CHAPTER I

INTRODUCTION

1.1 Background of Study

Currently, the fiber optic technology has successfully met all expectations and the prediction is that it will not be replaced by another technology for many years to come. However, there are certain applications that require immediate ultra - high data rate services, but either there is no existing fiber deployed, or there is insufficient fiber infrastructure. In this case, and until fiber is deployed, another optical communications technology is needed rapidly. Such technology is the Free Space Optics (FSO) (Kartalopoulus *et al*, 2011:3).

For outdoor communication, FSO system uses a modulated laser beam as the transmitter and a sensitive photodetector as the receiver. As we can see in Figure 1.1, a simple communications link is constructed with a laser beam directed to an unobstracted photodetector. By using two laser photodetector transceivers the system will provide full duplex FSO link. There are many advantages of FSO system than fiber optic system. First is because the laser beam has a wavelength in the micrometer range which is not like the traditional electro magnetic radio spectrum (meter – millimeter), there is no need for Federal Communication Commission (FCC) or municipal license approvals. As a consequence, FSO links and FSO networks can be set up and be deployed rapidly. The second is FSO cost is also very low as compared with cost of fiber, if one considers the time and cost to obtain right of way permits (private, municipal, enterprise), and the labor intensive fiber planning and deployment. (Kartalopoulus *et al*, 2011:4)

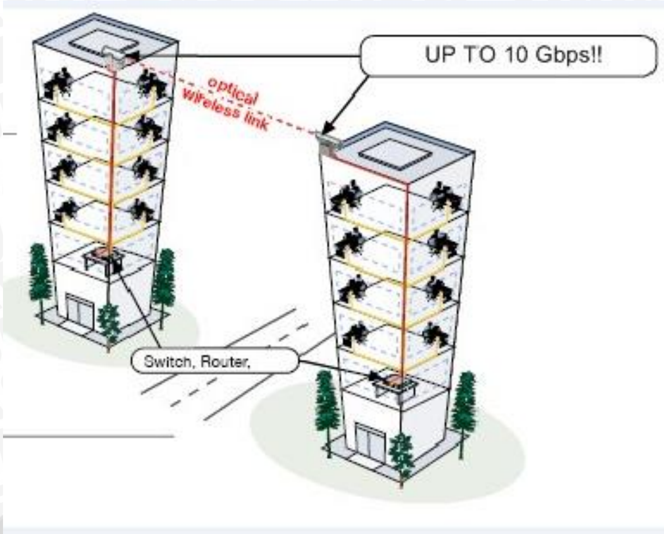


Figure 1.1 Free Space Optical communication network between two buildings (Source: http://www.laser-link.co.uk/)

As Free Space Optical Communication get more mature and become viable for multi-user communication systems, advanced multiple-access technique become more important and attractive in such systems. Among all multiple-access techniques in optical domain, Optical Code Division Multiple Access (OCDMA) is of outmust interest because of its flexibility, ease of implementation, no need for synchronization among many users, and soft traffic handling capability (Arnon *et al*, 2012:54).

But, it is known that OCDMA systems suffer from different noises such as a shot noise, thermal noise, a dark current, and a Multiple Access Interference (MAI) arising from other users. Of these noises, the MAI is generally considered as a dominating source. Reasonable designs of the code sequence are therefore important in order to reduce contribution of the MAI to the total power received. Spectral Amplitude Codewords for the Optical Code Division Multiple Access (SAC OCDMA) system offers a good solution that reduces the MAI effect by utilising codes with a fixed in-phase cross-correlation (Hussein *et al*, 2012:1).

A lot of codes have been suggested for the SAC OCDMA networks, an Optical Orthogonal Code (OOC), a prime code, a Khazani–Syed (KS) code, an Enhanced Double Weight (EDW) code, a Modified Frequency Hopping (MFH) code, a Modified Quadratic Congruence (MQC) code, a Random Diagonal (RD) code, a Modified Double Weight (MDW) code. These codes suffer from several limitations: the code length is often too long (e.g., for the OOC, KS and the EDW codes), the code construction is limited by the code parameter (e.g., for the MQC and MFH codes), whereas the crosscorrelation usually increases with increasing weight number (e.g., for the prime code and the RD code).

In addition, the codes suggested above, cannot support large enough numbers of simultaneous users or high data rates. To overcome these problems, there is a codeword called Multi Diagonal (MD) code. The MD code is designed basing on combination of diagonal matrixes. This new code has several advantages, including zero cross-correlation that cancels the MAI, flexibility in choosing the parameters *W* (code weight) and *K* (total subscribers), if compared with the other codes like the MQC one, a simple design, support of a larger number of users with higher data rates, and no overlapping occurred for the spectra characteristic for different users (Hussein *et al*, 2012:2).

However, the laser beam propagates through the atmosphere, and in most cases through its lower layer known as troposphere, which is not a well defined stable medium like the dielectric fiber. The troposphere is not a stable medium over time and thus its physics, chemistry and varying parameters should be well - understood and considered in FSO link design to warrant a link operation at the expected performance and efficiency (Kartalopoulus *et al*, 2011:5). Therefore selecting line coding format is also important to overcome this issue.

There are many kinds of line coding, like Non Return to Zero (NRZ), Return to Zero (RZ), and Manchester. In this thesis we successfully simulate MD-SAC OCDMA with 4 different line coding schemes which are non chirped NRZ, chirped NRZ, RZ, and Manchester by using OptiSystem 13. The performance has been evaluated on the effects of the variation of attenuation to the maximum distance and BER of the system

1.2 Problem Statements

Free Space Optical (FSO) communication should be considered in telecommunication system because FSO communication represents the most optimal solution in terms of technology (optical), bandwidth scalability, speed of deployment (compared with fiber optic system) and cost effectiveness (at least one fifth) (Willebrand et al, 2002:2). Therefore, FSO communication system becomes more popular and also there are many types of research that have been done about improving the quality FSO Communication system, for example Modelling and simulation of a 1.6 Tb/s optical system based on multi-diagonal code and optical code-division multiple-access which has been done by Hussein and team in 2012. In SAC OCDMA system, Multi-Diagonal Codeword is used because it has zero Multiple Access Interference (MAI) so that it is suitable to maintain the quality of multiple-access system.

As we know that Bit Error Rate is one of the fundamental parameters in telecommunication system that can be quality indicator of the system. There are several ways to improve the BER value of the system one of them is choosing correct line coding. There are many kinds of line coding which each has different impact to the quality of the system. Based on the problems associated with the performance of an FSO communication system, then formulation of problem can be made as follows:

1) How to design MD-SAC OCDMA simulation for 2 subscribers with 4 different types of line coding which are non chirped NRZ, chirped NRZ, RZ and Manchester ?
2) How the influence of the line coding formats to the MD-SAC OCDMA FSO system performance depend on the variation of distance and weather attenuations which are suitable to Malaysia weather?

1.3 Scope of Problems

Scope of problem based on the formulation of the problems above is focused on:

1. Transmission medium used is free space of Malaysia which has 5 different weather conditions.
2. The weather conditions of Malaysia are clear, haze, light rain, medium rain and heavy rain.
3. The line coding formats are non chirped NRZ, chirped NRZ, RZ, and Manchester.
4. Total subscribers of the system is 2
5. The simulation research used CW laser as the transmitter which has linewidth of 100 Mhz.
6. The receiver used is InGaAs pin photodiode which has responsivity up to 1 A/W and dark current 10 nA.
7. The receiver apperture diameter is 15 cm
8. The beam divergence is 2 mrad
9. The transmitter apperture diameter is 2.5 cm
10. The loss insertion of multiplexer and demultiplexer is 0.7 dB (http://www.ozoptics.com/ALLNEW_PDF/DTS0089.pdf)

11. The bit rates used are 10 Gbps
12. The wavelength system is operated in 1550 – 1552.4 nm.
13. The data used in this thesis based on simulation by OptiSystem 13 software, without direct experimental.

