PROJECT REPORT

ON

STUDY ON THE EFFECT OF RAIN ON PERFORMANCE OF FREE SPACE OPTICAL COMMUNICATION

BY

NNOLI, JOHN CHIMEBUKA

EEE/13/3813

SUBMITTED TO

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING,

SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY,

FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE.

IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR IN ENGINEERING (B.ENG) DEGREE IN ELECTRICAL AND ELECTRONICS ENGINEERING OF THE FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE.

NOVEMBER, 2018.

CERTIFICATION

This is to certify that this report is a detailed account of the project undertaken by **NNOLI, JOHN CHIMEBUKA (EEE/13/3813)** and has been prepared in accordance to regulations guiding the preparation of reports in the Department of Electrical and Electronics Engineering, Federal University of Technology, Akure.

Student's signature/Date	Supervisor's signature/Date
NNOLI JOHN C.	**DR S.A OYETUNJI**

Head of Department signature/Date

DR A.A PONNLE

DEDICATION

This project work is dedicated to Almighty God who in His infinite mercy has made this research work a reality. To my parents and siblings for their great support in my academic carrier, may the good God bless them with fruit of their labour.

ACKNOWLEDGEMENT

My sincere appreciation goes to God Almighty, the creator and giver of life who in His immeasurable mercies made this research successful and kept me all through my academic years up until this period.

My gratitude goes to my able supervisor in person of Dr. S. A. Oyetunji, who has been a major personality in this research. My regards goes to the Head of Department, Dr. A. A. Ponnle for his passion to build student in terms of practical aspect of this field and to all my lecturers in the Department of Electrical and Electronics Engineering for their moral and academic support.

My appreciation goes to my departmental mates and close friends for their invaluable contribution to the success of this work. I say more power to your elbow.

It is my pleasure to express my deep gratitude to my parents, Mr. N. O. Nnoli and Mrs. B. N. Nnoli, who have always been there for me, aiding immensely in finances all through.

ABSTRACT

Optical communication is one of the most widely used technologies in field of telecommunication now days. However, the vulnerability of Free Space Optic (FSO) towards atmospheric conditions like rainfall has become a main issue towards its implementation. Many studies conducted to estimate the climatological effects on FSO links are based on link centered in temperate and tropical regions. This however, has not been considered in this part of the world. Hence, this project aims at making analysis on the performance of FSO links in Akure, Nigeria. This analysis is based on the use of Arduino to send data bits serially via a laser diode to the receiving Arduino for processing of the bit error rate (BER), carried out under controlled rain conditions using a rainfall simulator with rainfall data obtained from The Department of Meteorology, The Federal University of Technology, Akure. The BER observed to increase with increase in distance of rain along the FSO link path, having error rate of up to 0.35 at distance of 250cm.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

Free Space Optics (FSO) is a technology, which uses laser (light amplification by stimulated emission of radiation) as a medium of transmission between transmitter and receiver, frequently called fibreless optics. The transmitter converts the electrical signals into optical signals and sends it through the atmosphere (free space), modulation from a laser beam is used to send optical binary information. The Receiver converts the optical signal back to an electrical signal. FSO is a line of sight (LOS) emerging technology that has a great chance to complement the traditional wireless communications. Communication is theoretically possible as long as the line of sight between the transmitter and the receiver is clear, and as long as the transmitted power is high enough to overcome atmospheric attenuation. FSO is in reality an alternative method of transmitting information from one place to another by sending pulse of light in Terahertz spectrum. With the increase in usage of high speed internet, video-conferencing, live streaming etc., the bandwidth and capacity requirements are increasing drastically leading to congestion in conventionally used radio frequency (RF) spectrum and arising a need to shift from RF carrier to optical carrier.

US military and NASA, and being used for more than three decades in various forms to provide fast communication links originally developed FSO. The latest fourth-generation FSO lasers are 100 per cent class 1m eye-safe technology. These systems offer excellent automatic power-level control, and eliminate short-distance optical saturation. It is similar to fiber optic communications in that modulated laser light transmits data. Instead of containing the pulses of light within a glass fiber, these transmitted in a narrow beam through the atmosphere made it become an optimal solution for last-mile connection because of the capability in transmitting higher speed of data, which is up to 2.5Gbps. The motivation for FSO is to eliminate the effort of installing fiber optic cable, time, cost and yet maintaining the data rates up to 1Gb/s and beyond for transmission of voice, video and data services. Light travels through air faster than it does through glass, so it is fair to classify FSO as optical communications at the speed of light.

Fiber optic communications, which is the most reliable solution for optical communications, is one of the backbones in most cities. However, the cost to digging and laying down the fiber cable are huge. Furthermore, the time of deployments is also economically too expensive. It is also quiet difficult to relocate fiber cable once it is already being deployed (Ramasarma, 2002). Last-mile access; to lay cables of users in the last mile is very costly for service providers as the cost of digging to lay fiber is so high and it would make sense to lay as much fiber as possible. FSO used to solve such problem by implementing it in the last mile along with other networks with its high-speed link. There are several significant advantages offered by FSO especially easily deployment by saving time and cost as well as does not require any frequency authorization or any specific license are;

1. It has very low initial investment (Willebrand and Ghuman, 2001). It is a secure system because of line of sight operation and so no security system up gradation is needed (Vigneshwaran *et al*, 2013).
2. High data rate obtained which is comparable to the optical fiber cable's data rate but error rate minimal and the extremely narrow laser beam enables having unlimited number of FSO links installed in a specific area (Vigneshwaran *et al*, 2013).

3. There is immunity to radio frequency interference (Vigneshwaran *et al,* 2013).
4. Electromagnetic and radio-magnetic interference cannot affect the transmission in FSO link.
5. FSO offers dense spatial reuse (Rahman *et al,* 2008). Low power usage per transmitted bit.
6. There is relatively high bandwidth (Rahman *et al,* 2008). It has flexible rollouts (Singh and Kumar, 2013).

However, the performance and the availability of terrestrial FSO links depends strongly on the atmospheric conditions in the area where the link is installed. More specifically, the fog, the rain, the hail, etc. affect significantly their effectivity, while another very significant phenomenon for the availability and performance decreasing is the atmospheric turbulence, which causes the scintillation effect that, induces rapid fluctuations of the optical signal on the receiver's side. Thus, the FSO channels have randomly time-varying characteristics due to the scintillation effect. In order to study these signal's fluctuations, many statistical models are been proposed and tested experimentally for various atmospheric turbulence conditions. More specifically, for the case of strong to very strong turbulence conditions, the K-distribution model is usually used, for saturated turbulence, the negative exponential statistical distribution, and, for weak turbulence, the lognormal, the gamma, the Malaga and the Rayleigh distributions can be used, while, for moderate to strong cases, the gamma–gamma, the Malaga and the I-K models are used.

1.2 MOTIVATION

In recent years, Free Space Optical (FSO) communication is being preferred over the radio frequency communication and microwave systems because of its license-free long-range operations, small size, high bandwidth, low cost, no need of licensed frequency, absence of radiation hazards and immunity to interference. The ever growing demand of increase in data and multimedia services has led to congestion in orthodoxly used RF spectrum and arises the need to embrace FSO technology serving as a decent alternative.

1.3 PROBLEM STATEMENT

Climatologically the phenomena in tropical regions, Nigeria, dominated by Rain and Haze as it occurs almost year-round. The distance-reducing impact of rain on FSO classified under absorption and non-selective scattering since the radius of raindrop (200-2000μm) is significantly larger than the wavelength of FSO light source. The attenuation loss for light rain (2.5 mm/hr) to heavy rain (25 mm/hr) ranges from 1 dB/km to 10 dB/km for wavelengths around 850 nm and 1500 nm (Suriza et al, 2011).

Absorption caused by the beam's photons colliding with various finely dispersed liquid and solid particles in the air such as water vapor, dust, ice, and organic molecules. Absorption has the effect of reducing link margin, distance and the availability of the link. Scattering defined as the dispersal of a beam of radiation into a range of directions because of physical interactions that occurs when a particle intercepts an electromagnetic wave, part of the wave's energy been removed by the particle and re-radiated into a solid angle centered on it.

1.4 AIM AND OBJECTIVES

1.4.1 AIM

This research aims at studying the effect of rain on performance of Free Space Optical Communication in Akure, Nigerian Climate.

1.4.2 OBJECTIVES

The objectives of this research are as follows:

1. Acquire rainfall data, raindrop size, and rain rate, from the Department of Meteorology.
2. Fabricate a model of Free Space Optics transmitter and receiver.
3. Develop a testbed to simulate rainfall based on the rainfall data obtained.
4. Carry out study on rainfall effect on signal propagation of FSO link and draw conclusive remarks.

