantage of LED and white LED as a source. The fundamental analysis on visible-light communication system using LED lights is studied. In this paper they discussed the optical lighting, optical transmission and designed an experimental set up. In VLC, optical lighting and optical transmission are the important requirements for the communication. This paper discusses the basic concepts of visible-light communication using LED. In the proposed system, these devices are used not only for illuminating rooms but also for an optical wireless communication system [2].
In this paper, they have done a study of VLC using LED lights. In this they present a set up for VLC transmission. So this paper is very helpful for designing my proposed VLC system by just modifying some circuit and parameters [2].

In this paper Le-Minh H, O'Brien D C, Faulkner G explained the typical basic configuration, and the performance available using simple modulation schemes for visible light communication in 2009. The topic of the paper is 100-Mb/s NRZ visible light communications using a post equalized white LED. In this paper it is described that different techniques can be used to improve the data rate and one of the techniques is the equalization process. In this paper they explained several approaches to offer data rates of 100 Mb/s and above.
In this paper, equalization is employed at the receiver to improve the data rate. In this work they also consider different parameters for improving data rates which are: Optical filtering, Transmitter equalization, Receiver equalization, Optical Multi-Input Multi-Output (MIMO) transmission. By analyzing these parameters they found how these are related to data rate and they concluded by reporting future challenges. They also discussed that by

using different techniques and combination of some system we easily increase the bit rate value but the only problem is system complexity is increases [3].

In year 2016, Sivanantharaja Avaninathan and S. Selvendran presented a paper on VLC in optisystem. In this paper, optisystem simulation tool is used for performance investigation of VLC System. So this paper is very helpful for designing the VLC system in optisystem and also check execution of the VLC system. So in this study author describe the VLC system in optisystem simulation tool and check its performance by measuring the value of Q-factor and bit rate. In this paper they investigated the indoor visible light communication using Optisystem simulation tool for a practically measured channel characteristics of a white LED. The performance of the visible light communication system is evaluated through Q-factor and BER values for various bit rate and link distance. In this paper VLC system can support 2 Gbps data rate up to 3 m of link distance with a Q factor of 5.76. White LED is used as a source for the communication, PIN photo detector as a receiver og the signal and the study is carried for NRZ-OOK and RZ-OOK modulation formats. The VLC system performance is also measured in the case of external atmospheric light influence. The designed system in this paper provides good Quality factor for the RZ-OOK signal compare to the NRZ-OOK [4].

In this paper H. Q. Nguyen, J. H. Choi, M. Kang, Z. Ghassemlooy, D. H. Kim, S. K. Lim and C. G. Lee presented a simulation program for indoor visible light communication environment based on MATLAB and Simulink in 2010. In this the positions of transmitter and the reflections at each wall is different. When LOS communication is not possible then we have to try to use reflection technique to transmit the signal from transmitter to receiver. In this communication environment, the light source LED is not only for lighting, but also like a communication purpose because LED light is able to carry data from one point to another. Using the simulation on software, author gets the received signal waveform considering the positions of the transmitters and the reflections on walls [6].

Multiple parallel sources are very common in optical communications. In 2018, Darko ivanovich, Samuel B. Powell try to check the activity of polarization division multiplexing, the separation of different parallel optical sources using the polarization technique through polarizer. Polarization is the unique property of the light which is very useful in lots of application. One of the major application is it is useful for separation of two or more optical signals. Lights from different sources passing through polarizer having different polarization angles. After polarizer these signals are very much same with each

other but they are different with their polarization angle [7].
In this paper, it is clearly describe that when we polarize an optical signal with some polarization angle then throughout the transmission its angle is same with that value and that value is unique for this signal in a particular VLC system. We also know a simple light rays have electric field as well as magnetic field and both are perpendicular to each other and after polarizer direction of the electric field changes. When light passes through the linear polarizer then the electric field oscillate in a single direction and when it passes through circular polarizer the electric field rotate at a constant rate in a plane where wave travels. This polarization technique they first investigate a 2-channel system with two filters, having 0° and 90° angles of polarization and using this they separate two signals which have same frequency.

In 2016, C. Wang, Hong-Yi Yu, Yi-J. Zhu designed a long distance VLC system in underwater using avalanche photo-diode. This study is helpful when we are working on underwater VLC system. They also describe two types of water one is Pure Seawater and another is clean ocean. This paper is very helpful for finding the value of attenuation for these waters because they explained and gives the value of Attenuation Coefficients for these two water types. These parameters are a,b and c and the unit is λ/m. By using the values of Attenuation Coefficients we can easily calculate the value of attenuation. The value of attenuation is important because we can use it for designing the underwater VLC system in opti-system also. This paper also explained when we use trans impedance amplifier(TIA) how this will increase the noise intensity because TIA adds thermal noise and signal will distorted. SPAD detector does not need a TIA. This paper clearly discussed about underwater VLC but their are so many works which are like a future work for this growing field [8].

Chapter *3*

Opti system simulation and design of VLC system

Visible light communication is very new research field so for that very few software is there which is compatible with VLC system and in that optisystem is very common and best simulation tool which is very compatible and reliable for observing the VLC performance. Changing the parameters values and observing VLC system performance is very simple in optisystem. For simulation and analysis of VLC system here I use Optisystem software of Optiwave Corporation. The designing of the VLC system is also very easy and easy to change the system according to our application. In practical experimental setup in labs, the modification of the system is very difficult so this is best way to analyze the VLC system.

3.1 Opti system

Optisystem is a simulator tool which provide a platform to design a system in a low cost and a very less time. Like a physical experimental set up, this software provide a proper field to set up the system and analyze [25]. It is very flexible software because you can easily change the values of inputs and find the outputs. This software is very useful because it is user friendly and you can easily check and analyses the performance of any system for different values. Optisystem have so many versions but in this project I am using optisystem-7 software. Figure 3.1 is a optisystem icon and it is helpful for downloading this software setup via internet.

In this software using the value of Q-factor, minimum BER and eye diagram we easily check if our communication is perfect or not and for that there are many component like BER analyzer, eye diagram analyzer etc. By using different value of bit rate, different channel length, different wavelengths we can easily check which value is best for this particular system. So this software is more reliable and user friendly.

Figure 3.1: Opti system software icon [25]

3.2 Basic block diagram of VLC system

The simple block diagram of VLC uses LEDs as the optical source, free space optics channel like a medium and Photo detector at the receiver. So in VLC system there is three major portion which is helpful to design a perfect, suitable, reliable and user friendly system for many applications. Figure 3.2 shows a basic block diagram of VLC system by using this block I further design the VLC system in Opti system. So overall fundamental

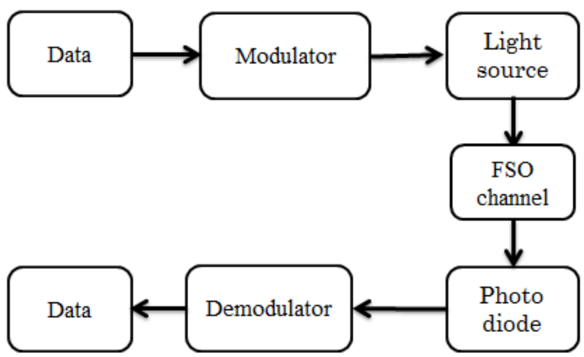


Figure 3.2: Block diagram of VLC system

entries in a VLC system are the transmitter (LEDs) as a source, receivers (photo detectors) as a destination, modulation (OOK) of data to optics, the optical communication channel or FSO medium and some analyzing tools for observing the outputs. Inside the transmitter and receiver their are several devices or components which is needed for making the VLC system better and useful.

3.2.1 VLC transmitter

There are so many possible light sources used for illumination as well as communication. However, Laser Diodes (LD) and Light Emitting Diode (LEDs) are the two most popular ones among these especially preferred for optical data communication. In VLC both illumination and communication are important. So at the time of choosing the transmitter we have to take care about these two purposes.

LASER and LED both can take part in VLC system but more common transmitter is LED [2]. The main difference between a LASER and a LED is that, the LASER is a coherent light source and while LED is an incoherent source. That is, in the LED structure photons are emitted spontaneously with different phases which is called incoherent radiation. The way in which LASER radiations radiates is called coherent because one photon is guided with the other one. We can also say that one photon simulates other one.

So VLC uses LED in the transmitter side. In VLC system when we are using LED we have to know its wavelength because wavelength decides which color for this LED have. In the place of optical source only LED is the best source which proves itself to do this job properly. Lots of researchers also done many work on LED just for encouraging to do work on VLC because VlC and LED dependent to each other.
There are many types of LED's are present and for each LED we can achieve different data rate. So it's up to our choice for choosing LED's for desirable data rates like:

- Phosphorous LED's - 40 Mbps
- RGB LED's - 100Mbps
- RC (resonant cavity) LED's - 500Mbps

Table 3.1 express the comparison betweem phosphorous LED and RGB LED [26]. Choose the light source according to our need.

Table 3.1: Comparison of Phosphorous LED's and RGB LED's

	Phosphor based-LEDs	**RGB LEDs**
Data rates	Up to 50 Mbps	Up to 100 Mbps
Price	Less expensive	More expensive
Modulation	Low complexity	Complex
Bandwidth	Low	High

In this VLC system there is bit sequence generator which generate some data, pulse generator and LED as a light source in the transmitter side. Commonly in optisystem two bit sequence generator are famous one is pseudo random bit sequence generator and another is user defined bit sequence generator [4] [20]. Figure 3.3 shows a block diagram of VLC transmitter.