1.4 Objective

The objective of this thesis is to design and compare the performance of non chirped NRZ, chirped NRZ, RZ, and Manchester line coding formats for MD-SAC OCDMA with variation of distances and weather attenuations in Free Space Optics system.

1.5 Systematic of Writing

The systematic of writing this thesis consists of five chapters which are introduction, literature review, research methods, experimental results and discussion and conclusions and advice. Background, formulation of the problems, the scope of project, objective, and systematic writing described in Chapter I.

Chapter II is a review of the literature. This chapter examines the theories that support this thesis. The theory discussed is about FSO, non chirped NRZ, chirped NRZ, RZ, and Manchester line coding. In Chapter III will describe the research methods used to answer the problem formulation. The steps being taken in this research are the determination of the type and method of data collection, variables and method of analysis used, and framework solution to the problems presented in the form of flow charts and discussion.

Chapter IV contains experimental results and discussion. In this chapter described the process to obtain measurement data along with the specifications of the devices used and analysis of the data that has been obtained from experiments. Conclusions and suggestions obtained from this thesis is outlined in Chapter V.

CHAPTER II
LITERATURE REVIEW

This chapter is divided into several main topics about the basic concept of Free Space Optics, Free space optical communication components, butterworth filter and NRZ, chirped NRZ, RZ, Manchester line coding format and the last is Multi Diagonal Spectral Amplitude Codeword Optical Code Division Multiple Access (MD-SAC OCDMA). This part is compulsory to ensure that the objectives and the scope of project research are achieved.

2.1 Free Space Optics

Free-Space Optics (FSO) offers high-speed wireless communication between two locations, delivering fiber-like performance without the fiber. FSO operates by sending infrared laser beams from a transceiver mounted on the rooftop of a high-rise building or behind a window of a building. The laser beams are directed at a similarly positioned transceiver located on or within another building. Clear line-of-sight between the two transceivers is required for the system to work.

Compared with fiber optic, free space optics has some advantages, first is free-space optical communications can be implemented in a matter of weeks or even days at a fraction of the cost because free space optics is not currently covered by radio communication, so that we don't need any permission to deploy free space optical communication system. The second is fiber deployments are a sunk infrastructure, which is lost when the customer leaves the building or decides to cancel the service. In contrast, FSO is a redeployable platform, thereby proposing a zero sunk cost model. Furthermore, because of FSO's flexibility and ease of deployment in multiple architectures, it offers an economic advantage over fiber optics. And the third is as we know that sometimes to deploy fiber optic communication system requires digging of trenches, which may cause pollution, cutting of trees, and destruction of historical landmarks. FSO does not, therefore, it is friendly to the environment (Willebrand *et al*,2002:6).

Whereas fiber-optic cable is a predictable medium, free space, as an open medium, is less predictable (atmospheric attenuation is one example). Because of this unpredictability, it is more difficult to control the transmission of optics through free space. This unpredictability affects the system availability and maximum design capacities. FSO is also a line-of-sight technology, which means that the points that interconnect have to be able to see each other without anything in between. The one of main issues creating potential compromise of a link is attenuation which is caused by wheater.

2.2 Free Space Optical Communication Components

The purpose of Free Space Optical Communication to send data using optical signal through space or air. The main component of Free Space Optical Communication system is shown by Figure 2.1.

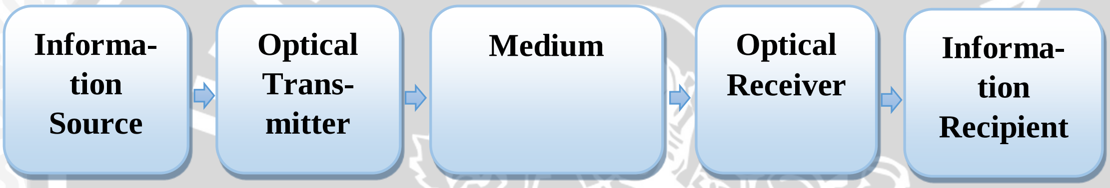


Figure 2.1 Free Space Optical Communication Component

For Transmission and receiver side,each has several modules following (Bouchet *et al*, 2006:174) :

- For Transmission:

- the connection interface: electric or optic to send and receive numerical data,
- the electric/optic conversion module (in the event of optical interface),
- the filtering and amplification of the digital electric signal,
- the optical transmission module containing the laser.

- For Reception:

- the optical reception module containing the diode,
- the filtering and amplification of the digital electric signal,
- the optic/electric conversion module (in the event of optical interface),
- the connection interface: electric or optic to send and receive the numerical data.

The example of free space optical transceiver is shown by Figure 2.2

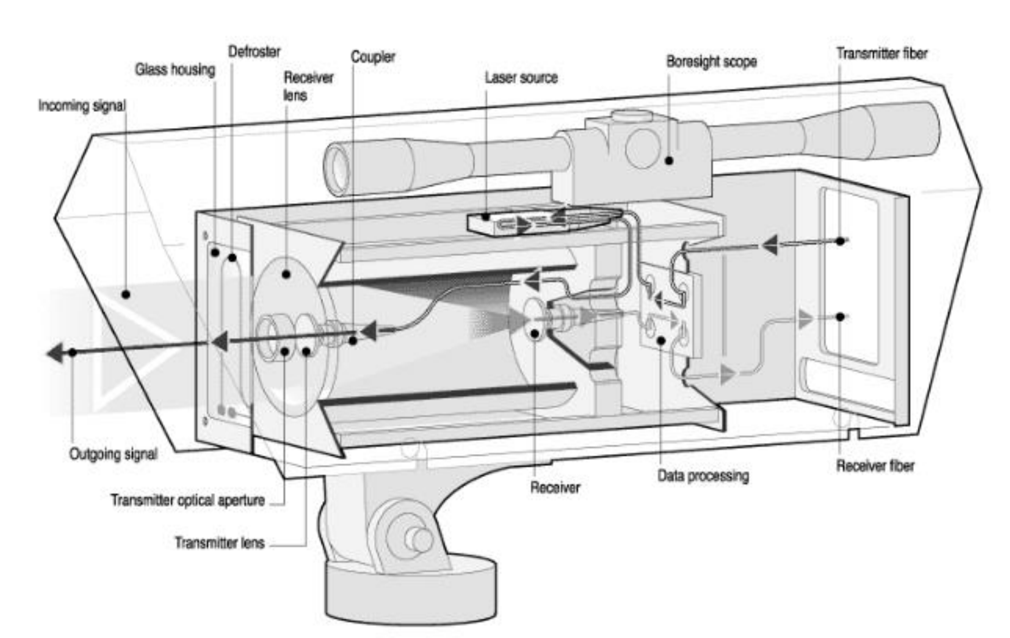


Figure 2.2 Example Equipment for Free Space Optical Link

(Source: Bouchet *et al*, 2006:175)

2.3 Butterworth Filter

The Butterworth filter is the best compromise between attenuation and phase response. It has no ripple in the pass band or the stop band, and because of this is sometimes called a maximally flat filter. The Butterworth filter achieves its flatness at the expense of a relatively wide transition region from pass band to stop band, with average transient characteristics.