1.5 JUSTIFICATION OF PROJECT

As established earlier the need to move from conventional RF carrier to optical carrier, studying this emerging technology in order maximize its use in communication is of necessity. Free Space Optical communication has few limitations also like beam dispersion, scintillation, and absorption. A well-known limitation of FSO is the effects of weather conditions on it like rain, haze, snow, hail etc. As known, free space, optics is highly affected by the various atmospheric conditions that degrade the performance of FSO link. This research hence, studies the effect of rain on the performance of FSO link.

1.6 SCOPE OF RESEARCH

This research only studies the effect of rain atmospheric condition on performance FSO using bit error rate (BER) in tropical region, Akure, Nigeria.

1.7 CONTRIBUTION TO KNOWLEDGE

1. This research would ensure awareness of Free Space Optics as an emerging technology.
2. The advantages of FSO over its relative fibre optics and conventional RF spectrum.
3. This research helps in creating awareness of the rate of errors in communication using FSO in Akure, Nigeria.

CHAPTER TWO

LITERATURE REVIEW

2.1 HISTORY OF FREE SPACE OPTICS

In several forms, optical wireless communications are been used for many of years. Cleoxenus, Democleitus and Polybius developed a coded alphabetic system of signaling with torches, which the Ancient Greeks used. In the modern era, semaphores and wireless solar telegraphs called heliographs developed, using coded signals to communicate with their recipients.

2.1.1 ALEXANDER GRAHAM BELL'S DISCOVERY

Early experiments in FSO included demonstrations by Alexander Graham Bell, which preceded his invention of the telephone. Beams of light to transmit voice conversations through the air used by Bell, he dubbed the 'photophone'. Though Bell's experiment never translated into a commercial device, the principle of FSO was proved. In 1880, Alexander Graham Bell and his assistant Charles Sumner Tainter created the photophone, at Bell's newly established Volta Laboratory in Washington, DC. Bell considered it his most important invention. The device allowed for the transmission of sound on a beam of light. On June 3, 1880, Bell conducted the world's first wireless telephone transmission between two buildings, some 213 meters (700 feet) apart.

Its first practical use came in military communication systems many decades later, first for optical telegraphy. German colonial troops used heliograph telegraphy transmitters during the Herero and Namaqua genocide starting in 1904, in German South-West Africa (today's Namibia) as did British, French, US or Ottoman signals.

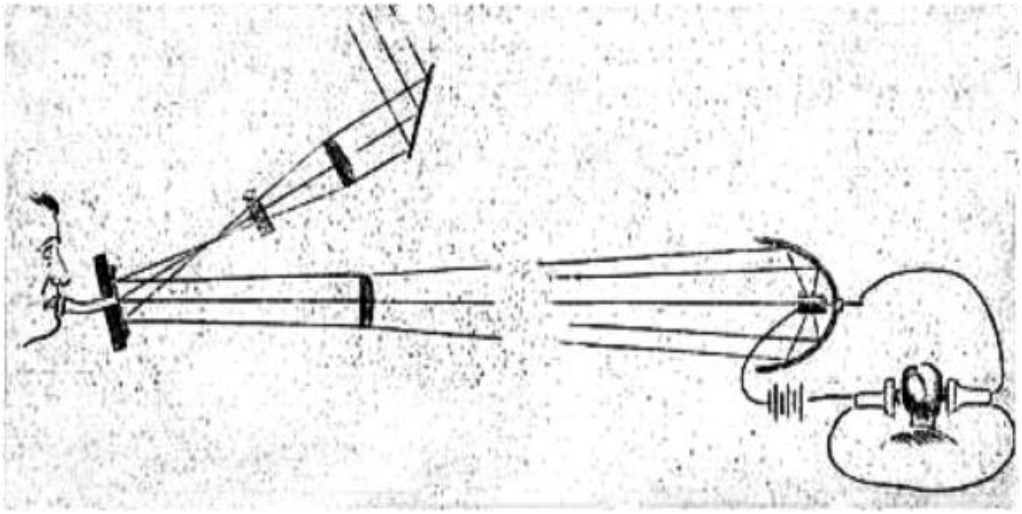

Figure 2.1: The FSO Photophone Concept

2.2 RAIN ATTENUATION PREDICTION MODEL

Heavy rain is expected to be the limiting factor for FSO link availability. In recent years the need to develop prediction model to study and analyze the effects of rain on Free Space Optics (FSO) has arisen being that FSO is considered as a better alternative to the present Radio Frequency (RF) means of communication. Rain attenuation prediction means attenuation per unit length because of rainfall. Rain attenuation is predominantly severe and significantly dependent on various models of raindrop-size distribution in terahertz wave system like FSO (Ishii, 2010). The raindrop size distributions predominantly used proposed by Marshal and Palmer. Marshal and Palmer distribution proposed the renowned empirical expression by fitting data and the Laws and Parsons data.

Power law represents rain specific attenuation;

$$A_{rain} = KR^{\alpha} \text{ (db/km)} \qquad (1)$$

Where R is the rain rate in mm/hr, k and α, are power law parameters. The power law parameters depend on frequency, raindrop size distribution and rain temperature. For calculating the attenuation, it is adequate to assume that raindrops have spherical shape (Suriza, 2011). To model rain prediction attenuation in tropical weather condition, an approach adopted by International Telecommunication Union-Radio communication sector (ITU-R) is used, based on the relationship between the equally probable experimental rain rates and received level signal (Emiliani, 2008). In ITU-R methods, it is recommended that the rainfall needs to be measured at interval of 1 minute in order to determine the rain rate.

Studying and making analysis on the effect of rain on FSO link done by knowing the rain attenuation on FSO links and corresponding rainfall intensity, with modeling of rain attenuation prediction done using two methods, namely empirical method and the physical method (Ojo, 2008). According to Zhou, 2009, the empirical method based on correlation between observed attenuation distributions and corresponding observed rain-rate distribution measured at 1-minute integration time, while the physical method is an attempt to use the physical behavior involved in the attenuation process.

Table 2.1: Rain Attenuation prediction model

ATTENUATION	**RELATION**
Drizzle or light rain (Joss) (R<3.8 mm/hr)	$0.509R^{0.63}$
Mean rain (Joss) (3.8 < R < 7.6 mm/hr)	$0.319R^{0.63}$
Strong rain (storm) (Joss) (R < 7.6 mm/hr)	$0.163R^{0.63}$
Rain (Marshal and Palmer)	$0.365R^{0.63}$

Model proposed by Carbonneau had values to predict the k & α based on measurement done in France (Carbonneau, 1998). However, the measurement done was for very low rain intensities when compared with rain intensity in tropical region. In the United Kingdom (UK), 5mm/hr rain rate taken as the highest rain rate in measurement considered as exceptional (Carbonneau, 1998). In tropical region, the highest rain intensity measured above being 200mm/hr. The most of the data from Japan's model were concentrated below 50 mm/hr, which is much lower than measured in Malaysia. Marshal-Palmer and Joss distributions values of k and α, are developed by considering measured drop size distribution. For other countries, the use of drop size may result in the prediction error when applied in tropical region (Awang, 2004). Although the analysis was done for microwave system, the application on drop size distribution is also applicable in FSO.

Table 2.2: K and α values of specific rain attenuation model of FSO

MODEL	**K**	**Α**	**COUNTRY/REGION**
Carbonnea	1.076	0.67	France/Temperate
Japan	1.58	0.63	Japan/Temperate
Martine	0.231	0.7	Prague/Temperate
Samir	2.03	0.74	Malaysia/Tropical
Suriza	0.4195	0.8486	Malaysia/Tropical

These models developed based on regression analysis and other methods of measured rain intensities (mm/hr) and rain attenuation (dB) in their respected areas. Table 1 shows the values of k and α for these models. Carbonnea and Japan models, which recommended by ITU, gave average attenuation compare with other models.

2.3 BASAHEL’S RAIN RATE MEASUREMENTS

According to Basahel (2015), a one-year rain rate data-measurement collected by using tipping bucket rain gauge (Casella) from 1 January 2011 to 30 December 2011, the highest rain rate was 168 mm/hr, whereas the lowest rain rate was 12 mm/hr. The percentage of time exceeding 0.01% level is almost corresponding to 100 mm/hr.