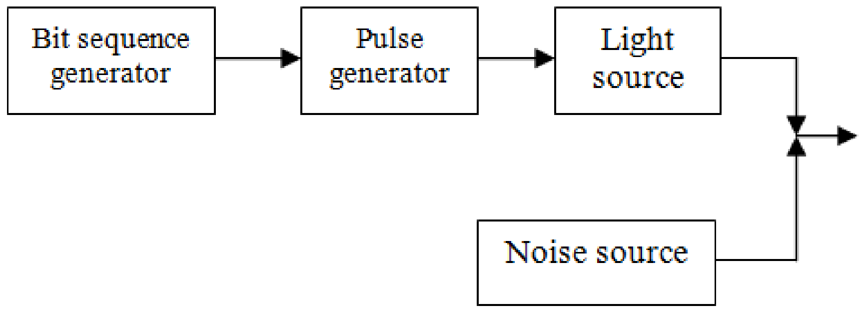


Figure 3.3: Block diagram of VLC transmitter side

3.2.2 VLC receiver

In the VLC receiver, the photo diode is generally used for reception of the VLC signals. The light is detected using a photo diode and then converted to photo current. Means here first light is detected as an optical source and then converted into a electrical signal. There are many types of photo diodes are present which are able to detect the light, receive it and convert into current. some of these are:-

- Silicon photodiode
- PIN photodiode
- Avalanche photodiode

All above are used for VLC but the most common one is PIN photo diode. The only advantage in avalanche photo diode is because of its higher gain than a PIN photo diode [5]. That's why in the case of underwater visible light communication we use avalanche photo diode as a receiver. But in my proposed VLC system I use PIN photo diode as a Photo detector because of its advantages over APDs like low cost, linear response characteristics over the wide ranges. The typical VLC receiver contains an amplification circuit, optical filter for removing noise and regenerators [1] [20] as shown in Figure 3.4. In these three, amplifier and optical filter are not a necessary component because it is useful when its required. If these is no any type of noise then there is no use of optical filters. Low pass filter is also helpful when there are some noise added whose frequency is high. Figure 3.4 shows a basic block diagram of VLC receiver in VLC system which is helpful for understanding the components used in this side.

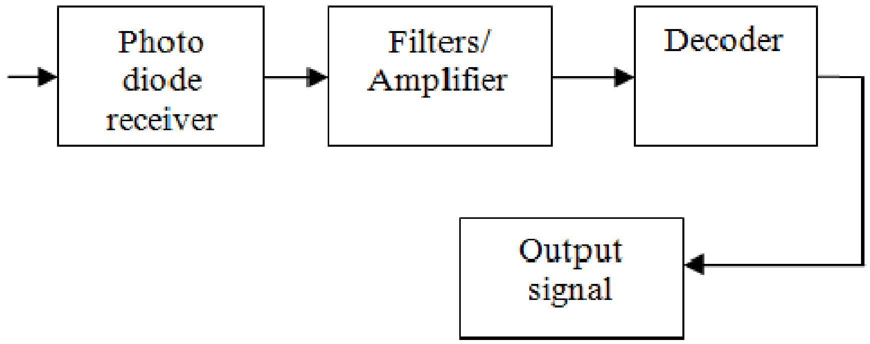


Figure 3.4: Block diagram of VLC receiver side

3.2.3 Channel for transmission

For channel after the transmitter part in this paper we use FSO channel with proper link distance and have some attenuator. This is the most important part in any communication system because the maximum parameters are effected with the length of the channel. In VLC here no any physical channel are present. Here the channel is free space that's why it is a wireless communication. Our source light with data and noise propagate in this area. In optisystem if we want to use different channel instead of free space we have to use OWC channel and set attenuation value according to the type of channel it is like pure water, sea water etc.

3.2.3.1 FSO

FSO full form is Free Space Optics also called as free space photonics, refers to the transmission of visible light through the free space or atmosphere to obtain broadband communication [10]. The working principle of FSO is slightly similar to the fiber optic transmission. The difference is that in free space transmission, the energy beam is collimated and sent through free space from the source to the end point, but in fiber optics communication energy beam is guided through an optical fiber.

The less possible attenuation present in FSO medium makes communication better for any situation. Line of sight (LOS) communication between the source and the destination, also effect the performance of the VLC system. If in some area there is no direct line of sight between source and destination, positioned mirrors can be used to reflect the energy.

FSO is one of the best solution for communication but there are limitations. At the time of rain, dust, fog, smog or snow can block the transmission path and break the communication also. So this channel part play a very important role in VLC system [20].

3.3 Simple structure of VLC system in opti system

VLC system contains three major blocks Transmitter, free space optics channel and receiver. So according to this we design a VLC system in optisystem and choose the parameters values according to desired output. Below structure in Fig. 3.5 is a simple VLC system in optisystem. This structure is very useful for further designing of the VLC system according to our need. We can easily modify this VLC system whenever modification needed.

In spite of transmitter, receiver and medium in this system we also use some analyzer

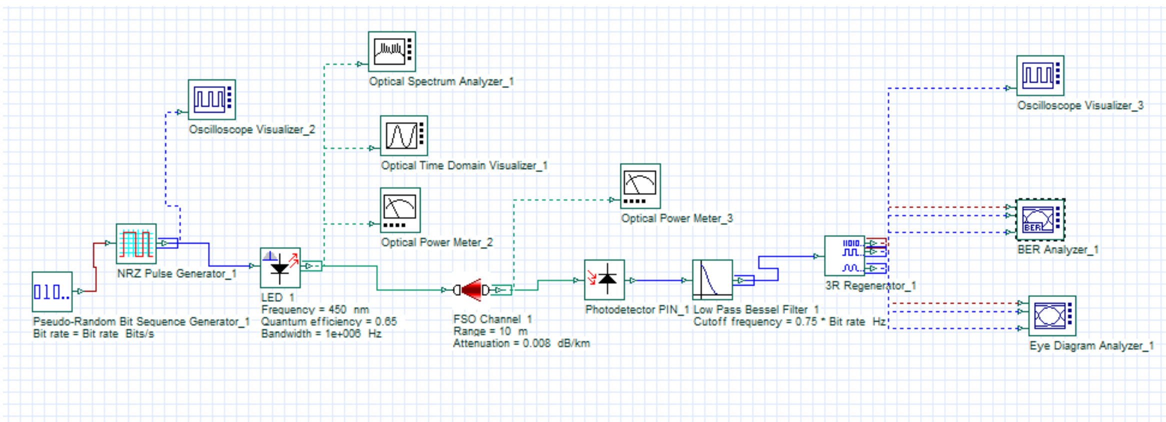


Figure 3.5: Basic diagram of VLC system in Opti-system

which helps for analyzing the VLC system and its performance because there are many types of output so we have to use different analyzer tools and in opti-system we can easily check any value and spectrum at any point like we use optical power meter at any point just for checking power value and using optical spectrum analyzer we obtain the spectrum of the light source [5] [25]. Opti-system gives freedom to change any parameter like link distance, wavelength of the LED, Bit rate, attenuation in medium, photo diode responsivity etc.

Here distance between transmitter and receiver is 10m and attenuation is 0.008 dB per km and we can change this value easily in optisystem. Other devices which are important in VLC system are as follows:

3.3.1 Input section tools

In the transmitter side it consists of a PRBS generator/UDBS generator, NRZ pulse generator, a LED operating at wavelength 450nm. First one is useful for generating the bit sequence, second one is useful for modulation and the most important third one is useful to transmit the modulated signal in optical form [25].

1- PRBS Generator:- A Pseudo random Binary/Bit Sequence (PRBS) is the most important sequences ever generated. In opti-system there are a component named PRBS generator which is helpful for generating these types of sequences. Basically in the VLC system or in any communication system some data or bit sequence is needed to transmit. As its name suggests, PRBS generator generate random binary sequences. It is not generated the bit sequence according to us.

Now if we want to generate the bit sequence as we want then in that case we have to use user defined bit sequence generator. Both are generating the bits but Pseudo random Binary Sequence generates random bits while user defined bit sequence generator generates user defined bit sequence. We can choose the bit rate for this bit sequence generator and change its value also.

2- UDBS generator:- User defined bit sequence generator is useful for generating the bits which user wants because it provide a input section where we put the binary bit sequence which we wants to insert in a system at input section. User defined and pseudo random both generates the bits but only different is pseudo random generates the random bits while user defined generates fix predefined bit sequence.

3- NRZ pulse generator:- The NRZ Generator pulse generator creates a sequence of non-return to zero pulses coded by an input digital signal. first PRBS is generates bit sequence but for VLC before transmitter their is pulse generator whether it is NRZ or RZ pulse generator. It convert bits into pulse form. The pulses in NRZ have more energy than a return-to-zero (RZ) code that is the reason we use NRZ in VLC system [5].

In VLC system modulation is different this is because in VLC we use light signal. Therefore, it is clear in mind that we cannot use analog modulation in the case of VLC. Mainly just put in mind that here LED takes place for modulation. LED is deciding when signal is transmitted and when not by using its on off property. That's why LED is helpful because it has fast switching property. In VLC we use OOK modulation. In OOK, the LEDs are turned off and on according to the bits in the stream.