The normalized poles of the Butterworth filter fall on the unit circle (in the *s* plane). The pole positions are given by:

$$-sin\frac{(2K-1)\pi}{2n} + j\cos\frac{(2K-1)\pi}{2n} \qquad K = 1,2,\dots,n \;, \qquad (2\text{-}1)$$

where K is the pole pair number, and n is the number of poles. The poles are spaced equidistant on the unit circle, which means the angles between the poles are equal. Given the pole locations, ω_o and α (or Q) can be determined. These values can then be use to determine the component values of the filter. The design tables for passive filters use frequency and impedance normalized filters. They are normalized to a frequency of 1rad/sec and impedance of 1 Ω. These filters can be denormalized to determine actual component values. This allows the comparison of the frequency domain and/or time domain responses of the various filters on equal footing. The Butterworth filter is normalized for a –3 dB response at $\omega_o = 1$ (http://www.analog.com/library/analogDialogue/archives/4309/EDCh%208%20filter.pdf?doc=ADA4666-2.pdf)

2.4 Signal Element Versus Data Element

A data element is the smallest entity that can represent a piece of information or it can be called bit. In digital communications, a signal element carries data element. A signal element is the shortest unit (timewise) of a digital signal. In other words, data elements are what we need to send, signal elements are what we can send. Data elements are being carried and signal elements are the carriers. The ratio *r* is the ratio between number of data elements to signal elements which are carrying the data elements (Forouzan,2007:102). Figure 2.3 shows the ratio *r* = 1 and Figure 2.4 shows the ratio *r* = ½

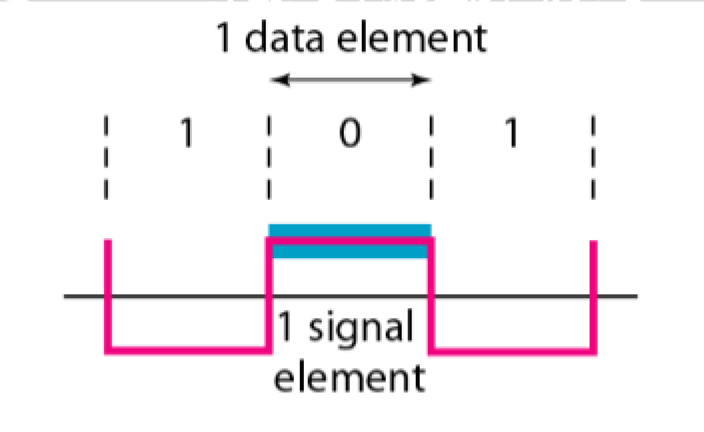


Figure 2.3 Data Elements

(Source: Forouzan, 2007:102)

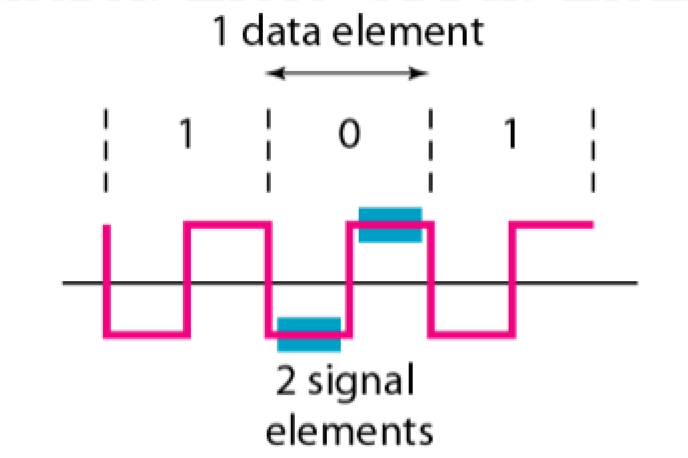


Figure 2.4 Signal Elements

(Source: Forouzan, 2007:102)

2.5 Data Rate Versus Signal Rate

The data rate defines the number of data elements (bits) sent in 1 second. The unit is bits per second (bps). The signal rate is the number of signal elements sent in 1 second. The unit is baud. There are several common technologies used in the literature. The data rate is sometimes called the bit rate, the signal rate is sometimes called the pulse rate, the modulation rate, or the baud rate.

We can formulate the relationship between data rate and signal rate as

$$S = c \times N \times \frac{1}{r} \tag{2-2}$$

Where N is the data rate (bps), c is the case factor, which varies each case, S is the number of signal elements, and r is the ratio between number of data elements to signal elements which are carrying the data elements (Forouzan,2007:103).

2.6 Non Return to Zero (NRZ)

2.6.1 Unipolar NRZ

Traditionally, a unipolar scheme was designed as a Non Return to Zero (NRZ) scheme in which the positive voltage defines bit 1 and the zero voltage defines bit 0. It is called NRZ because the signal doesn't return to zero at the middle of the bit. Figure 2.5 show a unipolar NRZ scheme. If we compared with polar NRZ, this scheme is very costly because the normalized power (power needed to send 1 bit per unit line resistance) is double that for polar NRZ. For this reason, this scheme is normally not used in data communication today (Forouzan,2007:107).

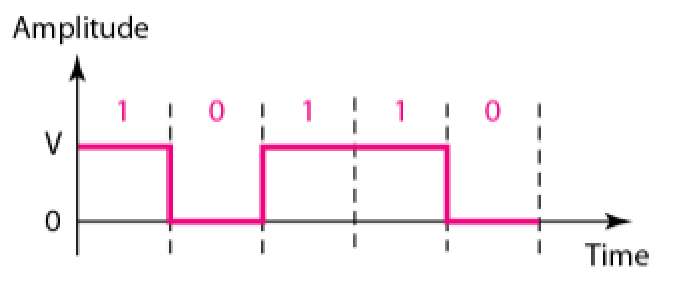


Figure 2.5 Unipolar NRZ Signal

(Source: Forouzan, 2007:107)

2.6.2 Polar NRZ

In polar scheme, the voltage are on both sides of the time axis. For example, the voltage level for 0 can be positive and the voltage level for 1 can be negative. In polar NRZ encoding, we use two of voltage amplitude. We can have two version of polar NRZ : NRZ-L and NRZ-I, as shown in Figure 2.6. In the first variation, NRZ-L (NRZ-Level) the level of voltage determines the value of bit. In the second variation, NRZ-I (NRZ-Invert) the change or lack of chanfe in the level of the voltage determines the value of the bit. If there is no change, the bit is 0, if there is a change, the bit is 1 (Forouzan,2007:107).

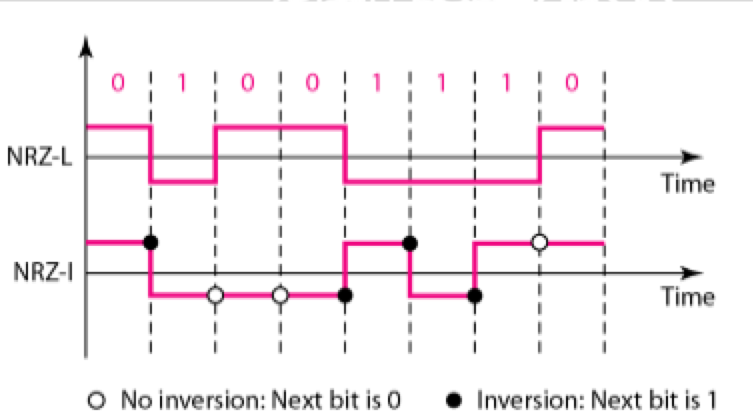


Figure 2.6 NRZ-L and NRZ-I Signal

(Source: Forouzan, 2007:107)

2.6.3 Chirped NRZ

The chirped NRZ pulses are generated by a phase modulation of NRZ pulses in an additional phase modulator, which is driven by the cosine-clock signal at the half bit-rate (Hodzig *et al*, 2011:1). The chirped NRZ generator is presented in Figure 2.7.