Table 2.3 Rain gauge specification

ITEM	SPECIFICATION
Catchment area	$200cm^2$
Resolution	0.2mm per tip
Accuracy	1% up to 26mm/hr
Output	Contact Closure
Contact rating	24 VDC 500mA

2.3.1 DERIVATION OF PATH LENGTH REDUCTION FACTOR

Due to the inhomogeneity of rain while propagating along the path, the rain might not fall into the entire propagating path, causing some portion of the link to be effected. The effective path link, which is the connection between rain cell and path length. Confirmed from this definition the effective path length is smaller than total actual path (Basahel, 2015). The total path attenuation exceeded for 0.01% of the time according to ITU recommendation, estimated by:

$$A_{0.01\%}(dB) = \gamma_R d r \quad (2)$$

Where; γ_R is the specific rain attenuation (dB/km) and d is the total path length (km) and r is reduction factor. There exists a model developed based on measurements at seven different locations in Malaysia using 15 GHz frequency and for 0.01% (Abdulrahman, 2011). The value of r for this model estimated by:

$$r_{0.01} = \frac{1}{1+\frac{d}{2.6379 R_{0.01}^{0.21}}} \quad (3)$$

Where R is rain intensity (mm/hr)

Sharma, 2011 also developed a model based on measured rain intensity and rain attenuation for a fixed distance of 2.29 km and 28.75 GHz under tropical climate in India but for all percentage of time. The value of r for this model obtained by:

$$r = 3.6435 R^{-0.377} \quad (4)$$

Based on the model (Abdulrahman, 2011), the value of r it depends on rain intensity and distance of path link. Whereas; model (Sharma, 2011) it depends on rain intensity only. As the matter of fact, the r, value should be less than one, but in model (Sharma, 2011) the value of r showed to be greater than one at lower rain intensity < 30 mm/hr. That due to fact low rain intensity is widespread over the path length which represent uniform rain rates (Sharma, 2011), in contrast high rain rates can be much localized (Abdulrahman, 2011) model. In order to develop r for all percentage of time the model (Sharma, 2011) needs to be multiplied by a factor so that can be fit with our local measurements of rain rate (Basahel, 2015). Model (Abdulrahman, 2011) is developed based on Malaysia climate and it is a function of *d* as well, so the combination of these two models can produce a new model of reduction factor which can be suitable for all percentage of time and as a function of distance (Basahel, 2015). Assume that a path link of 5 km distance, and given 100 mm/hr for 0.01% from measured data of Malaysia. Also we assume a single scatter of optical attenuation (Martin, 2014). Based on this assumption the model (Sharma, 2011) will give constant (C) value for all 5 km, whereas, Abdulrahman, (2011) model will lead to variation of r (Δy) at each distance point. Dividing each Δy over C will lead to a new function (Δx), by applying the regression analysis; the best fit curve gave an exponential function with the following expression:

$$\Delta x = 1.4912e^{-0.102x} \tag{5}$$

CHAPTER THREE

METHODOLOGY

In order to make analysis on the effect of rain on performance of FSO link, a serial communication between the optical transmitter and the receiver needs to be established, and the bit error rate when rain is introduced to the channel is displayed on a 16x2 LCD and recorded.

3.1 SERIAL COMMUNICATION

Serial communication is the procedure of transmitting data one bit at a time. In parallel communication, however data bits are sent as a whole. Parallel data transmission is faster than serial transmission though has a number of disadvantages:

I. More wires are needed and therefore can be more expensive to implement.

II. The presence of greater number of wires limits it to shorter transmission distances.

III. It is susceptible to clock skew, which limits the speed of transmission to the slowest of the links.

IV. Crosstalk is also an issue due to the juxtaposition of the wires.

Serial data transmission, by risen of the above problems, most especially the first one, as cost and limited pins are common issues in microcontroller system design, is preferable to parallel in the course of this research. There are two basic types of serial transmission: asynchronous and synchronous which literally means "not synced" and "synced" respectively.

Synchronous transmission; the bit stream is combined into longer "frames," which may contain multiple bytes; there is an extra line for the clock signal. Each byte, however, introduced onto the transmission link without a gap between it and the next one is left to the receiver to separate the bit stream into bytes for decoding purposes. In other words, data are transmitted as an unbroken string of 1s and 0s, and the receiver separates that string into the bytes, or characters, it needs to reconstruct the information. I2C (actually I^2C, stands for inter–integrated circuit bus) and SPI (Serial Peripheral Interface) are both considered synchronous. The clock signal is used to ensure that the correct data bits are received.

Asynchronous transmission is one in which the timing of a signal is unimportant. Instead, information is received and translated by agreed upon patterns. As long as those patterns are followed, the receiving device can retrieve the information without regard to the rhythm in which it is sent. Data transfer here requires no clock signal transmitted and received. Patterns based on grouping of the bit stream into bytes. Each group, usually 8 bits, sent moves along the link as a unit. The sending system handles each group independently, relaying it to the link whenever ready, without regard to a timer. The common Universal Asynchronous Receiver/Transmitter (UART) (also known as RS-232 or SCI) device found in **microcontrollers** is asynchronous; all Arduino boards have at least one serial port (also known as a UART or USART). In SCI, the effect of the absence of a clock signal mitigated by adding **overhead**. The added overhead affects throughput (the rate of production) since they do not carry useful information. However, the absence of the clock signal also means that SCI is simpler to setup and implement as compared to the complex hardware needed by synchronous protocols. Asynchronous transmission is more suited for this research; hence, Arduino Nano (microprocessor) is use of in modelling the transmitter and receiver.

3.1.1 SERIAL TRANSMISSION WITH ARDUINO

The communication between Arduino boards and PC is established via USB (Universal Serial Bus) cable or to other serial devices using the serial pins. Asynchronous serial transmission is more appropriate for Arduino boards. Every Arduino board has at least one serial port and is commonly assigned to digital pins 0 and 1 (Tx and Rx respectively). Using these pins while loading a program to the board causes an error because it's the same pins that are used for USB connection. The Arduino serial port uses TTL signal levels, which means the logic 1 is +5V and logic 0 is 0 V. A computer's serial port uses different voltage levels: the logic 1 is -3 to -25 V while the logic 0 is +3 to +25 V. This is why it's a wrong practice to connect the Arduino’s serial pins directly to a PC's serial port.

The USB port (which is serial) also uses different voltage levels and protocol. Arduino boards have USB to TTL chips included to interface the board to the computer via USB. Some AT Mega microcontrollers have bootloaders that does not require a USB to TTL chip. The Serial.begin( ) function specifies the baud rate. Here it is set to 9600 bauds.

3.1.2 ASYNCHRONOUS SERIAL TRANSMISSION PROTOCOL

This protocol being best suited for this research follows a simple procedure to ensure correct transmission. It consists orderly of;

I. Synchronization Bits.

II. Data Bits.

III. Parity Bits.

IV. Baud rate.

I. **Synchronization Bits:** The added **overhead** earlier mentioned are the synchronization and parity bits. The synchronization bits are start and stop bits to indicate the start and end of transmission. When the serial bus (or data line) is idle, the voltage level is toggled high. The sending device sends a logic 0 (the start bit) to kick-start the transmission.

II. **Data Bits:** Data bits can range from 5 to 9 bits. The order by which the data bits sent is from the least significant bit (LSB) to the most significant bit (MSB).

III. **Parity Bits:** Used for error checking. Parity can be either even or odd. If even parity is chosen, the parity bit is added to make the number of 1's even. For odd parity, the added parity bit must make the number of 1's odd.

IV. **Baud Rate:** The baud rate, or speed of transmission, is also part of the protocol. It is imperative that the sender and the receiver should have the same baud rate. The rates have been standardized to any of these values; 1200, 2400, 4800, 9600, 19200, 38400, 57600, 115200 on microcontrollers. 9600 is the most commonly used and is the default baud rate for most serial terminals and simulators.

3.2 TRANSMITTER

A typical optical transmitter converts an electrical bit sequence to an optical data stream. Since light output of a LASER (Light Amplification by Stimulated Emission of Radiation) diode defined as a function of the input current rather than voltage, laser diodes are driven by currents.