3.3.2 analyzing tools

After designing the VLC system and put all the parameters, now the task is to analyze this system and check its performance based on bit rate value, link distance, wavelength and bandwidth of the LED, effect of the noise etc.. OptiSystem allows you to visualize simulation results in a lots of ways. So for this work in optisystem their are some tools which is helpful and user friendly for analyzing the VLC system. These are:

1- Eye diagram analyzer:- For analyzing the quality of the communication and for checking how much noise and distortion are present in VLC system we use eye diagram analyzer and find eye pattern. By using this pattern we easily obtain the following measurements:
1- Eye amplitude
2- Eye crossing amplitude
3- Eye height/ Eye opening - Measures additive noise in the signal
4- Eye signal-to-noise ratio
5- Jitter
6- Quality factor - quality og the communication
7- Eye closure - Measures intersymbol interference, additive noise

2- BER analyzer:- BER analyzer and eye diagram both can be connected in two ways in VLC system at receiver side. Both have three input ports by which they collect data and then give us output. so one way is all 3 input ports are directly connected with the regenerators at receiver side only and the other way is connecting top two input ports with PRBS generator and NRZ pulse generator, and then lower input port with regenerators at receiver side.
BER analyzer mainly gives the maximum Q-factor and minimum bit error rate value. Q-factor is helpful for quality of the communication and BER (Bit Error Rate) denotes how much error occurs after communication in the bit sequence. For better communication the value of Q-factor is greater than or equal to 6 and this Q-factor value is effected with many parameters in VLC system. Also the value of BER for better communication is 10^-9 or less than that. The meaning of this BER value means if we transmit 10^9 bit then only 1 bit have error.

3- Oscilloscope visualizer:- Oscilloscope visualizer is helpful to check the oscillation of the signal. For visualizing the signal we use this component. After NRZ pulse genera-

tor if we connect this component it will give the user defined bit sequence in the form of pulses also gives the sequences which PRBS generator generates.
Except these there are some other optical and electrical visualizers which are used in VLC system like optical power meter, electrical power meter, optical spectrum analyzer etc.

3- Optical power meter:- The name itself indicates that it is useful for measuring the value of power at any point. In optisystem there are two types of power meter: One is optical power meter and another is electrical power meter [5]. By using these two meters we can measure the value of power. Where there is optical signal use optical power meter and where electrical signal is present use electrical power meter for measuring the power value.

Chapter 4

Proposed work and Analysis of the model

In this chapter, I proposed my VLC system for analysis and for mitigating the noise as well as separation of two bit sequence or optical signal which transmitted in same medium by using polarization technique.

In chapter 3, Fig. 3.5 represent the basic visible light communication system without any noise. At the transmitting end it consists of a PRBS generator, NRZ pulse generator, a LED operating at wavelength 450nm and the transmitted signal is sent through the free space channel of distance 10 m and have some attenuation. The value of bit rate for this system is 10kbps and LED bandwidth is 1MHz. Also line of sight link is considered so that no obstructed path between the transmitter and receiver. Now at the receiving end photo diode is used to detect the signal and which converts optical signal from the channel into electrical signal. And finally there is low pass Bessel filter after the photo-diode having cut off frequency of 0.75 $\times$ bit rate Hz. After this, 3R regenerator is present which is helpful to prepare the signal for the analyzer to observe the bit error rate value and Q-factor value in BER analyzer and also see the eye diagram with the help of eye diagram analyzer.

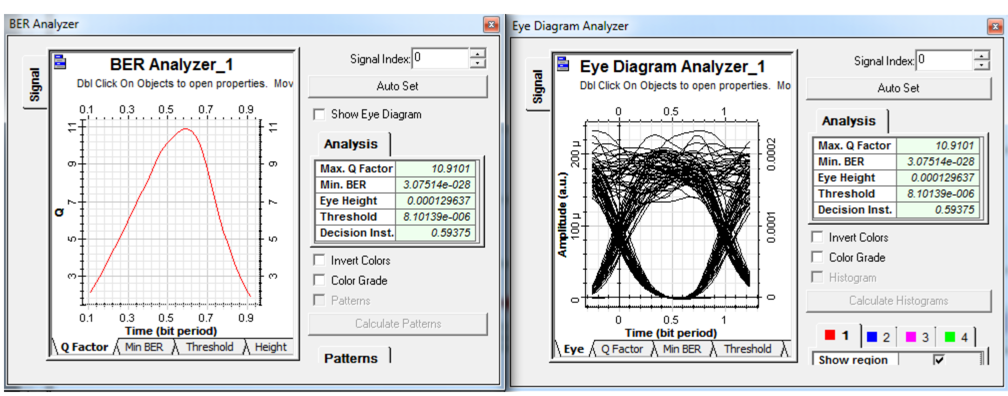


Figure 4.1: Q-factor, BER and eye pattern

Figure 4.1 represent the output of the BER analyzer and eye diagram analyzer. So the value of Q-factor for this VLC system is 10.9101 and the value of Min. BER is 3.07514e-028 is achieved and this given value is better for visible light communication. Also eye pattern is achieved with the help of eye diagram analyzer and near about better pattern achieved which shows that the disturbance and noise is less in this VLC system.
From the below output as shown in Fig. 4.2 it is analyzed that the bit sequence which is generated at the input end using PRBS generator was transmitted successfully and recored back using some receiving component in optisystem and bit sequences are displayed in output monitor of the oscilloscope visualizer.

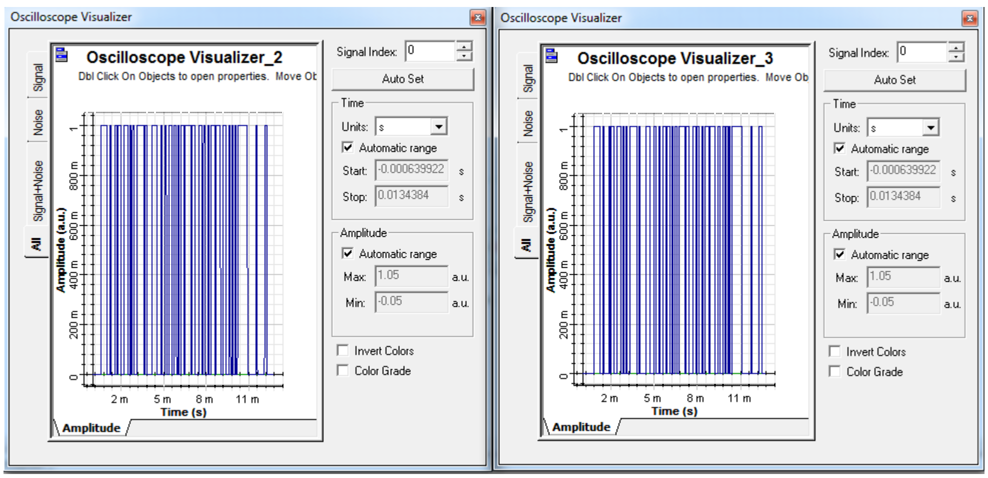


Figure 4.2: Input and Output bit sequence

4.1 Proposed VLC system 1

Now in this proposed work, with the help of above NRZ-OOK VLC system, visible light communication is done under the influence of noise by using rectangular optical filter noise reduction is achieved.
In this system also the transmitter section contains a PRBS generator working at 10 Kbit/Sec, NRZ pulse generator, LED emitting the lights at wavelength of 450 nanometer and have a modulation bandwidth of 1 MHz. These all parameters are according to us so if we want to change some data or want some other wavelength then we can easily set this parameters. Ambient light noise source(Fluorescent lamp driven by conventional ballast) act as a noise source and effect the performance of the VLC system. Thus, it is necessary to mitigate the noise generated by the ambient light so for that we use rectangular optical filter before the photo diode. This filter is a flat top filter of rectangular shape.

This optical filter is working like a pass band filter, and have pass band wavelength of 450 nm from the transmitted optical signal and stops other wavelengths which come from transmitter side. A low pass Bessel filter, after the photo diode is used to remove the other undesired frequency components of the transmitted signal. Below the table 4.1 represents the list of important optisystem components for the simulation of VLC system along with the value assigned to each component [1]:

Table 4.1: List of important opti system components used for the simulation of VLC systems with noise using NRZ-OOK modulation also value assigned to each parameter

Parameter	**Value**
Bit rate	10 kbps
Modulation	NRZ-OOK
Optical source(LED)	Frequency= 450nm : Bandwidth= 1MHz
Optical background noise	Frequency=50 Hz : Power=36W
Transmission Channel	Free space optics(FSO)
Distance	10 m
Rectangular optical filter	Wavelength:450 nm Bandwidth: 1 MHz
PIN photo-detector	Responsivity = 1 A/W
Low pass Bessel filter	cut off frequency= 0.75 times bit rate
Channel attenuation	0.008 db/km

By using these parameters I have designed the VLC system using NRZ OOK modulation under the influence of optical background noise in optisystem as shown in Fig. 4.3. In this optisystem I use all the input components and analyzing component which I mention earlier in chapter 3.