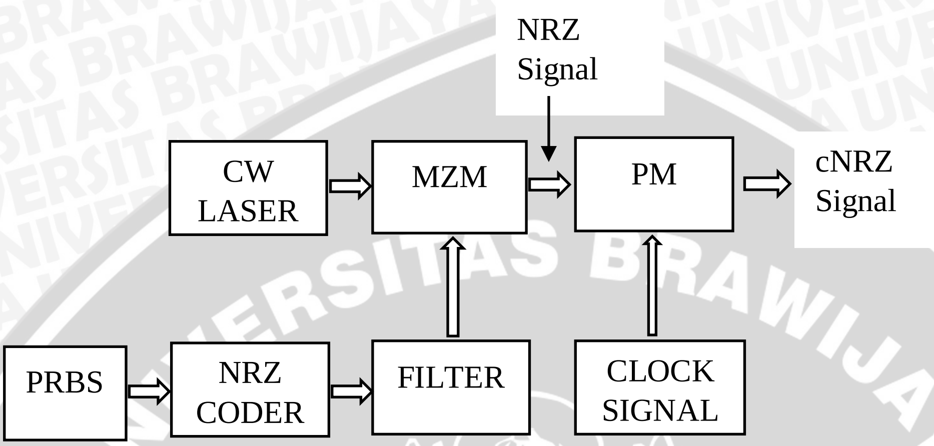


Figure 2.7 Pre Chirp System Setup

(Source: Hodzig *et al*, 2011:1)

2.7 Return to Zero (RZ)

Return to Zero (RZ) is a line coding scheme which uses three values: positive, negative, and zero. In RZ, the signal changes not between bit, but during the bit. Figure 2.8 show the signal goes to 0 in the middle of each bit. It remains there untill the beginning of the next bit. The main disadvantge of RZ encoding is that it requires two signal changes to encode a bit and therefore it occupies greater bandwidth. The another problems it needs 3 level of voltage which is more complex to create and discern (Forouzan, 2007:109).

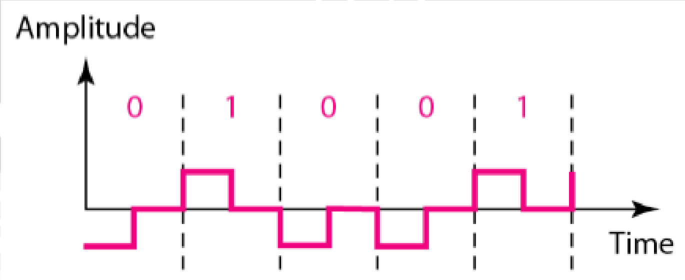


Figure 2.8 RZ signal

(Source: Forouzan, 2007:109)

2.8 Manchester

The idea of RZ (transition at the middle of the bit) and the idea of NRZ-L are combined into the Manchester scheme. In Manchester encoding, the duration of the bit is divided in two halves. The voltage remains at one level during the first half and moves to the other level into second half. The transition at the middle of the bit provides synchronization. Figure 2.9 shows how the Manchester scheme works (Forouzan, 2007:109).

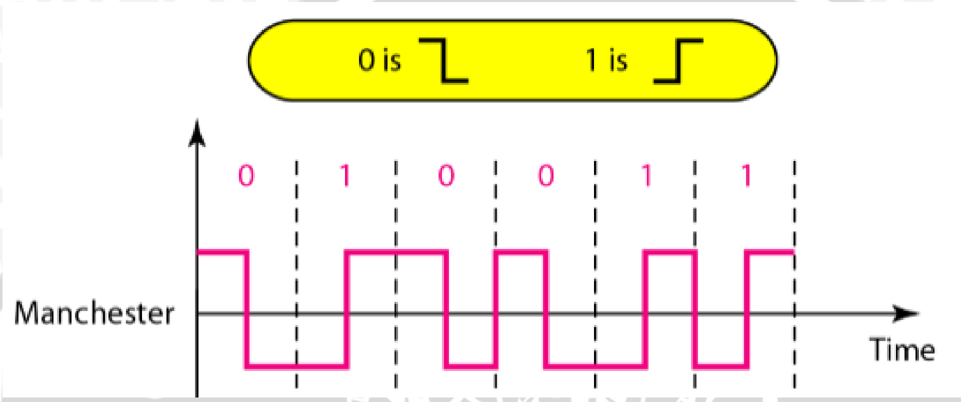


Figure 2.9 Manchester signal

(Source: Forouzan, 2007:109)

2.9 Multi Diagonal Spectral Ampltude Codewords for Optical Code Division Multiple Access (MD-SAC OCDMA)

The MD code is characterised by the parameters *N*, *W* and λ_c where *N* is the code length (i.e., the number of total chips), *W* the code weight (the number of chips having the unit value), and λ_c is in-phase cross-correlation.

Now let us formulate the cross-correlation theorem. First let us introduce, as usual in the linear algebra, the identity (or unit) matrix of size *N* as an *N*-by-*N* square matrix with unit components on its main diagonal and zero components elsewhere. It is denoted as I_N , or simply *I*, if the size is immaterial. Eventually, it can be defined as follows:

$$I_1 = [1]\ I_2 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}\ I_3 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}, \ldots, I_N = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \ddots & 0 \\ 0 & 0 & \cdots & 1 \end{bmatrix}$$

Using a notation used sometimes to concisely describe diagonal matrices, we can write I_N = diag (1,1,1,...).

The orthogonal matrix represents a square matrix with real entries whose columns and rows are orthogonal unit vectors. In Other words, a matrix A Is orthogonal if its transpose is equal to its inverse $A^T A = AA^T = I$. The orthogonal matrix represents a square matrix with real entries whose columns and rows are orthogonal unit vectors. In other words, a matrix A Is orthogonal if its transpose.

The matrix of the MD code represents a $K \times N$ matrix depending functionally on the number of users K, and the code weight W. For the MD code, the choice of the weight value is free, though it should be larger than unity ($W > 1$). The following steps explain how the MD code is constructed.

Step 1 :

First, let us construct a sequence of diagonal matrices using specific values of the weight W and the number of subscriber K. According to these values, we have the set i, j_W. Here K and W are positive integer numbers, so that $i = 1, 2, 3, \dots i_n = K$ are defined by the number of rows in each matrix, and $j_W = 1, 2, 3, \dots i_n = W$ represent the number of diagonal matrices.