Small variations in voltage over the diode would result in dramatic changes in current and light output. VCSEL (Vertical Cavity Surface Emitting Laser) is a commonly used type of laser diode in high-speed communication. A laser driver considered as a simple high-speed current switch controlled by a modulated data stream at the input. Generally, the laser driver is the component that determines the maximum speed and overall performance of the transmitter. To control the laser's output power that varies over temperature and over lifetime, some laser driver circuits incorporate a monitoring photodiode (MPD) that provides feedback. Typically, differential input is used and that offer many advantages, as reduced noise and a higher bandwidth. The first step in a transmitter is the serializer which multiplexes several low speed data signals to a single high speed data stream. Components needed for the transmitter;

I. Arduino Nano board
II. Jumper wires
III. Laser diode module (KY-008)
IV. 9V battery

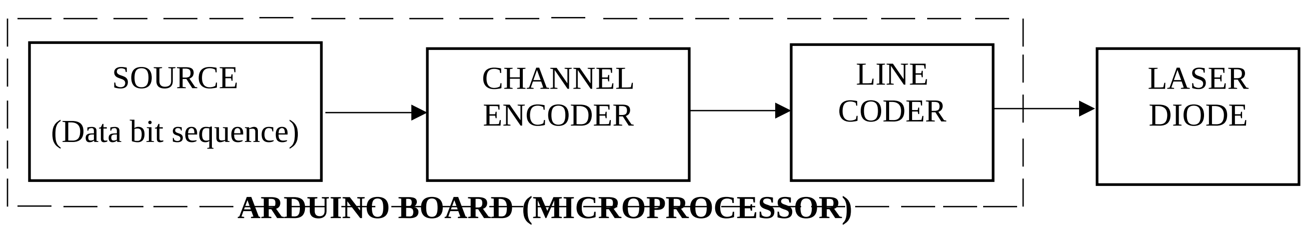

Figure 3.1: Block Diagram showing basic components of FSO Transmitter Model

Figure 3.2: Arduino Nano board

Figure 3.3: KY-008 Laser Diode Module

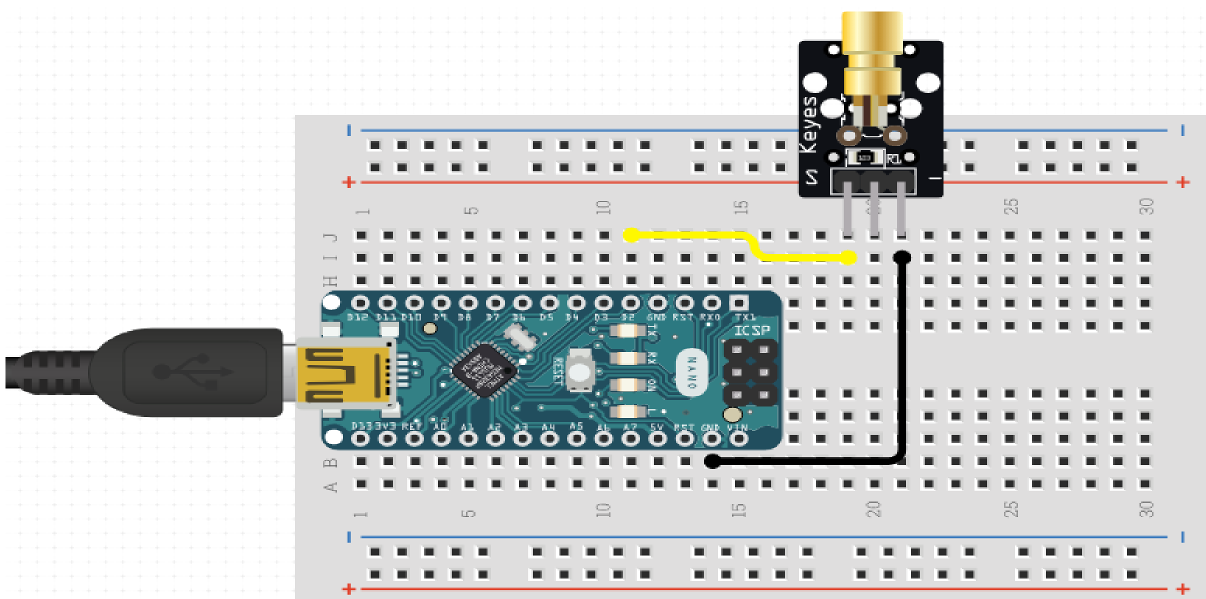

Figure 3.4: Breadboard design of transmitter

1. **SOURCE:** The input to a digital system is in form of sequence of digits. The input can be output from such sources as a data set, a computer, a digitized voice signal (PCM or DM).
2. **CHANNEL ENCODER:** The purpose of the channel encoder is to add redundancy to the transmitted signal, so that errors caused by noise during transmission are corrected at the receiver. Error-control coding is the process of encoding for protection against channel errors. There are two commonly employed methods for protecting electronically transmitted information from errors. One method called forward error control (FEC), in which information-bits are protected against errors by the transmitting of extra redundant bits. In case of errors occurrence during transmission, the decoder determines where the errors have occurred and how to correct them can use the redundant bits. Typical example seen in **Hamming code**, which is used in the course of this research, written block of codes, is imported to the microcontroller chip on the Arduino Nano board to implement this. Automatic repeat request (ARQ) is the second method of error control in which redundant bits added to the transmitted information and used by the receiver detect errors. The receiver then signals a request for a repeat transmission. Generally, the number of extra bits needed simply to detect an error, as in the ARQ system, is much smaller than the number of redundant bits needed both to detect and to correct an error, as in the FEC system.
3. **LINE CODER:** This converts or codes the bit sequence from the channel encoder into electrical pulses or waveforms for the purpose of transmission over the

channel. There are 3 basic types of line coding; Unipolar, Polar and Bi-polar under which some examples are seen;

a. Non-return to zero (NRZ) and Return to zero (RZ) unipolar format.
b. NRZ and RZ polar format.
c. Bipolar NRZ format.
d. Manchester format.
e. Polar quaternary NRZ format.

For the purpose of this research, **Manchester format** selected as the most suitable, block of code written into the microcontroller to implement this.

4. **LASER DIODE:** A laser diode is an optoelectronic device, which converts electrical energy into light energy to produce high-intensity coherent light. In a laser diode, the p-n junction of the semiconductor diode acts as the laser medium or active medium. Laser diodes are used in optical fiber systems, compact disc (CD) players, laser printers, remote-control devices, and intrusion detection systems.

   KY-008 (Laser Diode Module) Specifications;

   a. Parameter – Value.
   b. Supply Voltage - 5 Vdc.
   c. Current - 30 mA.
   d. Wavelength - 650 nm.
   e. Color – Red.

3.2.1 HAMMING CODE

Hamming code is a set of error-correction codes used to detect and correct the errors that can occur when the data is moved or stored from the sender to the receiver, was developed by R.W. Hamming for error (noisy channel) correction. Hamming codes can detect up to two-bit errors or correct one-bit errors without detection of uncorrected errors. Due to the limited redundancy that Hamming codes add to the data, they can only detect and correct errors when the error rate is low. Hamming codes are perfect codes, that is, they achieve the highest possible rate for codes with their block length and minimum distance of three, Hamming distance. Hamming distance, the distance between two codewords defined as the number of locations in which their respective elements differ.

Redundant bits

Redundant bits are extra binary bits generated and added to the information-carrying bits of data transfer to ensure that no bits are lost during the data transfer. The number of redundant bits calculated using the following formula:

$$2^r \geq m + r + 1$$

Where, r = redundant bit, m = data bit

Parity bits

A parity bit being a bit appended to a data of binary bits to ensure that the total number of 1's in the data are even or odd is used for error detection. If an odd number of bits is changed in transmission, the message will change parity and the error can be detected at this point; however, the bit that changed may have been the parity bit itself. The most common convention is that a parity value of one indicates that there is an odd number of ones in the data, and a parity value of zero indicates that there is an even number of ones. If the number of bits changed is even, the check bit will be valid and the error not detected. There are two types of parity bits:

i. Even parity bit: In the case of even parity, for a given set of bits, the number of 1's counted such that if the count is odd, the parity bit value is set to 1, making the total count of occurrences of 1's an even number. If the total number of 1's in a given set of bits is already even, the parity bit's value is 0. To calculate even parity, the XOR operator is used.

ii. Odd Parity bit: In the case of odd parity, for a given set of bits, the number of 1's counted such that if that count is even, the parity bit value is set to 1, making the total count of occurrences of 1's an odd number. If the total number of 1's in a given set of bits is already odd, the parity bit's value is 0. To calculate odd parity, the XNOR operator is used.

Even parity bit is the technique used in this research to detect errors. Hamming also noticed the problems with flipping two or more bits, and described this as the "distance". Parity has a distance of 2, so one-bit flip can be detected, but not corrected and any two bit flips will be invisible.

3.2.2 MANCHESTER CODE

In data transmission, Manchester encoding is a form of digital encoding (line coding technique) in which data bits represented by transitions from one logical state to the other is different from the more common method of encoding, in which a bit is represented by either a high state such as +5 volts or a low state such as 0 volts. In Manchester encoding, the duration of the bit divided into two halves ensures the voltage remains at one level during the first half and moves to the other level in the second half. The transition at the middle of the bit serves as a clocking mechanism and as data thus, providing synchronization.