By analyzing this VLC system we observed that visible light communication is done under the influence of the noise and rectangular optical filter having same wavelength 450 nm as LED have, pass the wavelength of 450 nm from the transmitted optical signal and blocks other wavelengths. A better eye diagram is achieved which shows that less distortion is present in this visible light communication. With the help of optical power meter we can observed the value of power at any point in this VLC system. The optical power of source LED is 835.5 mW which added to the ambient light noise whose optical power 35.977 W. The NRZ-OOK input signal is modulated using LED. The transmitted signal with noise travel through the FSO channel with line of sight of distance 10m. The input signal and noise power after the 10m distance is measured as 8.33 mW. The transmitted signal then detected by the photo diode and changed into electrical signal. The electrical

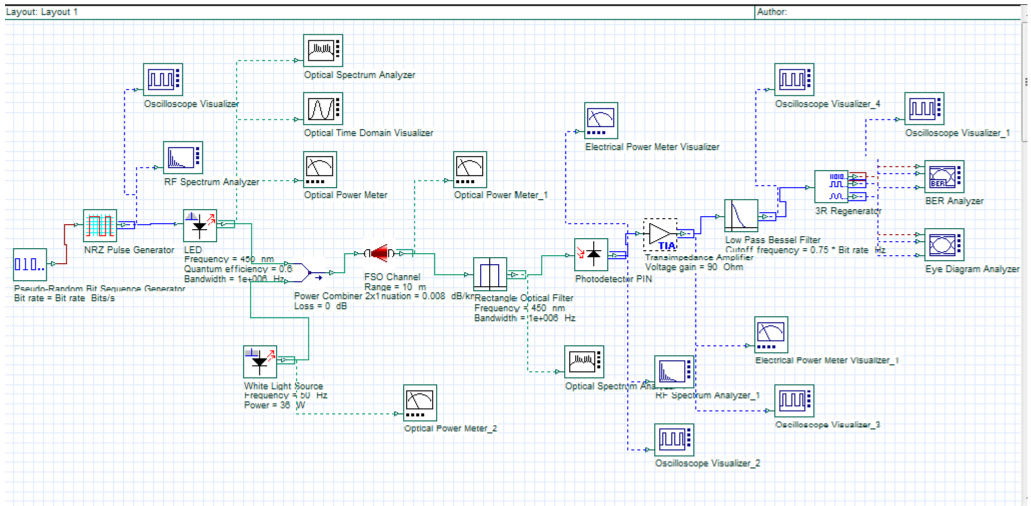


Figure 4.3: proposed VLC system with noise simulation set up using Optisystem

power after photo diode is 5.39×10^{-9} W. TIA(Trans Impedance Amplifier) is used to convert electrical current which comes from photo diode to voltage also increase the value of power. Power after TIA is 43.71×10^{-6} W.

More complicated system required more component in optisystem so that the value of power at any point and the value of eye height also changes. Distortion is easily observed with the value of eye height and seeing eye diagram.

Q-factor and BER value is observed with the help of BER analyzer. Value of bit error rate shows that the percentage of bits that have error with respect to the number of bits in receiving signals. Figure 4.4 shows the BER analyzer and eye diagram analyzer output. The value of Q-factor observed in this system is 9.14872 and the value of BER is 1.60191 $\times 10^{-20}$. The value of Q-factor without noise is greater in previous VLC system but in this system noise effect the performance of the VLC system but rectangular optical filter reduce its effect and help for better communication. Optical filter is helpful for reducing the noise effect but it can not able to remove the all the noise so the value of Q-factor which achieved earlier without the noise is higher than this value when the system is under the influence of noise.

Graphical method is a very easiest way and best way for understanding the relation and dependency between the two or more parameters. Here I am trying to express some relations between some outputs vs. distance.

Figure 4.5 shows the channel distance vs. electrical power after the photo-diode for 10 Kbps NRZ-OOK signal. Using the electrical power meter I observed all the electrical

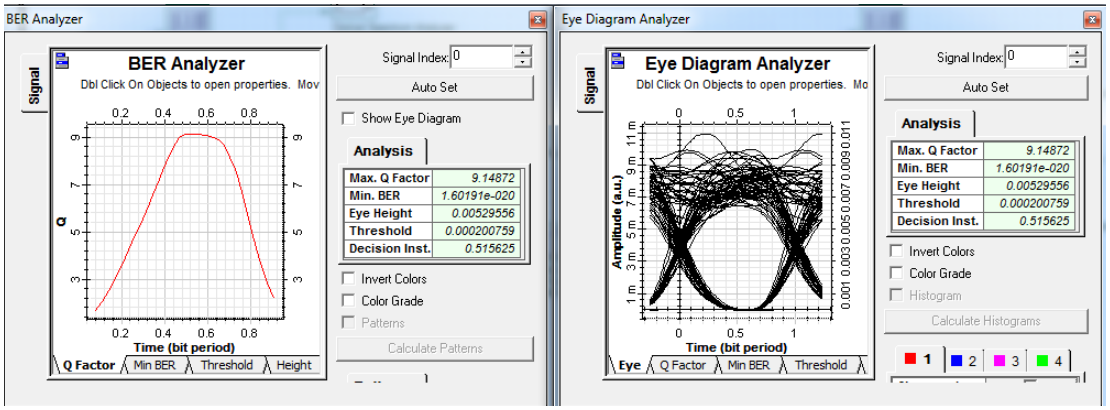


Figure 4.4: Q-factor, BER and eye diagram for VLC system with noise

power with respect to distance and plotted the distance vs. electrical power graph in M.S.Excel and from the graph it is analyzed that electrical power after the photo diode is linearly decreases with increase in distance between the transmitter and receiver for 10 Kbps signal in this VLC system.

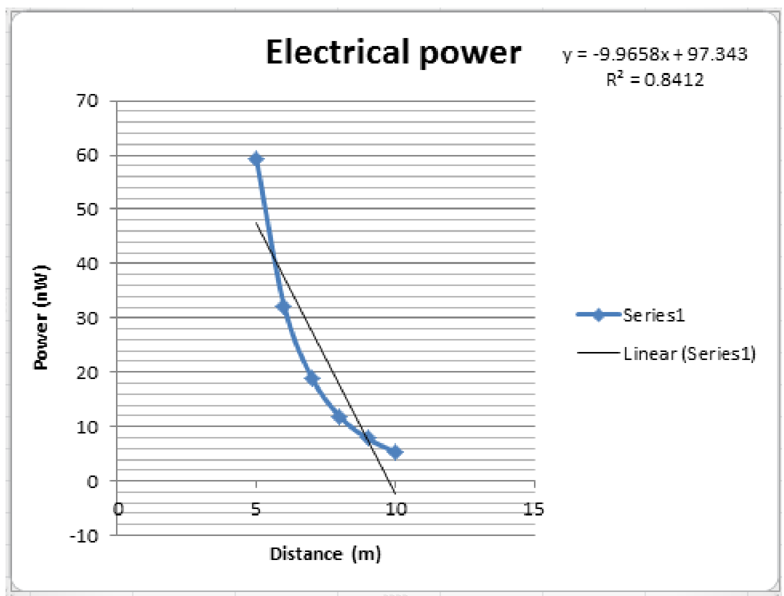


Figure 4.5: FSO channel Distance vs. Electrical power at the photo diode

Figure 4.6 shows the distance between transmitter and receiver vs. eye height value for 10 Kbps non return to zero on off keying signal. Using the eye diagram analyzer I observed all the eye height value with respect to distance and plotted the distance vs. eye height graph in M.S.Excel and it is observed that the eye opening linearly decreased means distortion is increases with increase in distance between the transmitter and receiver. Means as distance of the medium increase, the distortion in visible light communication also increases because increase in distance means signal need to travel more distance in the channel to reach at the receiver so signal gets more distorted.

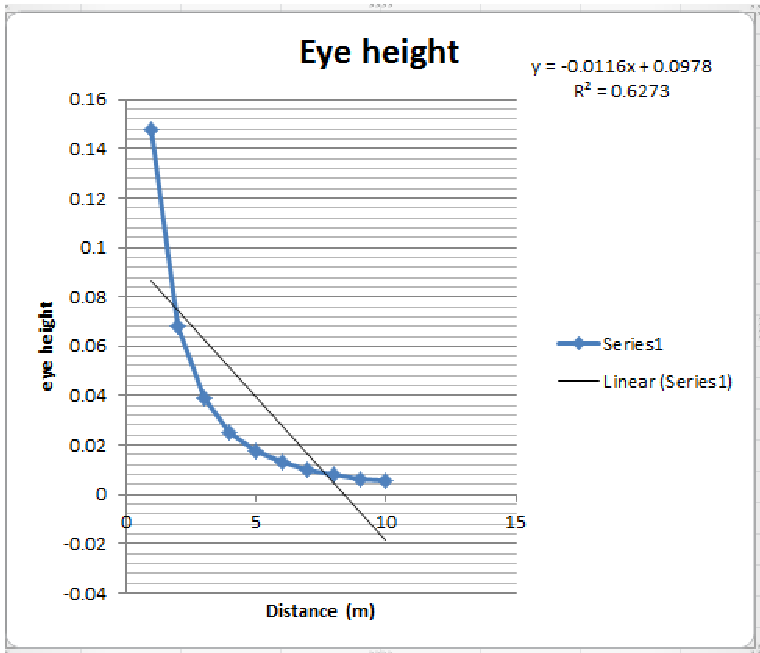


Figure 4.6: FSO channel Distance vs. Eye height

We can also observe that transmitted data is recovered back at the receiver and the bit sequence generated remains the same at both the ending point by using oscilloscope visualizer which proves that the communication is done properly using the VLC system.