Step 2 :

The MD sequences are computed for each diagonal matrix basing on the relations

$$s_{\boldsymbol{i},\boldsymbol{j}_W} = i_{\boldsymbol{n}} + 1 \Rightarrow \quad \text{for } j_W = \text{even number}$$

$$s_{\boldsymbol{i},\boldsymbol{j}_W} = i \quad \Rightarrow \quad \text{for } j_W = \text{odd number}$$

$$S_{i,1} = \begin{bmatrix} 1 \\ 2 \\ 3 \\ \vdots \\ K \end{bmatrix}, S_{i,2} = \begin{bmatrix} K \\ \vdots \\ 3 \\ 2 \\ 1 \end{bmatrix}, S_{i,3} = \begin{bmatrix} 1 \\ 2 \\ 3 \\ \vdots \\ K \end{bmatrix}, \dots, S_{i,W} = \begin{bmatrix} 1 \\ 2 \\ 3 \\ \vdots \\ K \end{bmatrix}$$

It is evident that $T_{i,1} = [S_{i,1}]_{KxK}$, $T_{i,2} = [S_{i,2}]_{KxK}$ and $T_{i,W} = [S_{i,W}]_{KxK}$. Therefore we get

$$T_{i,1} = \begin{bmatrix} 1 & 0 & \dots & 0 \\ 0 & 1 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1 \end{bmatrix}_{KxK}, T_{i,2} = \begin{bmatrix} 0 & \dots & 0 & 1 \\ 0 & \dots & 1 & 0 \\ \vdots & \iddots & \vdots & \vdots \\ 1 & 0 & \cdots & 0 \end{bmatrix}_{KxK}, \dots, \quad T_{i,W} = \begin{bmatrix} 1 & 0 & \dots & 0 \\ 0 & 1 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1 \end{bmatrix}_{KxK}$$

Step 3 :

The total combination of diagonal matrices given by Eq. (3) represents the MD code as a $K \times N$ matrix:

$$\text{MD} = [T_{i,1} \vdots T_{i,2} \vdots \cdots \vdots T_{i,W}]_{KxN}$$

$$MD = \begin{bmatrix} a_{1,1} & a_{1,2} & \cdots & a_{1,N} \\ a_{2,1} & a_{2,2} & \cdots & a_{2,N} \\ a_{3,1} & a_{3,2} & \cdots & a_{3,N} \\ \vdots & \vdots & \cdots & \vdots \\ a_{i_n,1} & a_{i_n,2} & \cdots & a_{i_n,N} \end{bmatrix}$$

In the basic matrix given by Eq. (5), the rows determine the number of users. Notice that the association between the code weight, the code length and the number of subscribers may be expressed as

$$N = KxW$$

In order to generate the MD code family according to the previous steps, let us put, as an example, K= 4 and W = 3. Then $i = 1,2,3,4$, $i_n + 1 = 5$, and $j_W = 1,2,3$

$$S_{i,1} = \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}, S_{i,2} = \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}, S_{i,3} = \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}$$

The MD code sequence for each of the diagonal matrices is defined by

$$T_{i,1} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}_{4x4}, T_{i,2} = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}_{4x4}, T_{i,3} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}_{4x4}$$

and the total MD code sequence would be

$$MD = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}_{4x12}$$

where K = 4 and N = 12.

So, the codeword for each user according to the example cited above would be as follows:

- User 1 = $\lambda_1, \lambda_8, \lambda_9$
- User 2 = $\lambda_2, \lambda_7, \lambda_{10}$
- User 3 = $\lambda_3, \lambda_6, \lambda_{11}$
- User 4 = $\lambda_4, \lambda_5, \lambda_{12}$

(Hussein *et al*, 2012:2-4).

CHAPTER III

METHODS OF RESEARCH

This thesis is about comparison of NRZ, chirped NRZ, RZ, and Manchester line coding performance for MD-SAC OCDMA with distance variations in FSO communication system. This chapter explains the simulation design of the FSO systems. Relevant block diagram of the components will be elaborated in this chapter. The project plan and simulation set up will shows the whole system.

3.1 Types and Data Acquisition Methods

This thesis is used two types of data which are primary and secondary data. Primary datas are obtained by the simulation of MD-SAC OCDMA in FSO system communication by using four types of line coding in different weather conditions which is suitable to Malaysia weather. Figure 3.1 shows the flow chart of getting the primary data.

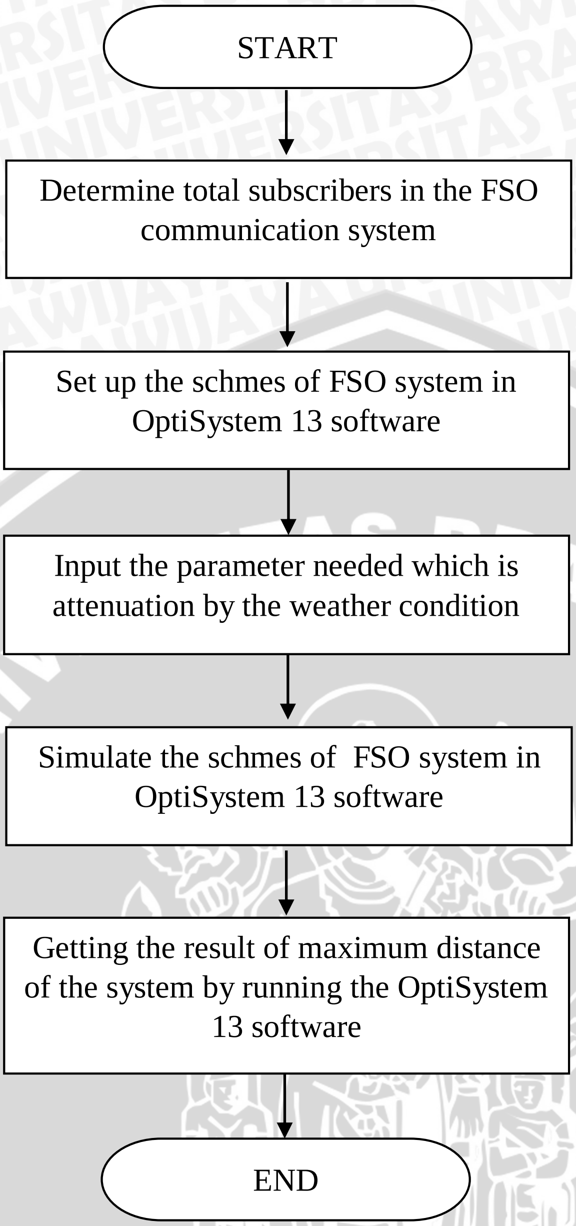


Figure 3.1 Steps to Collect Primary Data

(Source: Design Configuration)

The secondary data are referring to publicated journal and research, internet, and literature books. The secondary data are used as a reference to this thesis. The secondary data which are used for this thesis as follow :

1. Standardization system for Free Space Optic (FSO) based on ITU-R (International Telecommunication Union-Radiocommunication) as follow:

   Based on standard IEC825/EN60825, the laser safety is able to operate at power 3.4 dBm< P < 27 dBm. Few products exist in 3R category; nevertheless, the following safety measures are essential:

- If possible, use warning enclosures and ensure the beam's path conforms to certain rules (short Distances, not at normal eye level),
- the person in charge of monitoring of such systems must have received training and the users must have appropriate medical follow-up
- And concerning the equipment:
    - avoid accidentally exposing the people present by using a beam attenuator or by stopping the beam,
    - ensure instructions accompany the equipment and contain instructions for

2. Parameters in the performance of Free Space Optic (FSO) which fixed are as follows:
    a. Transmitter diameter aperture = 2.5 cm
    b. Receiver diameter aperture = 15 cm
    c. The RSesponsivity of receiver is 1 A/W
    d. Wavelength in range of 1550 nm – 1552.4 nm
    e. Beam divergent = 2 mrad
    f. Optical power transmitted is 15 dBm, it is safe.
3. Continuous Wave (CW) laser is used for the transmitter.
4. InGaAs pin photodiode is used for the receiver because of its high responsivity.
5. Transmission medium used is the free space in Malaysia which has five different weather conditions.
6. Loss insertion multiplexer and demultiplexer are 0.7 dB (http://www.ozoptics.com/ALLNEW_PDF/DTS0089.pdf)
7. By referring to research which has been done by Fadhil in 2013, different weather condition has their own attenuation. For clear condition, the attenuation is 0.233 dB/km, haze is 2.37 dB/km, light rain is 6.27 dB/km, medium rain is 9.64 dB/km and 19.28 dB/km for heavy rain.