The Manchester scheme overcomes several problems associated with NRZ-L, and overcomes several problems associated with NRZ-I. First, there is no baseline wandering. There is no DC component because each bit has a positive and negative voltage contribution. The only drawback is the signal rate. The signal rate for Manchester and is double that for NRZ. The reason is that there is always one transition at the middle of the bit and maybe one transition at the end of each bit. In the Manchester code, there is a transition at the middle of each bit period.

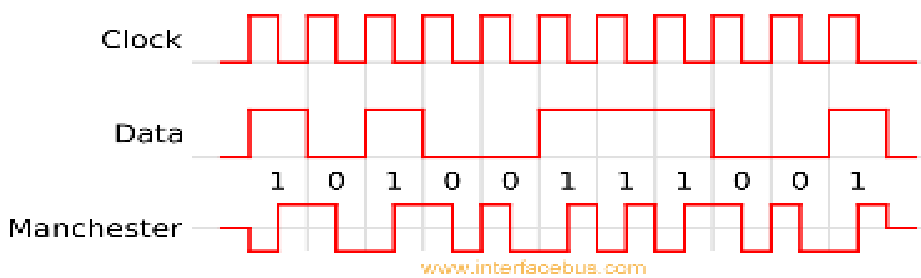

Figure 3.5: Waveform diagram of Manchester Data Encoding per IEEE-802.3

Advantages of Manchester code;

i. Synchronization: Since there is a predictable transition during each bit time, the receiver can synchronize on that transition. For this reason, the Manchester code is known as a self-clocking code.

ii. No dc component: It has no dc component, yielding the benefits described earlier.

iii. Error detection: The absence of an expected transition used to detect errors, since noise on the line would have to invert both the signal before and after the expected transition to cause an undetected error. Hence, high noise immunity.

3.3 RECEIVER

The receiver of the optical signal is a critical part in optical communication systems. The receiver principally determines the total performance because it handles the lowest signal level in the communication link. To obtain electrical output signal from optical input signal, a basic receiver consists of some type of photodiode and a trans-impedance amplifier (TIA). The photodiode for a high-speed system can consist either of a PIN photodiode or of Avalanche photodiode. A TIA converts the small photocurrent from the photodiode to a voltage while adding minimal noise. The voltage output from the TIA is generally too small to reach a detectable logic level so additional voltage amplification is necessary and thus a limiting amplifier (LA) is connected. A LA has a high gain and a maximum output voltage swing. The input signal generally always amplified to the maximum output voltage at the rails of the LA, produces a reasonable constant output voltage swing for a wide range of input signals. The LA connected to the TIA by dc-coupling, offset compensation is needed to avoid that the LA saturates at one rail. After the data stream amplified to detectable logic levels, noise removed from the signal and the clock extracted from the data by the clock and data recovery (CDR) circuit that also retimes the data to the extracted clock. The LA and TIA together generally called the analog front-end of the optical receiver.

However, the use of phototransistor in place of photodiode is of essence because it is more sensitive in view of the gain provided by the transistor and efficient. Hence, the use of phototransistor in this research.

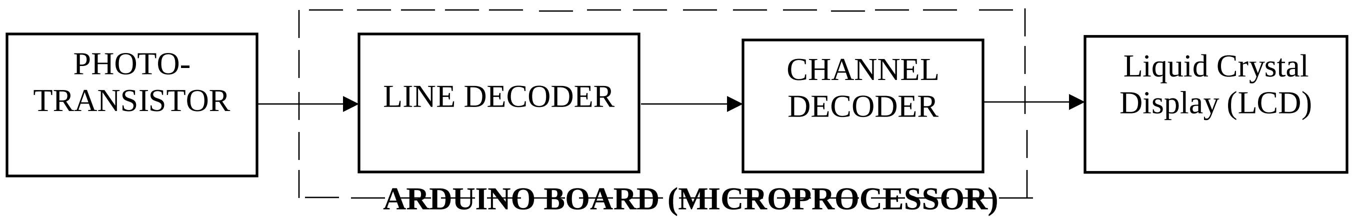

Figure 3.6: Block Diagram showing basic components of FSO Receiver Model

Figure 3.7: A Phototransistor

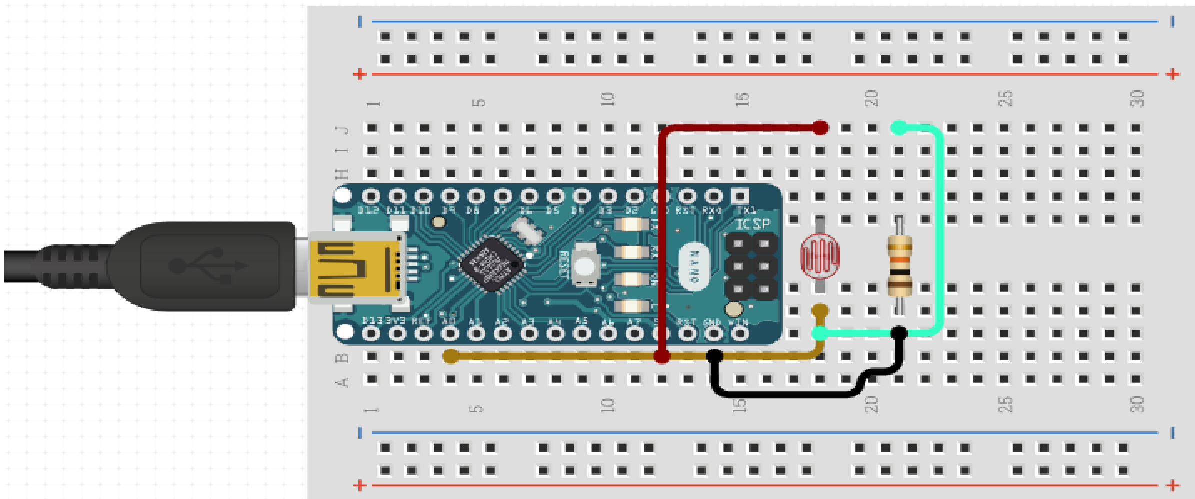

Figure 3.8: Breadboard design of receiver

Components needed for receiver;

I. Phototransistor.

II. Arduino Nano board.

III. Jumper wires.

IV. 9V battery.

V. Resistor, 1KΩ.

VI. Liquid Crystal Display (LCD) 16x2.

1. PHOTOTRANSISTOR

Phototransistors are more or less like normal transistors except for the fact that the base terminal is not present in case of the phototransistor. Phototransistors convert the incident light into photocurrent. Instead of providing the base current for triggering the transistor, the light rays used to illuminate the base region generates current that depends on several factors apart from luminous intensity such as:

i. DC current gain of the transistor: The higher the DC current gain of the transistor, the higher will be the intensity of photocurrent generated.

ii. Time constant: Response time of the transistor also effects the efficiency of phototransistor to generate photocurrent.

iii. Luminous Sensitivity: The luminous sensitivity determined by the ratio between the photoelectric current and incident luminous flux.

iv. Area of the collector-base junction: The area of the collector-base junction is crucial for the generation of photocurrent, the higher the area of the collector-base junction the higher will be the magnitude of photocurrent generated by the phototransistor.

v. Wavelength of the incident light: The wavelength of the light incident on phototransistor controls the amount of photocurrent generated. The higher the wavelength the lower will be the frequency.

Advantages of Phototransistor

a. **Higher Efficiency in Comparison to Photodiode:** The efficiency of the phototransistor is higher than that of the photodiode. This is because the current gain in case of the phototransistor is more than that of the photodiode, thus, even if the amount of light incident on both is same the phototransistor will generate more photocurrent than the photodiode.

b. **Faster Response:** The response time of phototransistor is more than that of the photodiode; this provides the advantage of using the phototransistor in our circuit.

c. **Less Noise interference:** The major drawback of photodiodes especially that of avalanche photodiodes is that it is not immune to noise interference. On the contrary, the phototransistors are immune to noise interference.

d. **Economical:** Phototransistor is less costly than other light sensitive device, thus it is economical to use phototransistors in light-sensitive applications.

e. **Less Complex:** The designing of phototransistors is simple and less complex as compared to LDRs and photodiodes.

2. **LINE DECODER:** Converting electrical pulses or waveform to its equivalent bit.
3. **CHANNEL DECODER:** Decoding is the process of translating received message into codewords of a given code. Codeword is the n bits encoded block of bits, it contains message bits and parity or redundant bits. Example of decoding technique used is **Syndrome decoding**.