4.1.1 Effect of LED wavelength on visible light communication

Mainly semi-conductors are used for manufacturing of the LED's. Some LED's are manufactured with only one semi-conductor and some are made with the combination of two or more semi-conductor. The semi-conductor material used in manufacturing of the LED decides the color of the LED. The color of the emitted light through LED decides the wavelength of the LED because we know in visible light spectrum shown in Fig. 1.2 different different color have different wavelength range. It can effect the performance of the visible light communication and distortion in the communication is also depends on the wavelength of the LED. So basically wavelength of the LED effect the value of Q-factor, Electrical power and eye height. Table 4.2 shows how these values are effected by the wavelength of the LED:

Table 4.2: Q-factor, electrical power and eye height change with respect to LED wavelength

LED color	Wavelength (nm)	Max. Q-factor	Electrical power	Eye height
Violet	∼380	9.14872	7.569nW	6.27×10^{-3}
Indigo	∼450	9.14872	5.397nW	5.29×10^{-3}
Blue	∼500	9.14873	4.372nW	4.76×10^{-3}
Green	∼550	9.14873	3.613nW	4.33×10^{-3}
Yellow	∼580	9.14874	3.249nW	4.10×10^{-3}
Orange	∼620	9.14874	2.843nW	3.84×10^{-3}
Red	∼730	9.14875	2.051nW	3.26×10^{-3}

4.1.2 Effect of Bit rate value with LED Bandwidth

Value of bit rate for communication and source LED bandwidth are relative to each other because for better and fast communication in VLC system we have to set these value. Table 4.3 shown when I want to increase the value of bit rate for fast communication how LED bandwidth effect the performance of the VLC system and why we use prefix maximum before Q-factor because for a fix bit rate at particular bandwidth the value of Q-factor reaches its maximum value after that slightly decrease and then Q-factor remains same. So when Q-factor is reaching its maximum value then there is no use of using higher LED bandwidth. It is also observed that increase in bit rate value decrease the value of Q-factor in VLC.

When I am increasing the value of bit rate for fast communication accordingly I have to increase the value of LED bandwidth but not beyond its maximum range because after a fix value of Q-factor if I increase the value of LED bandwidth then there is wastage of LED bandwidth. So first check it these values like that in optisystem and then use it in your experiment. Table 4.3 shown the effect of Bit rate value with LED bandwidth in VLC system.

Table 4.3: Effect of Bit rate value with LED bandwidth in VLC

Bit rate	**LED bandwidth**	**Max. Q-factor**
	100KHz	3.63969
	650KHz	9.14876
10 kbps	700KHz	9.14874
	900KHz	**9.14872**
	100MHz	9.14872
	1MHz	3.67853
100kbps	10MHz	9.16894
	11MHz	**9.16895**
	100MHz	9.16895
	100MHz	3.31443
	1GHz	8.94503
10 Mbps	2.5GHz	8.95084
	2.9GHz	**8.95085**
	10GHz	8.95085

4.2 Proposed VLC system 2

Now in this section, the basic VLC system and under the influence of the noise are designed, and as previous by using rectangular optical filter this noise will be removed at the receiver end.

In this all the other component values are same like previous except bit rate value. Here I designed the VLC system for **20 kbps**. Optical background noise is also change for this system. In this system white light source having wavelength of 451 nm and optical power 6W is used to add noise in visible light communication.

4.2.1 Without noise VLC system

Figure 4.7 shows the simple designing of the VLC system for 20kbps having NRZ-OOK signal without any background noise.

Using the BER analyzer and eye diagram analyzer shown in the Fig. 4.8 we obtained the value of Q-factor is 9.03979 and the value of Min. BER is 4.56×10^{-20}. This is achieved because the distance between transmitter and receiver is 10 m. Eye pattern is also achieved by using eye diagram analyzer. The value of Q-factor for 20kbps is slightly less than the value for 10kbps because increasing the value of bit rate degrade the system

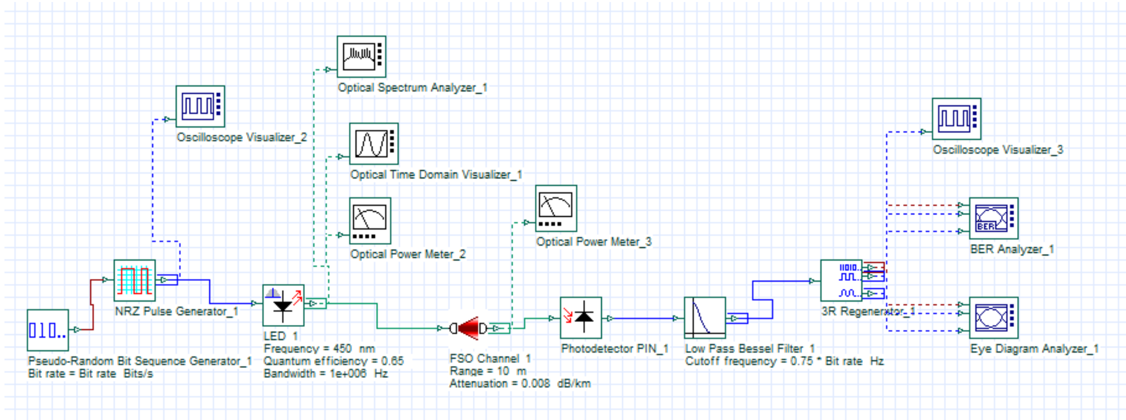


Figure 4.7: VLC system without noise for 20kbps

performance. Q-factor and BER values are inversely proportional to each other because as Q-factor increases BER decreases and when the value of Q-factor decreases by any reason the value of bit error rate increases.

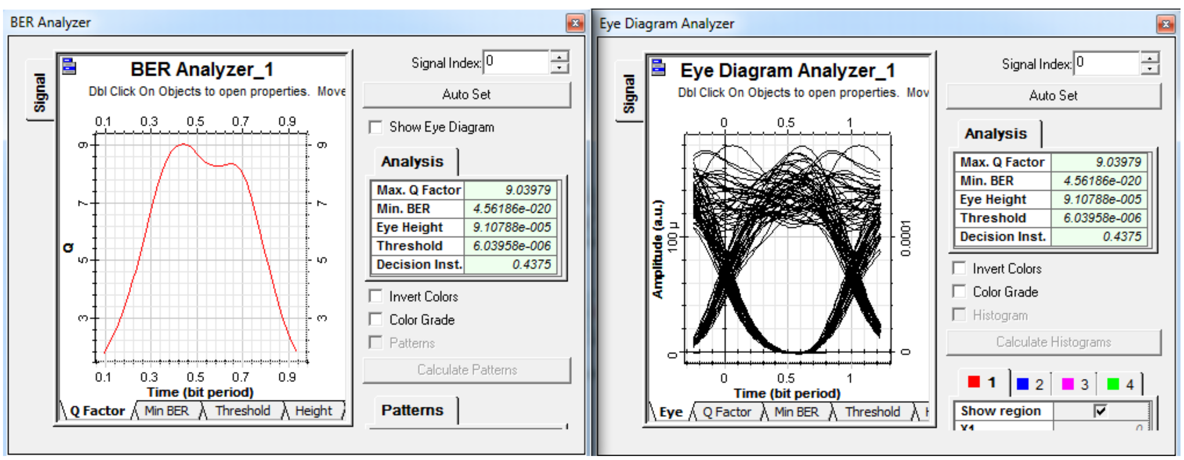


Figure 4.8: Q-factor, BER and eye diagram for 20kbps VLC

The channel distance also effect the performance of the VLC system because as we increase the value of the link distance, optical power of the receiver side decreases and hence the performance of the system is degraded. Also increase in distance, increases the probability to add some noise and distortion. Table 4.4 shows how Q-factor and BER values effected with increasing the value of channel distance:

Table 4.4: Change in Q-factor and BER value with respect to channel length

Distance	**Max Q-factor**	**Min. BER**
10 m	9.03979	4.56×10^{-20}
100 m	9.03762	4.60×10^{-20}
200 m	9.03427	4.72×10^{-20}
300 m	9.03266	4.90×10^{-20}
400 m	8.98704	7.90×10^{-20}
500 m	8.8994	1.79×10^{-19}
600 m	8.76694	6.28×10^{-19}
700 m	8.5939	2.98×10^{-18}
800 m	8.36869	2.16×10^{-17}
900 m	8.11894	1.85×10^{-16}
1000 m	7.82886	2.01×10^{-15}

4.2.2 With noise VLC system

This is a VLC system under the influence of the noise having NRZ-OOK signal with 20kbps bit rate. The noise which is white light source is basically a light source having 451 nm wavelength and 6W optical power. In opti-system adding the noise with source signal is done by using 2×1 power combiner. In this case also using rectangular optical filter we passed the frequency which comes from source and stops the frequency which come from the noise source. This noise is different from system 1 and also here bit rate value is 20 kbps. Below the Fig. 4.9 shows the designing of the VLC system under the noise and its performance and check how it is different from the earlier one by just observing the values of power, Q-factor and bit error rate value:

Observing the above system with 20kbps bit rate under the optical noise having power of 6W. The value of Q-factor for this system is 7.35143 and the value of BER is 5.37×10^{-14} as shown in Fig. 4.10 This value is only for distance of 10 m. After changing the distance these value also changes.

In this system the optical power of source LED is 643.19 mW. Noise whose optical power 5.99 W is gets added with the help of power combiner and combination of noise and signal transmitted through the FSO channel. The combined signal and noise power after the 10m distance is measured as 1.50 mW. The signal then detected by the photo diode whose main parameter is responsivity and this photo diode change optical signal into electrical signal. The electrical power after photo diode is 58.24×10^{-9} W when responsivity is 1 A/W and 2.819×10^{-9} W when responsivity is 0.22 A/W.