The MD-SAC OCDMA in FSO system for two subscribers scheme are shown by Figure 3.2.

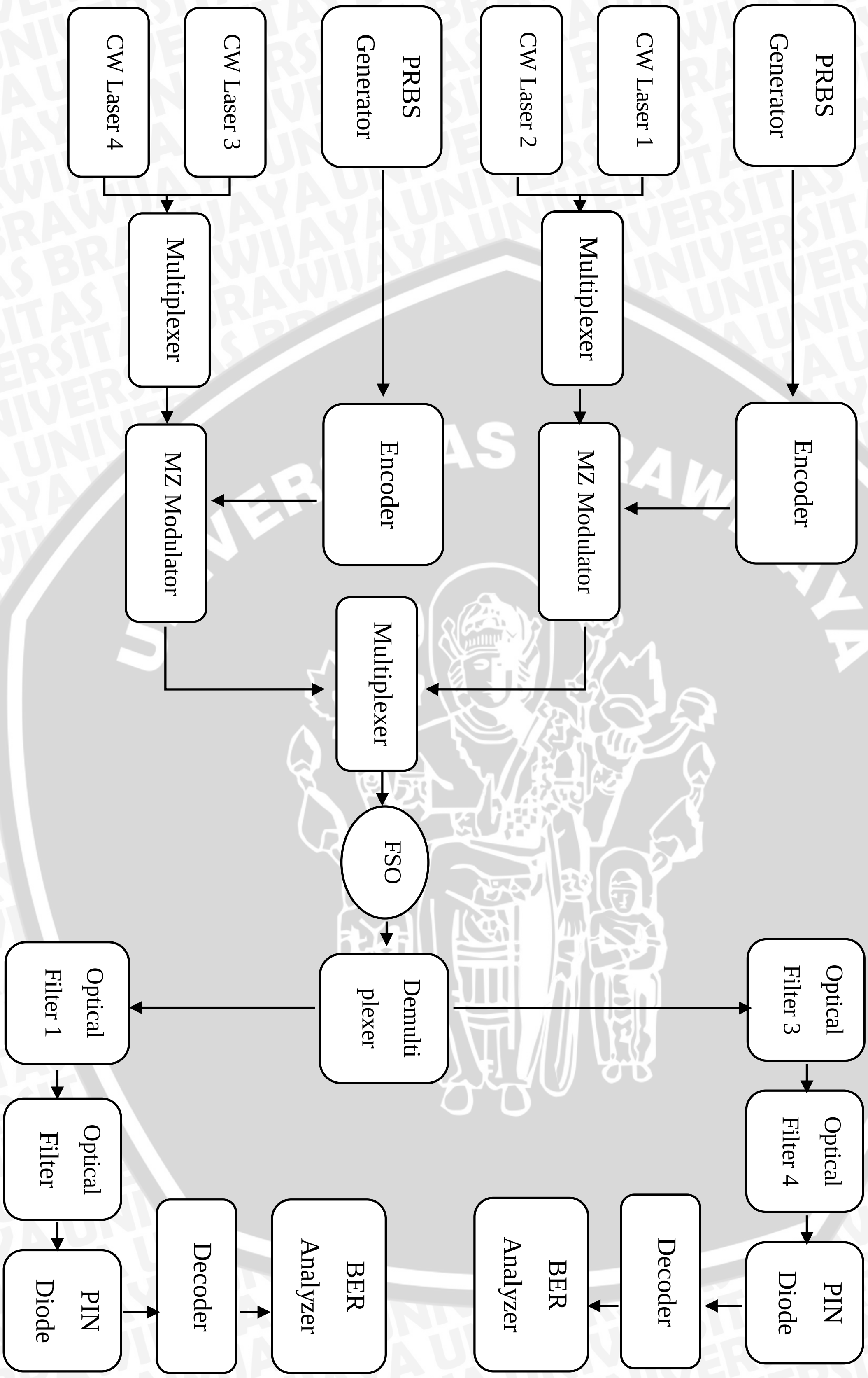


Figure 3.2. Scheme of FSO System

(Source: Design Configuration)

3.2 Variables and Method

Variables which are used in this thesis are variatons of Distances and attenuation from different weathers which is suitable to Malaysia weathers. Mathematical approach of this thesis is performed by the simulation of software OptiSystem 13.

3.3 Framework of Problem Solution

The framework of problem solution is the steps to solve the problems in a flow chart design. The parameter performance in this thesis is only Bit Error Rate (BER). The framework of the problem solution is shown by Figure 3.3