SYNDROME DECODING

This is a highly efficient method of decoding a linear code over a noisy channel, one in which errors are made. Syndrome decoding is minimum distance decoding using a reduced lookup table. Minimum distance decoding picks a code word to minimize the Hamming distance. Important functions of the decoder are:

i. Error detection in the received code word.
ii. Error correction.

4. **LIQUID CRYSTAL DISPLAY (LCD):** The 16x2 LCD is a very basic module commonly used in DIYs and circuits. The 16x2 translates on a display 16 characters

per line in two such lines. In this type of LCD, each character is displayed in a 5x7-pixel matrix.

3.4 DESIGN AND IMPLEMENTATION

3.4.1 TRANSMITTER AND RECEIVER

TRANSMITTER

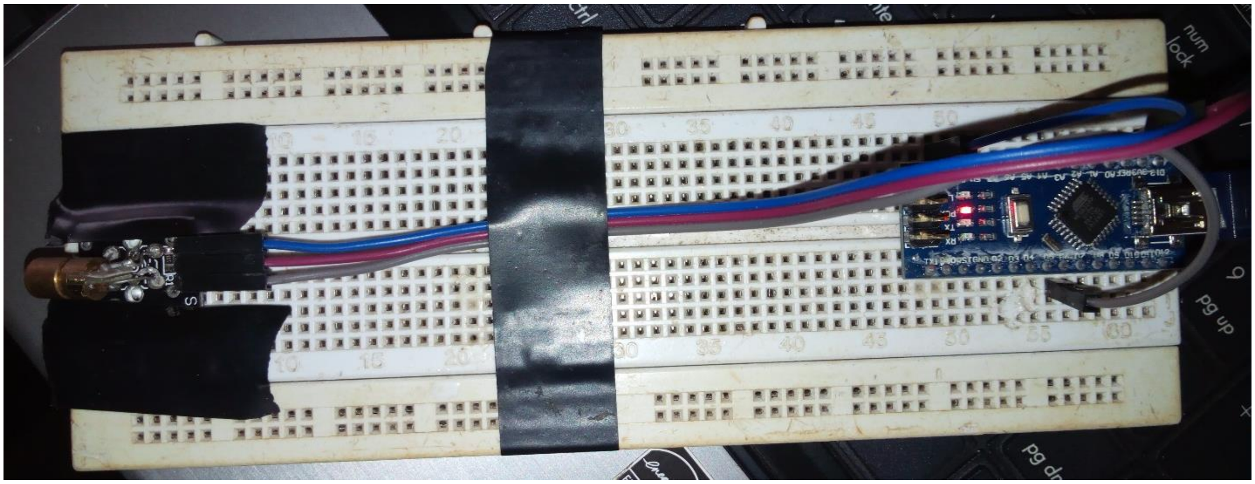

Figure 3.9: Breadboard implementation of transmitter

Steps to implementing transmitter:

I. Get a working Hamming and Manchester code library and integrate to Arduino software on a personal computer (PC).

II. Write the block of codes to send byte serially using an Arduino via laser diode. Include the Hamming and Manchester code library.

III. Connect the laser diode module via jumper wires to the Arduino board correctly; ground pin to ground and signal pin to programmed digital pin of the Arduino, in this case digital pin 6 (D6).

IV. Verify and import the block of codes to the microcontroller chip on the Arduino board via a USB cable.

```
1  /* Serial laser communicator, tran
2
3   The circuit:
4   * laser VCC pin to pin 6, - pin t
5   * photodiode signal on pin 7, pow
6
7   Note:
8   * timer 2 used
9   * For arduino uno or any board wi
10
11 */
12
13 #include <HT_hamming_encoder.h>
14 #include <HT_light_modulator.h>
15
16 HT_PhotoTransmitter laser;
17
18 void setup(){
19
20   laser.set_speed(5000);       // m
21   laser.begin();
22
23   Serial.begin(9600);
24
25 }//end setup
26
27
28 /*timer2 interrupt toggles LIGHT_S
30 /*timer2 interrupt toggles LIGHT_SEND_PIN
31 at determined speed to transmit each half bit*/
32 //via the manchester modulated signal.
33 ISR(TIMER2_COMPA_vect){
34
35   // transmit message, if any
36   laser.transmit();
37
38 }
39
40
41 void loop(){
42   char incomingByte;
43   uint16_t msg;
44
45   // Read text from the serial window
46   //incomingByte = Serial.read();
47   incomingByte = 209;
48   // Print incoming characters
49   if(incomingByte != -1){
50     Serial.print(incomingByte);
51
52    msg = hamming_byte_encoder(incomingByte);
53     laser.manchester_modulate(msg);
54
55     delay(1000);
56   }
57 }
```

Figure 3.10: Block of codes for the transmitter

Code explained:

i. Lines 15 and 16 handles the importation of the required libraries.

ii. Line 22 sets the frequency (speed) of transmission, which must be at least 500+ bits/sec, but less than the laser slew rate. Frequency of transmission is 5 KHz.

iii. Line 25 begins the serial monitor and serial communication with the PC at 9600-baud rate.

iv. Line 33 sets the interrupt for serial communication. An interrupt's job is to make sure that the processor responds quickly to important events. When a certain signal is detected, an interrupt interjects whatever the processor is doing and executes some code designed to react to whatever external stimulus is being fed to the Arduino. This is very vital in establish perfect optical communication using Arduino.

v. Line 47 declares the byte sent as 209 for example. A byte is equal to 8bits. 209 being 11010001 in binary.

vi. Lines 52 and 53 makes use of the included libraries to encode the data to be sent.

Figure 3.11: Packaged FSO transmitter

RECEIVER

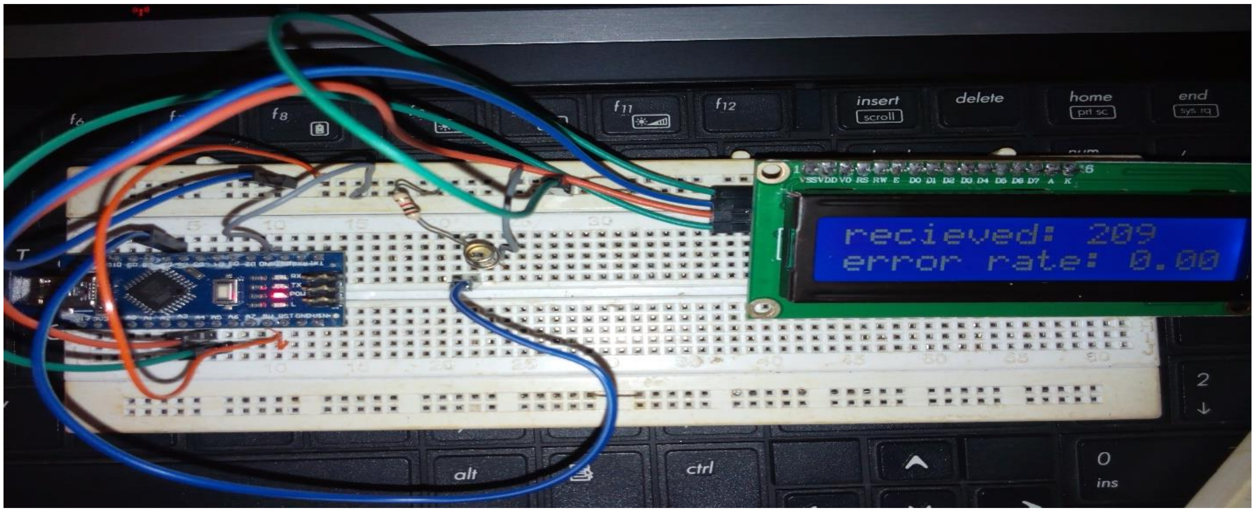

Figure 3.12: Breadboard Implementation of the Receiver

Steps to implementing receiver:

I. Include the Hamming and Manchester code libraries that have their respective decoding techniques.

II. Write the block of codes to receive incoming byte from the transmitter via the phototransistor.

III. Use common emitter configuration of phototransistor in which the emitter grounded via a 1kΩ resistor.

IV. Connect the collector to Vcc (5V) output pin on the Arduino board and connect the emitter to digital pin 7 (D7) programmed to receive the signal.

V. For the LCD, Connect the GND (ground) pin to the GND port on the Arduino board. Connect the Vcc pin to 5V the output pin on the Arduino board. Connect pin SCL to the analog pin 5 (A5) on the Arduino board. Connect pin SDA to the analog pin 4 (A4) on the Arduino board.