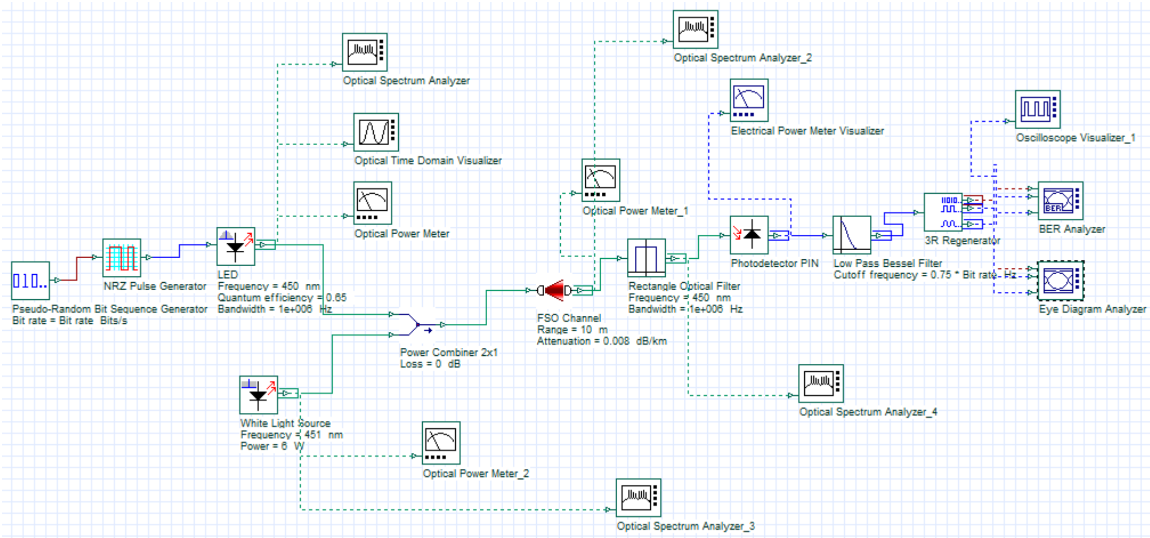


Figure 4.9: VLC system with noise for 20kbps

By using optical spectrum analyzer as shown in Fig. 4.11 I observed the spectrum of the LED of wavelength 450 nm and bandwidth is 1MHz.

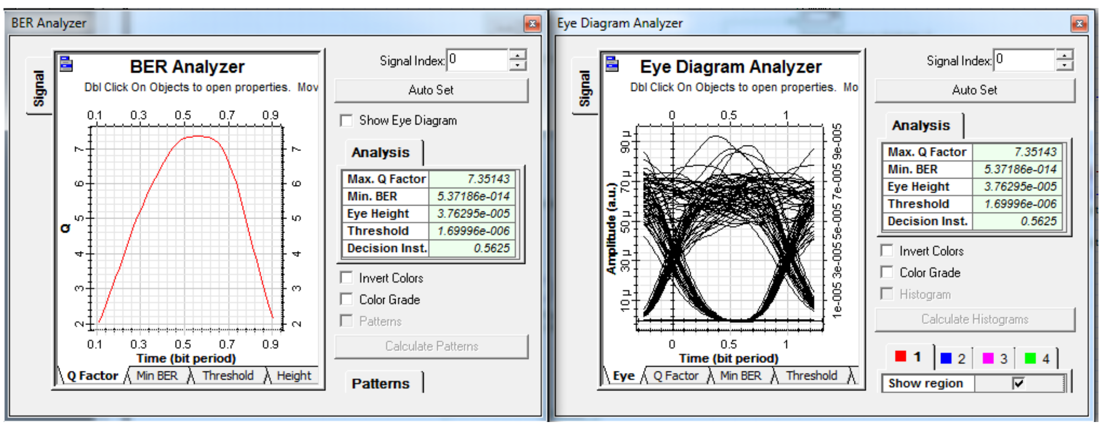


Figure 4.10: Q-factor, BER and eye diagram for 20kbps VLC with noise

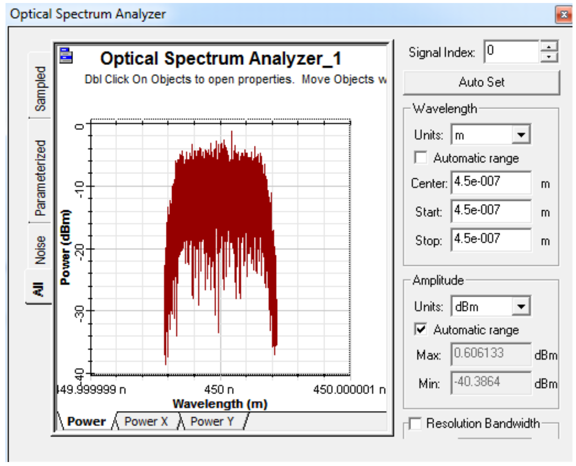


Figure 4.11: LED spectrum of wavelength 450 nm

4.3 Propose VLC system 3

In this proposed VLC system at the transmitter side I am using two user defined bit sequence generator which generate bits according to us. These two bit sequences are like two different data set. After the pulse generator I am using two LED's for these two bit sequences. The data gets modulated with the help of these LED's. Now till that point these two optical signals are identical and separate. Now these two optical signals are using same channel at the same time for transmission. So in this case if we are not using any technique or any type of filter to separate these signals, it is impossible to receive the original bits at the receiver side. Here I propose two model which is helpful for separating two or more signals when it gets added at the time of transmission.

4.3.1 Both the source LED have different wavelengths

Figure 4.13 shows the design of the VLC system where two user defined bit sequence generators are used for generating the bit sequences with 20kbps bit rate. It is user defined bit sequence generator so you can generate your bit sequence according to us. First user defined bit sequence generator generate 110001101110 bits and the second user defined bit sequence generator generate 0101101110 bits. Using oscilloscope visualizer as shown in Fig. 4.12 we can visualize the input bits:

Bit sequence 1 is modulated with LED having wavelength of 450 nm and Bit sequence 2 is modulated with LED having wavelength of 451 nm. Both are combine with the help of power combiner and transmitted through FSO channel of distance 10 m. Both the LED have different-different wavelengths that's why here we use rectangular optical filter.

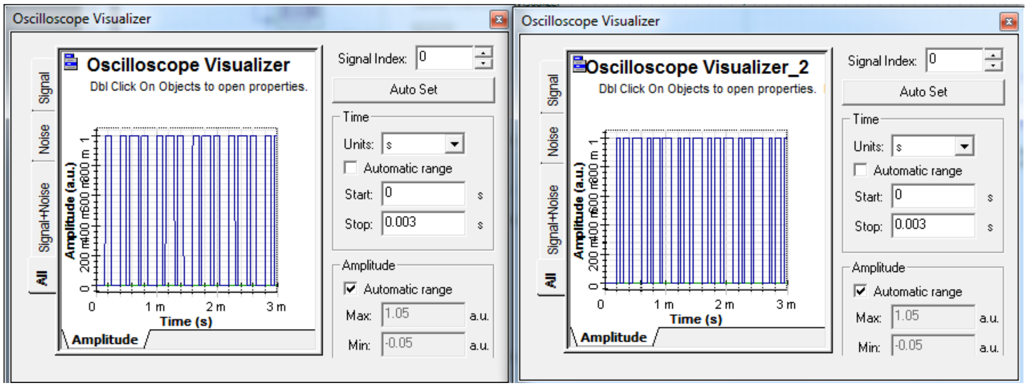


Figure 4.12: Bit sequence 1 and Bit sequence 2

Which LED's bits we want at the receiver side, we have to set the optical filters frequency like that. If I want first LED's bits at the output put the value of frequency 450 nm on rectangular optical filter. All the other parameters are same like previous.

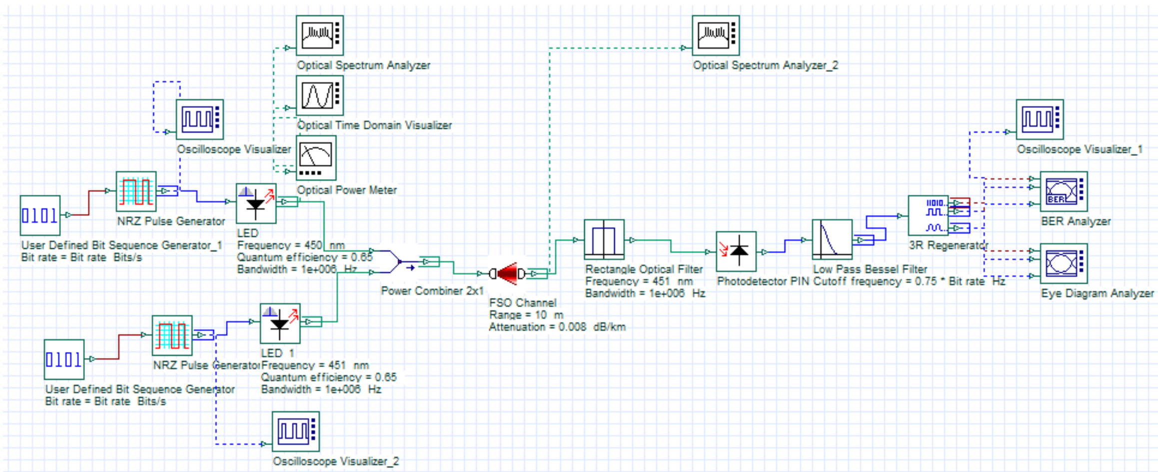


Figure 4.13: VLC system to differentiate the two bit sequences when LED's wavelengths are different

Firstly by using BER analyzer as shown in Fig. 4.14 we observed the value of Q-factor and BER and achieved Q-factor is 7.5248 and value of BER is 1.7×10^{-14}. This achieved values are enough for communication.

Also using oscilloscope visualizer after 3R-regenerator observed the output bit sequence as shown in Fig. 4.15 and it is same as the transmitted bits through LED having wavelength of 450 nm because I put the value of frequency 450 nm on rectangular optical filter.