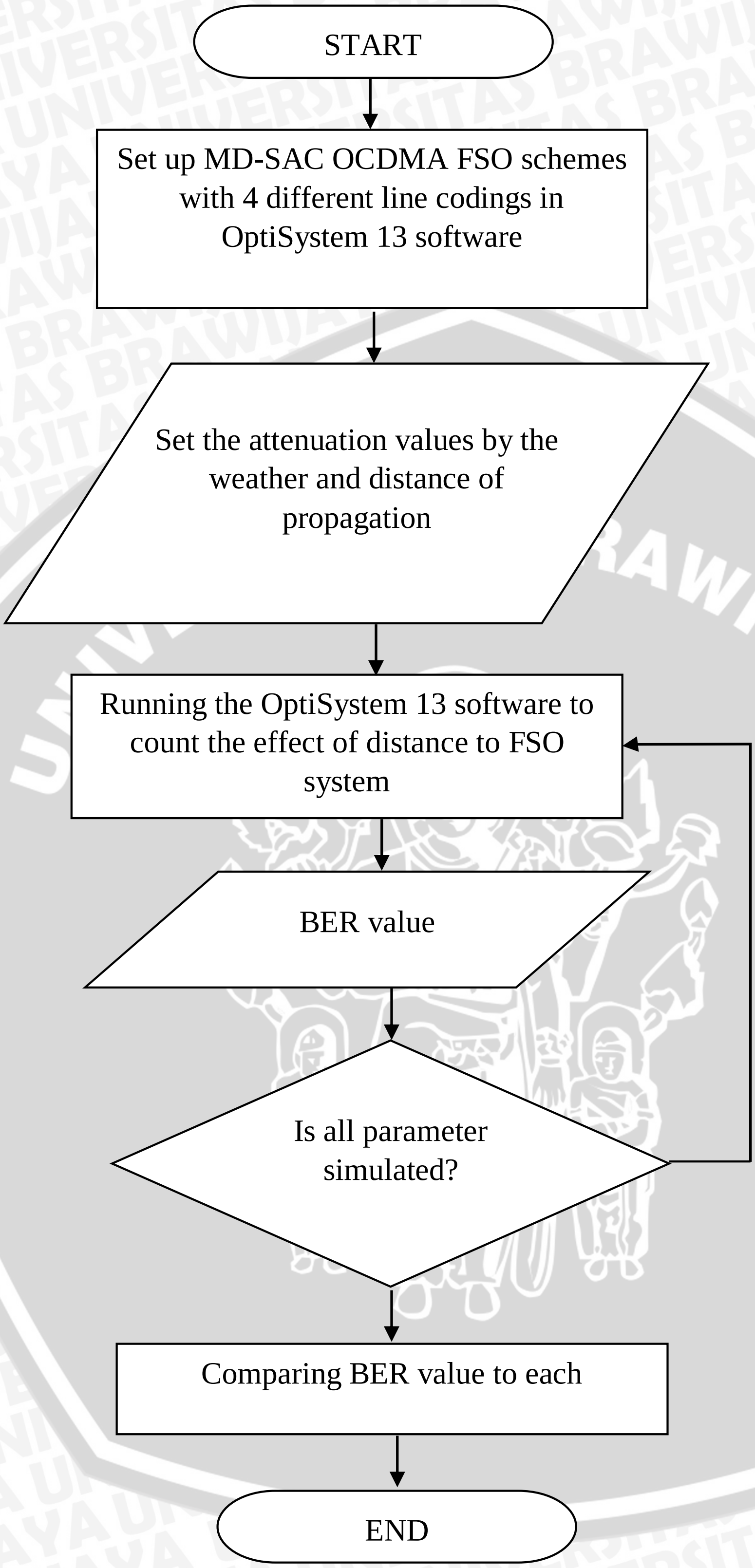


Figure 3.3 Flow Chart of Distances effect to FSO System

(Source: Design Configuration)

3.4 Project Plan of Research

In order to see the overall project plan, we can see in Figure 3.4 The flow chart shows that the project is divided into 4 main line codings which are non chirped NRZ, chirped NRZ, RZ, and Manchester. These four line coding types will be simulated in five different kind of weathers. These weathers are heavy rain, medium rain, light rain, haze, and clear. The system design uses 10 Gb/s data rate. This research is purposed to get the BER value at 1×10^{-9} with the variation of distance as a design parameter. The simulation and designing part have been done using OptiSystem 13 software.

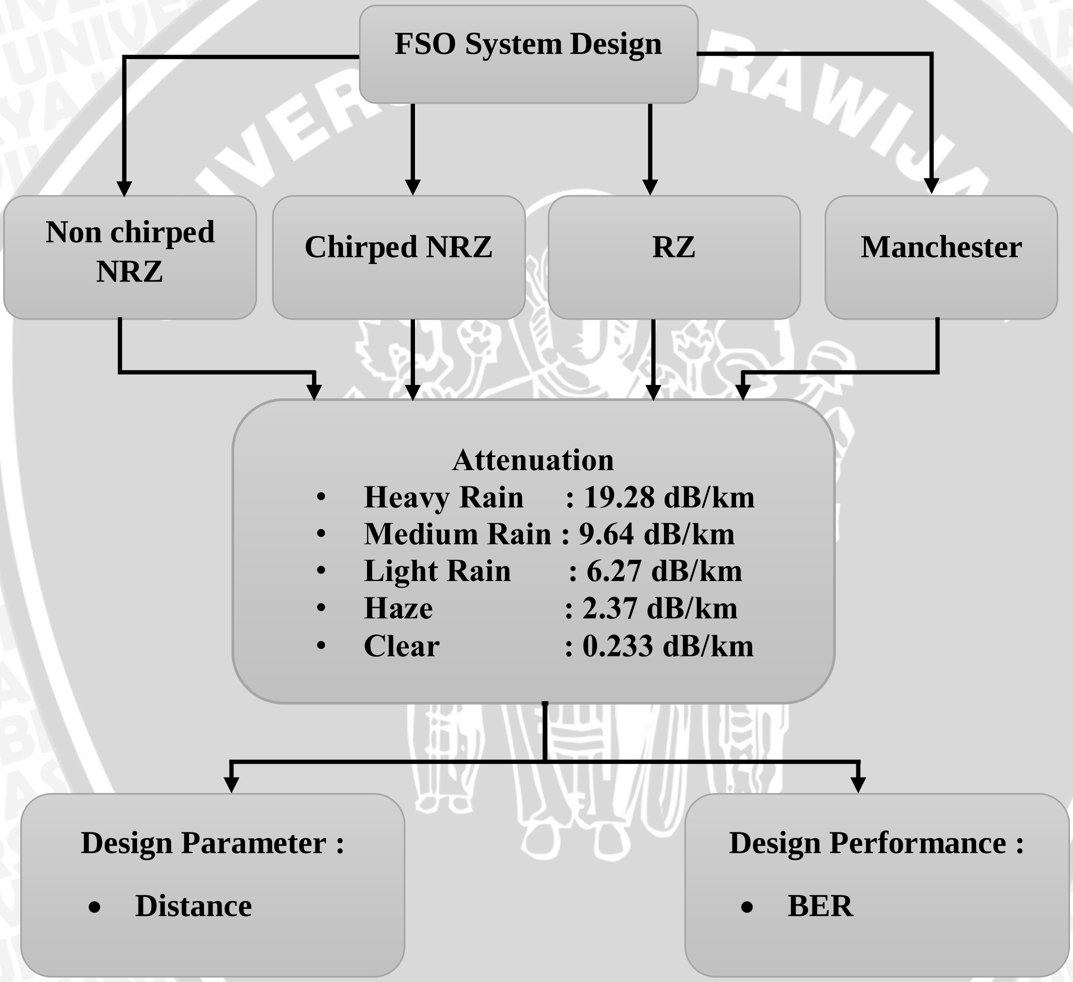


Figure 3.4 Project Plan of Research

(Source: Design Configuration)

CHAPTER IV

RESULTS AND ANALYSIS

This chapter contains the results and analysis of the MD-SAC OCDMA FSO system design with different types of line coding (non chirped NRZ, chirped NRZ, RZ, and Manchester). steps to design 2 subscribers is discussed in subsection 4.1, The setup configuration of each line coding in the simulation is discussed in subsection 4.2, and the result of the simulation is discussed in subsection 4.3. The attenuation factor such as clear, haze, light rain, medium rain and heavy rain have been taken into account based on the Malaysian climate.

4.1 Design Subscribers of the System

In this thesis, the FSO communication system is consisted of 2 subscribers, so the value of K = 2 and the value of W = 2 (the value of W is free, but must more than unity (W > 1)). The MD code sequence for each of the diagonal matrices is defined by

$$T_{i,1} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}_{2x2}, T_{i,2} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}_{2x2}$$

and the total MD code sequence would be

$$\text{MD} = \begin{bmatrix} 1 & 0 & 0 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix}_{2x4}$$

So, the codeword for each user according to the example cited above would be as follows:

- User 1 = λ_1, λ_4
- User 2 = λ_2, λ_3

And the spectral width is determined 0.8 nm each chirp. So $\lambda_1 = 1550$ nm, $\lambda_2 = 1550.8$ nm, $\lambda_3 = 1551.6$ nm, $\lambda_4 = 1552.4$ nm

4.2 Setup Configuration of the Simulation

In this simulation, the sequences of bits are generated by two components of User Defined Bit Sequence (UDBS) generator and bit rate of system is 10 Gbps. To make the difference bit sequences between subscriber 1 and 2, first UDBS generator has a sequence

0101101110, and for second UDBS generator has a sequence 0101011010. The sequences will be repeated until the total bits transmitted are 10 Gbits.