VI. Verify and import the block of codes to the microcontroller chip on the Arduino board via a USB cable.

```
/* Serial laser communicator, rec
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include <HT_hamming_encoder.h>
#include <HT_light_modulator.h>

LiquidCrystal_I2C lcd(0x3F,16,2);
HT_PhotoReceiver pdiode;

int expected = 209;
byte data = 0;
byte lastdata =0;
void setup(){
  lcd.init();
  lcd.init();
  lcd.backlight();
  pdiode.set_speed(5000);       //
  pdiode.begin();

  Serial.begin(9600);
  lcd.clear();
}//end setup


//timer2 interrupts LIGHT_RECEIVE
//via the manchester modulated si
ISR(TIMER2_COMPA_vect){

  //receive message, if any
  pdiode.receive();
}
int counterror(int bin){
  int n = bin, count = 0;
  while (n > 0){
     if (n % 2 == 0);
     else
      count++;
     n /= 2;
  }
  return count;
}
void loop(){

  //print and return most recently received byte, if any,
  data = pdiode.printByte();
  int val = int(data);
  Serial.println(val);
  if (val == expected){
    val = expected ^ val;
    val = counterror(val);
  }
  else {
    val = expected ^ val;
    val = counterror(val);
   Serial.println("number of wrong bits: " + String(val));
  }
  lcd.setCursor(0, 0);
  lcd.print("recieved: " + String(data));
  lcd.setCursor(0, 1);
  float error = val / 8.0;
  Serial.println(error);
  lcd.print("error rate: " + String(error));
  delay(1);
}
```

Figure 3.13: Block of codes for the receiver

Code explained:

i. Lines 2 through 5 imports all libraries required.
ii. Line 7 declares address for the LCD.
iii. Lines 10 declares the expected byte for purpose of error calculation.
iv. Lines 11 and 12 initializes variables.
v. Line 17 sets the receiver frequency that should be equal to the transmitter speed.
vi. Line 30 receives the incoming byte signal.
vii. Lines 32 through 41 is a function to covert the byte to bits.
viii. Lines 48 through 54 performs exclusive OR (XOR) logic operation on the received byte and the expected byte and counts the error bits.
ix. Lines 58 through 62 handles printing of received byte and bit error rate.
x. Line 60 calculates the bit error rate (BER).

$$BER = \frac{number\ of\ error\ bits}{total\ number\ of\ bits} \quad (6)$$

Figure 3.14: Establishing a link between transmitter and receiver at a distance of 3m.

Figure 3.15: Packaged FSO receiver

3.4.2 RAINFALL SIMULATOR

The rainfall simulator is used create a rainy environment at a controlled rate. Comprises of some basic components: a water pipe and stands to support the pipe. A measuring tape is used to obtain accurate distances between the transmitter and receiver. Controllable water supply from a tap serves as source of water.

Steps to making the simulator;

i. A pipe closed at one end of the pipe gotten.
ii. A drilling machine used to bore holes along the pipe to specific diameter relative to the raindrop size data of 1.5mm.
iii. Variation of distances used are 25cm to 250cm with a step of 25cm.

iv. Tap switched and allowed run to obtain rain rate according to rainfall data received, rain gauge used to obtain the rate.

Figure 3.16: Rainfall simulator along the path of FSO link.

CHAPTER FOUR

RESULTS AND DISCUSSION

According to Suriza (2011), determination of the rain rate to use in predicting accurately the attenuation of FSO signal under rain is done by obtaining the 0.01% exceeded rainfall rate. This is simply the occurrence of a particular rain rate 0.01% of the total frequency amongst the days of rainfall.

The rainfall data obtained from The Department of Meteorology, the raindrop size of rainfall in Akure is 1.5mm and the 0.01% exceeded rainfall rate obtained to be 12mm/hr, the highest rainfall rate being 15mm/hr. The maximum frequency below the laser slew rate for good reception is 5KHz. Wavelength of laser beam is 650nm.

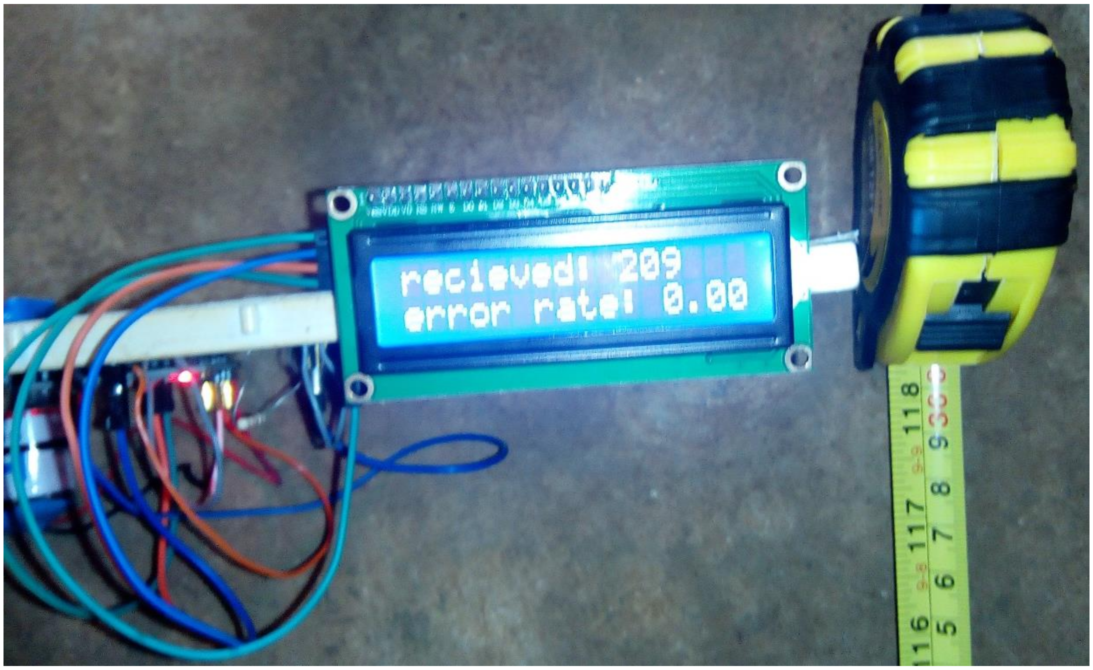

Figure 4.1: Test showing a distance of 300cm between transmitter and receiver without error

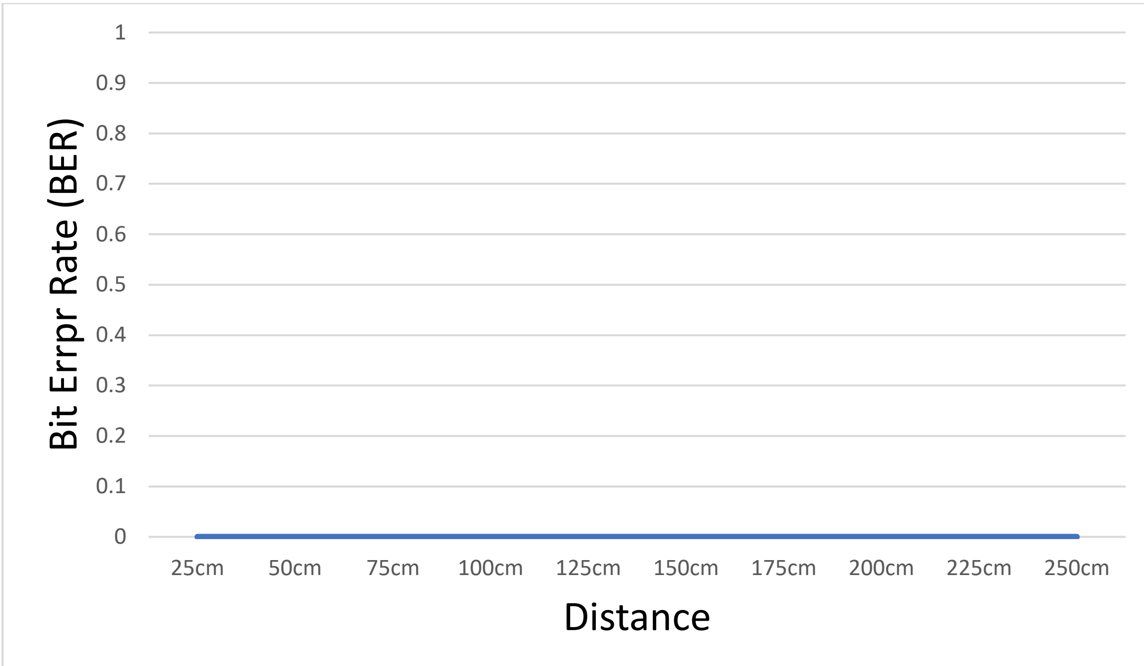

Figure 4.2: A line graph showing relationship between BER and distance without introduction the of rain along the transmission path