If I want to achieve the output bit sequence same as the transmitted bits through LED

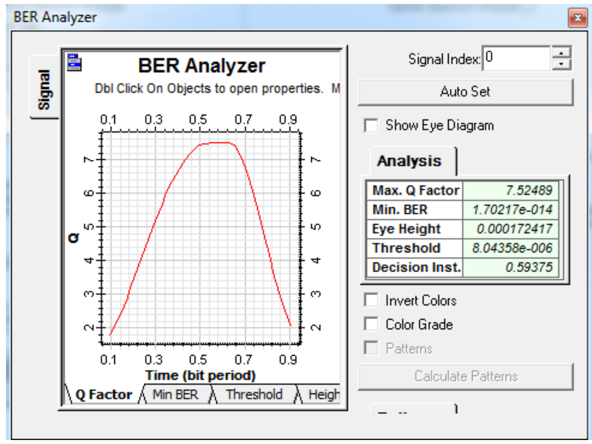
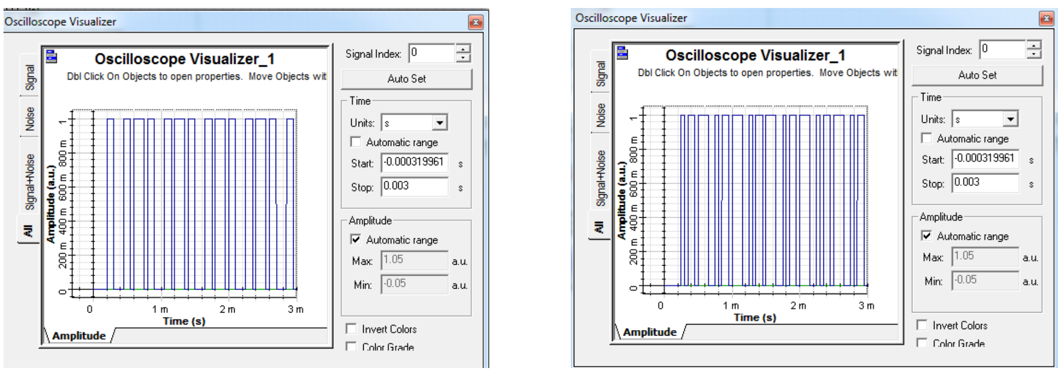


Figure 4.14: Value of Q-factor and BER

having wavelength of 451 nm then just we have to set the value of frequency 451 nm on rectangular optical filter so that it passes that frequency and block the other ones.



(a) (b)

Figure 4.15: Bit sequences: (a) 110001101110 from 450nm (b) 0101101110 from 451nm

4.3.2 Both the source LED have same wavelength

Figure 4.16 shown the designing of the VLC system in opti system where all the transmitter parts are same till the LED. The major difference in this system is here the wavelength are same for both the LED's and its value is 450 nm. Means both the bit sequences are modulated with two different LED whose wavelengths are same, then combine with power combiner and transmitted through the FSO channel.

In previous when both LED have different wavelength then rectangular optical filter is enough for separation of these two signals. But here both the LED have same wavelength so in this case rectangular optical filter is not able to separate the signals. So I am using the polarization technique for separating two signals. For this use linear polarizer at the transmitter end as well as receiver end.

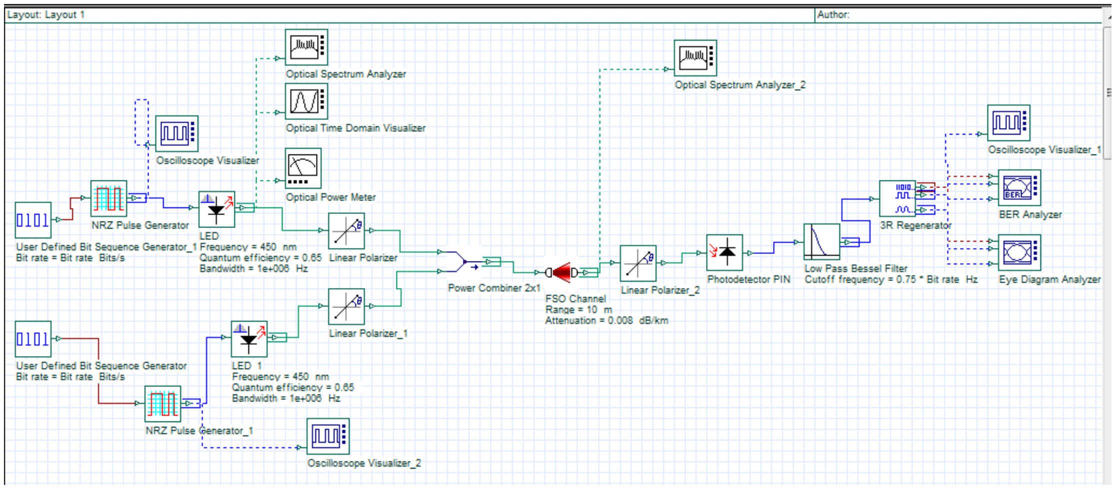


Figure 4.16: VLC system to differentiate the two bit sequences when LED's wavelengths are same

Both the input bit sequences are same like the previous 110001101110 and 0101101110. First input signal is polarized with linear polarizer having 90° and the second signal is polarized with linear polarizer having 0°. The benefit of using this technique is we know which signal is polarized in which angle. After successfully transmission of this combined signal, it contain both type of polarized signal.

At the receiver end before the photo diode again use a linear polarizer. This polarizer is act like a filter and pass that signal whose polarizing angle is equal to its own polarizing angle and all other angle are blocked by this polarizer. After this photo diode is used which receives the signal and change into electrical, then low pass filter removes the other unwanted frequencies signal then 3R-regenerator and finally use BER analyzer for the value of Q-factor and oscilloscope visualizer for observing received signal bit sequence. The value of Q-factor is 5.7167 is achieved and the value of Min BER is 3.35×10^{-9} is achieved as shown in Fig. 4.17:

In this system at the receiver side if we put the value of angle is 90° in linear polarizer then we get the bit sequence on the output of the oscilloscope visualizer which is transmitted from the first LED and the bit is generated from the first user defined bit sequence generator. Again when we put the value of angle is 0° in linear polarizer then we get the bit sequence on the output of the oscilloscope visualizer which is transmitted from the second LED and the bit is generated from the second user defined bit sequence generator.

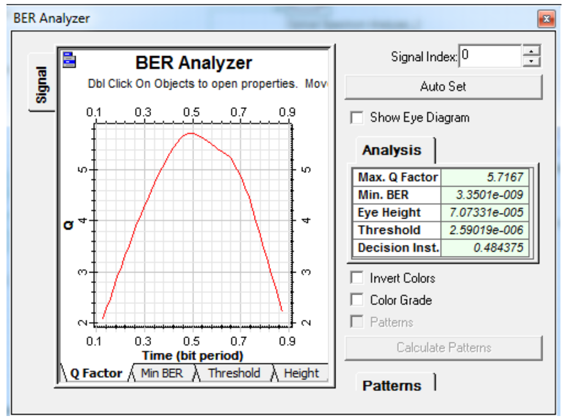
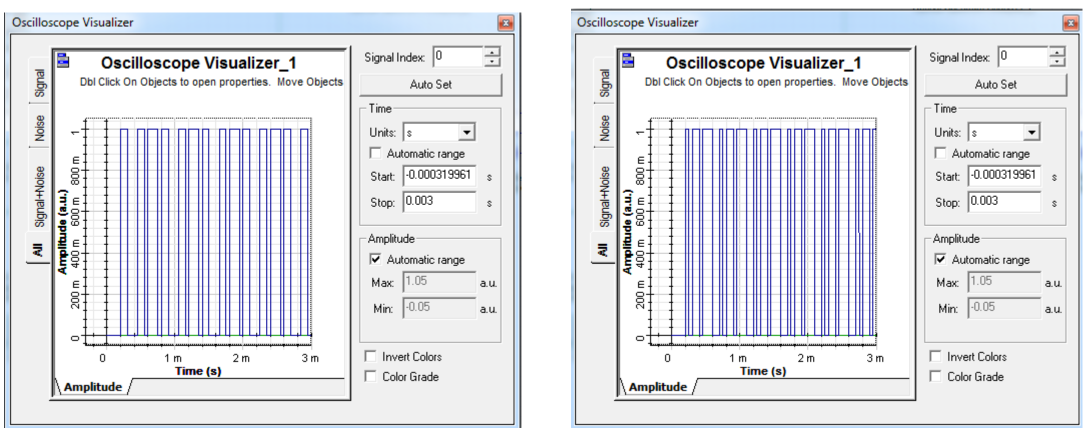


Figure 4.17: Q-factor and BER value

By observing the Fig. 4.18 it clearly shows that how the same bits are achieved at the output using polarization technique.



(a) (b)

Figure 4.18: Bit sequences: (a) 110001101110 from 90° polarizer (b) 0101101110 from 0° polarizer

So using the polarizer in both the transmitter and the receiver end visible light communication is achieved and separation of the two or more signal is also done by using this system when both the LED have same wavelength. This technique is very helpful for those kind of operation.

4.3.3 Both the source LED have same wavelength and bits are generating using PRBS generator

Figure 4.19 shown the designing of the VLC system in opti system where all the transmitter, receiver and channel components and their assigned values are same. The only different is that in this system I am using PRBS generator for generating the bit sequences in the place of user defined bit sequences because PRBS generator generates random sequence which are may be a difficult task to separate. In this also both the LED's are operating in same wavelength 450 nm so it is not possible to separate by using optical rectangular filter so here also I am using polarizer.