Table 4.1: Results of bit error rates obtained at 12mm/hr rain rate

S/N	Distance (cm)	Average BER of 5 reading (frequency=5KHz, Wavelength = 650nm)
1	25	0.03
2	50	0.05
3	75	0.10
4	100	0.13
5	125	0.15

6	150	0.19
7	175	0.21
8	200	0.23
9	225	0.25
10	250	0.35

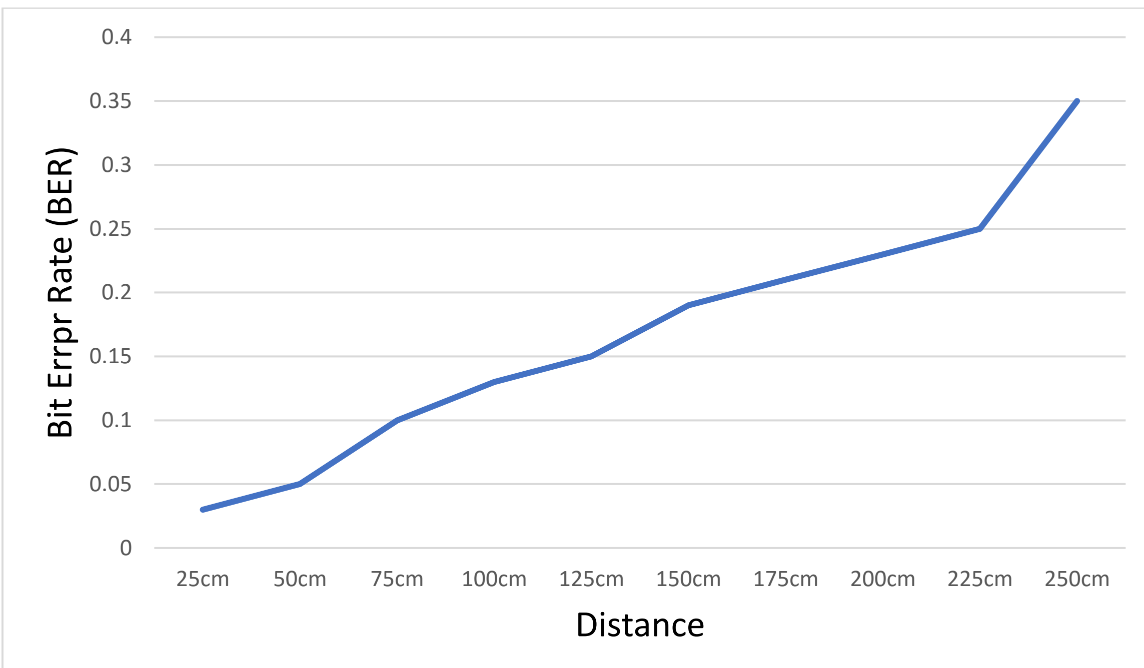

Figure 4.3: A line graph showing relationship between BER and distance with the introduction of rain along the transmission path

From figure 4.2, increase in distance up to the maximum 250cm has no effect on the performance of FSO since the BER recorded was zeros all through. From figure 4.3, increase in distance with rain led to increase in BER. Therefore, it can be said, from the results obtained, that rainfall has degrading effect on the performance of FSO link as increase in distance has proportional relationship with the quantity of rain along the path of FSO link leading to introduction of more errors in data stream sent.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Rainfall is the dominant factor that degrades the FSO link performance and its availability in tropical regions. In order to investigate the effects of rain on FSO, rain simulator modelled based on the rainfall data collected. The approach of using BER to obtain the performance of FSO link under rainy condition is effective in getting estimated values of attenuation of signal. This project has results of the increase in BER with increase in distance of rain along the transmission path, according to rain rate of Akure climate conditions.

5.2 CHALLENGES ENCOUNTERED

Challenges encountered during design and implementation are;

1. Ideal photo receiver: This is the major challenge encountered as getting the right component is paramount in obtaining sent data at the receiver. The use of a phototransistor that has a better sensitivity was as a result poor sensitivity of photo diode acquired.
2. Laser slew rate: The laser slew rate inhibited the range of frequencies feasibly used as higher frequencies resulted in no signal reception at the receiver.
3. Getting functional libraries of code: There was difficulty obtaining functional libraries for both Hamming code and Manchester code, which are vital in transmitting data, hence, reduced progress speed of the project.
4. Rainfall simulator: Controlling the rain rate was also a serious challenge as the tap control is not precise enough.

5. Limited number of bits: Complexity of code for transmitting a byte of data led to limitation in the number of bits that could be sent successfully, hence reducing accuracy of results obtained.

5.3 RECOMMENDATION

Because of the challenges encountered, below are some suggestions to produce better estimate of result:

1. The use of high-speed laser like VCSEL (Vertical Cavity Surface Emitting Laser) helps in overcoming the challenge of laser slew rate.
2. Photodiode module are ideally better when compared with transistors as they work better with Arduino boards.
3. Use of a more precise rainfall simulator would ensure better-controlled rain rate and hence, better results obtained.
4. Data including more bits of up to 1000bits would ensure high precision and hence better results.

REFERENCES

Abdulrahman A., R. T. (2011). Empirically derived path reduction factor for terrestrial microwave links operating at 15 GHz in Peninsula Malaysia. *Journal of Electromagnetic Waves and Applications. (25)*, 23-37.

Awang, M. A. (2004). Comparison of the rain drop size distribution model in tropical region. *Paper presented at the Proceedings of RF and Microwave Conference.*

B.S., W. H. (2001). Fiber optics without fiber. *IEEE Spectrum,vol.38,no.8*, 40–45.

Basahel A., A.-K. W. (2014). Availability analysis of terrestrial free space optical link under the impact of rain condition. *International Conference on in Computer and Communication Engineering*, 169-172.

Carbonneau T. H. and Wisely D. (1998). Opportunities and challenges for optical; the competitive advantage of free space telecommunications links in today's crowded market place. *SPIE Conference on optical wireless communications*, 119-128.

Channel encoding. (2018). Retrieved from britannica: https://www.britannica.com/topic/channel-encoding

computer network. (2018, september). Retrieved from geeksforgeeks: https://www.geeksforgeeks.org/computer-network-hamming-code/

Data Encoding Techniques. (2018, September 6). Retrieved from tutorialspoint: https://www.tutorialspoint.com/digital_communication/digital_communication_line_codes.htm

digest, c. (n.d.). *DIY*.

Emiliani, L. D. (2008). Extension of ITU-R method for conversion of rain rate statistics from various integration times to one minute. *Electronics Letters, 44(8)*, 557-558.

Ishii, S. S. (2010). Rain Attenuation at Terahertz. *Wireless Engineering and Technology 1*, 92-95.

J., K. (2011). Free space optical communications: an overview of applications and technologies. *Proceedings of the Boston IEEE Communications Society Meeting*.

Norhanis A. M., M. R.-K. (2013). Atmospheric Effects on Free Space Earth-to-satellite Optical Link in Tropical Climate. *International Journal of Computer Science, Engineering and Applications (IJCSEA) Vol.3*, 1.

Ojo, J. S. (2008). Rain Rate and Rain Attenuation Prediction for Satellite Communication in KU and KA Bands over Nigeria. *Progress In Electromagnetics Research B, 5*, 207-223.

Rahman A. K., A. M. (2008). Study of rain attenuation consequence in free space optic transmission. *Proceedings of the 2nd Malaysia Conferenceon Photonics Telecommunication Technologies (NCTT-MCP '08)* (pp. 64–70). Putrajay: IEEE.

semiconductor diodes. (2018). Retrieved from Physics and radio electronics: http://www.physics-and-radio-electronics.com/electronic-devices-and-circuits/semiconductor-diodes/laserdiode.html

Suriza A.Z., I. M.-K. (2011). Analysis of Rain Effects on Terrestrial Free Space Optics based on data measured in Tropical Climate. *IIUM Engineering Journal, Vol. 12, No. 5*, 46-47.

Vigneshwaran S., M. I. (2013). Investigations on free space optics communication system. In *Proceedings of the International Conference on Information Communication & Embedded Systems (ICICES '13)* (pp. 819–824). Chennai, India: IEEE.

Zhou, X. X. (2009). Conversion model of one-minute rainfall rate distribution in Singapore. *Paper presented at the IEEE Antennas and Propagation Society International Symposium.* APSURSI.