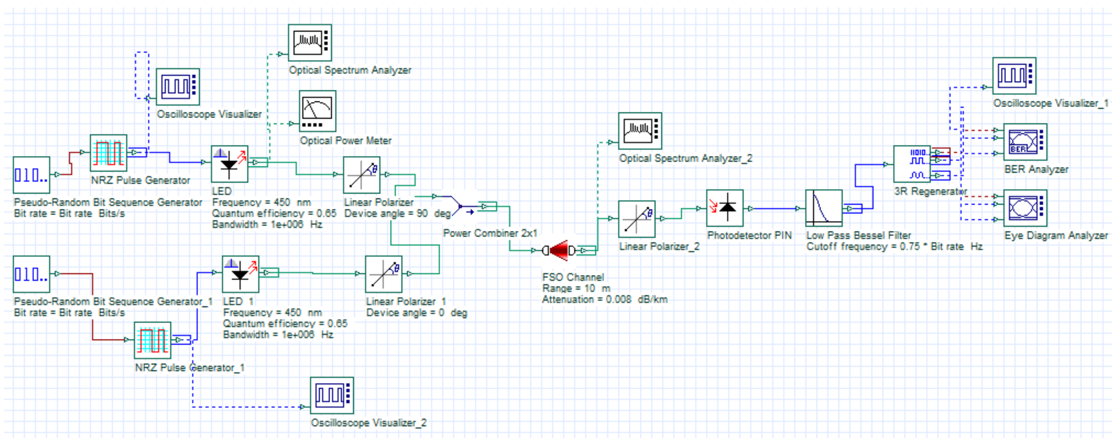


Figure 4.19: VLC system to differentiate the two bit sequences generated by PRBS generator when LED's wavelengths are same

Both the input bit sequences are generated randomly as shown in Fig. 4.20. First input signal is polarized with linear polarizer having 90° and the second signal is polarized with linear polarizer having 0°. The benefit of using this technique is we know which signal is polarized in which angle. After successfully transmission of this combined signal, using 2×1 power combiner, it contain both type of polarized signal. At the receiver end before the photo diode again use a linear polarizer. This polarizer is act like a filter and pass that signal whose polarizing angle is equal to its own polarizing angle and all other angle are blocked by this polarizer. After this photo diode is used which receives the signal and change into electrical, then low pass filter removes the other unwanted frequencies signal then 3R-regenerator and finally use BER analyzer for the value of Q-factor and oscilloscope visualizer for observing received signal bit sequence.

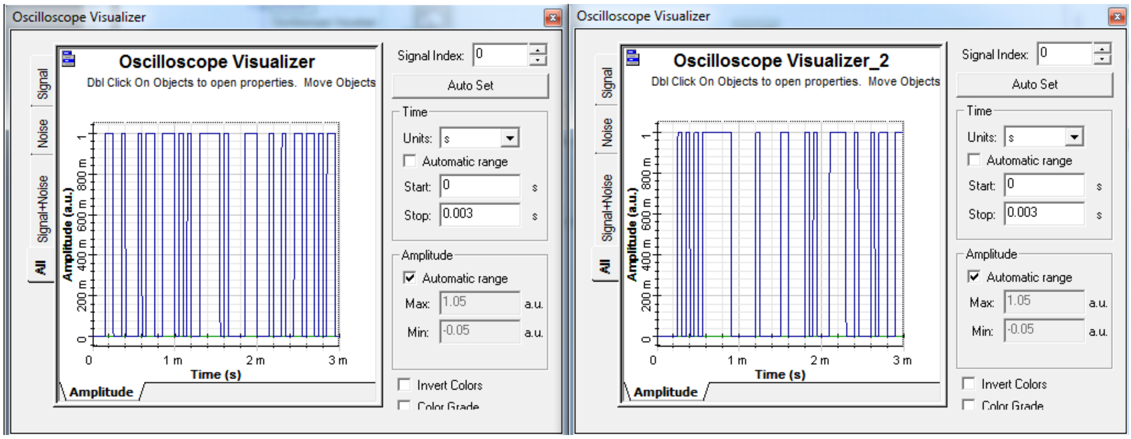


Figure 4.20: Bit sequence 1 and Bit sequence 2

The value of Q-factor is 6.32081 is achieved and the value of Min BER is 6.94×10^{-11} is achieved as shown in Fig. 4.21. This is a output monitor of the BER analyzer.

In this system at the receiver side if we put the value of angle is 90° in linear polarizer

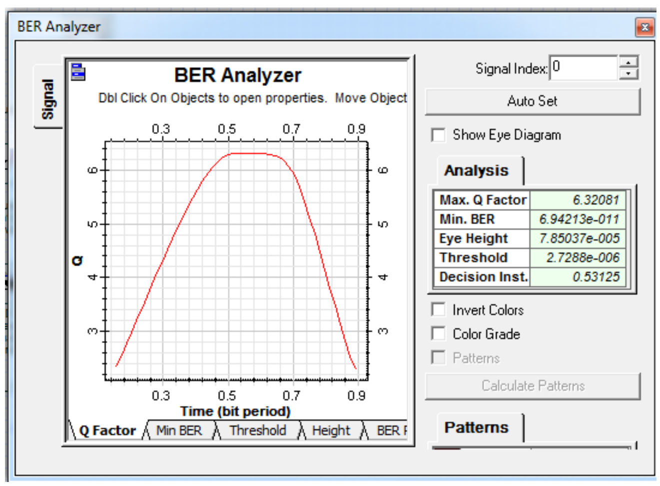
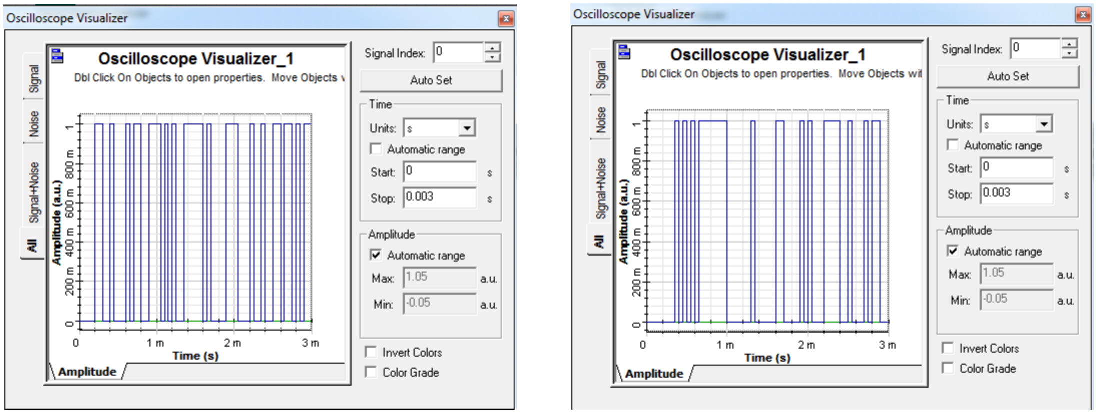


Figure 4.21: Q-factor and BER value

then we get the bit sequence on the output of the oscilloscope visualizer which is transmitted from the first LED and the bit is generated from the first pseudo random bit sequence generator. Again when we put the value of angle is 0° in linear polarizer then we get the bit sequence on the output of the oscilloscope visualizer which is transmitted from the second LED and the bit is generated from the second pseudo random bit sequence generator. By observing the Fig. 4.22 it clearly shows that how the same bits are achieved at the output using polarization technique.

So polarization technique is very best method for separating the two or more bit sequences



(a) (b)

Figure 4.22: Bit sequences: (a) Bits from first PRBS generator (b) Bits from second PRBS generator

which merge in the medium because they use same channel for transmission at the same time. Polarizers are helpful to separate both types of bit sequences which generates form user defined bit sequence generator or generates form pseudo random bit sequence generator.

Chapter *5*

Conclusions and Future Work

5.1 Conclusion and Discussion

I have presented the designing and study of performance of the visible light communication in optisystem with and without the influence of the noise and observe that how visible light communication is effected due to noise and which filter is required for mitigating the noise. The results show the BER performance and eye diagram is better in which condition. PRBS generator bit rate value is always less then the optical source bandwidth. This study is helpful for analyzing, which parameters effect the visible light communication and how much Q-factor and BER needed for better communication. From this study it is clearly observe that how distance between transmitter and receiver, bit rate value, LED bandwidth and LED wavelength effect the visible light communication.
Here I also propose a model which is helpful for getting the input bits at the output point when two or more signals gets added at the time of transmission in channel by using linear polarizer. Different angle of the polarizer also effect the performance of the system. This study shows importance of polarization technique in the field of optical. Also using optisystem, design and analyze the VLC system and use in a physical experiment.

5.2 Scope of further work

VLC technology has a great and wide scope in future. Firstly this proposed model is a basic and simple structure of the VLC system which is only for analyzing the visible light communication and transferring the bit sequences from one point to another. Use this system and technique and by just doing some modification according to our application we can use Visible light communication in many fields like traffic controlling and many more. There are some limitations in this VLC system as discussed earlier.In future its a research

work to overcome its limitation like two way communication and mitigating the noise when frequencies are same for source and noise.
For better performance in VLC system and for less noise we can use different types of optical filters and find some other ways to increase the responsively of the photo-diodes. Also find some other ways for removing noise at the time when source frequency and noise frequency are same.

5.2.1 Li-Fi technology

Li-Fi technology is based on source LEDs and receiver for the transferring of data. For transferring the data it can use all kinds of light, means it has any type of spectrum that is, infrared, ultraviolet and the visible part of the spectrum. With the help of this technology the speed of the Internet can be increases. So Li-Fi technology is a future work on this field.

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