The sequence bits are converted to electrical signal by encoder and then they are modulated by Continous Wave (CW) laser which has wavelength from 1500 nm to 1552.4 nm and linewidth of 100 MHz using Mach-Zehnder Modulator (MZM). The extinction ratio of MZM is set to 30 dB and the loss insertion of multiplexer and demultiplexer is set to 0.7 dB. At the receiver side there are 2 PIN photodetectors which are made by InGaAs semiconductor an the responsitivity are set to 1 A/W and 10 nA for dark current. The fiber bragg grating is used to eliminate the optical signal from other subscriber and for electrical signal filter is used butterworth filter. The description and specification of each simulation component as follow :

1) **User Defined Bit Sequence Generator**

This component has a function to generates a bit sequence that is user-defined. You can enter the string *Bit sequence* or choose *Load from file*. In this, case the parameter *Filename* is enabled. All bit files are formatted containing one bit per line, e.g. the bit file representing the sequence "01011...". If the defined bit sequence is shorter than sequence length, then the defined bit sequence will be repeated untill the length is equal to sequence length. Figure 4.1 shows the component in OptiSystem software.

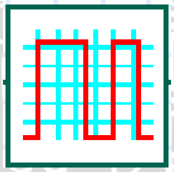


Figure 4.1 User Defined Bit Sequence Generator

(Source: OptiSystem 13 User Manual)

2) **NRZ Pulse Generator**

This component has a function to Generates a Non Return to Zero (NRZ) coded signal. The input must be bit sequences and the output is electrical signal. It can be set to generate unipolar NRZ or polar NRZ. Figure 4.2 shows the component in OptiSystem software.

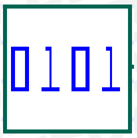


Figure 4.2 NRZ Pulse Generator

(Source: OptiSystem 13 User Manual)

3) **CW Laser**

This component has a function to generates a Continuous Wave (CW) optical signal. In the CW case, the average output power is a parameter that you specify. Figure 4.3 shows the component in OptiSystem software.

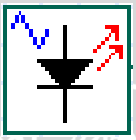


Figure 4.3 CW Laser

(Source: OptiSystem 13 User Manual)

4) **RZ Pulse Generator**

RZ Pulse Generator has a function to Return to Zero (RZ) coded signal. The input must be bit sequences and the output is electrical signal. Figure 4.4 shows the component in OptiSystem software.

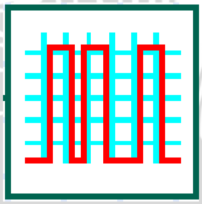


Figure 4.4 RZ Pulse Generator

(Source: OptiSystem 13 User Manual)

5) **Mach-Zehnder Modulator**

This component has a function to simulates a Mach-Zehnder modulator using an analytical model. The Mach-Zehnder modulator is an intensity modulator based on an interferometric principle. It consists of two 3 dB couplers which are connected by two waveguides of equal length. By means of an electro-optic effect, an externally applied voltage can be used to vary the refractive indices in the waveguide branches. The input and the carrier must be electrical and optical signal respectively. Figure 4.5 shows the component in OptiSystem software.

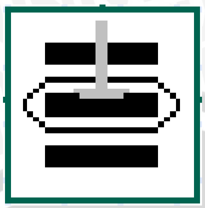


Figure 4.5 Mach-Zehnder Modulator

(Source: OptiSystem 13 User Manual)

6) **Sine Generator**

Sine Generator has a function to generates an electrical sine waveform signal. It can generate cosine signaly by set the value of phase equal to 90 degrees. Figure 4.6 shows the component in OptiSystem software.

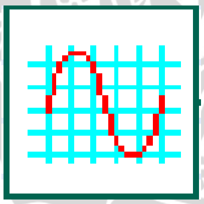


Figure 4.6 Sine Generator

(Source: OptiSystem 13 User Manual)

7) **Phase Modulator**

This component has a function to simulate ideal optical phase modulator. In this model, the electrical modulation signal imposes a phase modulation on an optical carrier. Figure 4.7 shows the component in OptiSystem software.

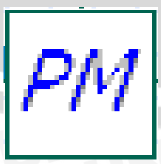


Figure 4.7 Phase Modulator

(Source: OptiSystem 13 User Manual)

8) **Ideal Multiplexer**

Multiplexers a user-defined number of input WDM signal channels. This model is equivalent to an ideal adder, since there is no power splitting and filtering. It only has insertion loss parameter. Figure 4.8 shows the component in OptiSystem software.

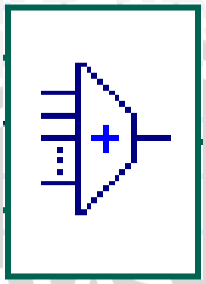


Figure 4.7 Ideal Multiplexer

(Source: OptiSystem 13 User Manual)

9) **Free Space Optics Channel**

This component allows for simulation of free space optical links. The component is a subsystem of transmitter telescope, free space and receiver telescope. Parameter *Range* defines the propagation distance between transmitter and receiver telescope. The attenuation of the laser power in depends on two main parameters: *Attenuation* and *Geometrical loss*. The first parameter describes the attenuation of the laser power in the atmosphere. The second parameter, Geometrical loss, occurs due to the spreading of the transmitted beam between the transmitter and the receiver. Figure 4.9 shows the component in OptiSystem software.

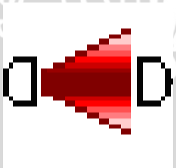


Figure 4.9 FSO Channel

(Source: OptiSystem 13 User Manual)

10) **Ideal Demultiplexer**

Demultiplexes a user-defined number of output WDM signal channels. This model is equivalent to an ideal splitter, since there is no power splitting and filtering. It only has insertion loss parameter Figure 4.10 shows the component in OptiSystem software.

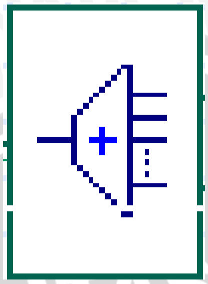


Figure 4.10 Ideal Demultiplexer

(Source: OptiSystem 13 User Manual)

11) **Uniform Fiber Bragg Grating**

This component has a function to Simulates a Uniform Fiber Bragg Grating (FBG). The solution to the coupled mode equations for a uniform grating is used. The unknown parameters in the grating (grating period, grating modulation intensity) are found by employing the information about maximum reflectivity and bandwidth. The result is a module for the calculation of the reflection and transmission spectra. In every scheme in this thesis is used 2 Uniform FBGs in order to eliminate undesired signal from another subscriber. Figure 4.11 shows the component in OptiSystem software.

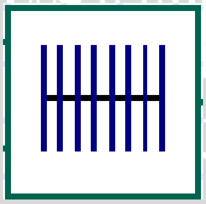


Figure 4.11 Uniform Fiber Bragg Grating

(Source: OptiSystem 13 User Manual)

12) **Photodetector PIN**

This component has a function to simulate PIN photodiode. The incoming optical signal and noise bins are filtered by an ideal rectangle filter to reduce the number of samples in the electrical signal. The new sample rate is defined by the parameter *Sample rate*. You can define the center frequency, or it can be calculated automatically by centering the filter at the optical channel with maximum power. Figure 4.12 shows the component in OptiSystem software.

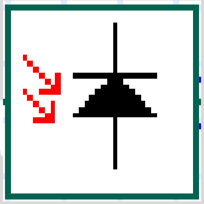


Figure 4.12 Photodetector PIN

(Source: OptiSystem 13 User Manual)

13) **Butterworth Filter**

This component has a function to simulate optical filter with a Butterworth frequency transfer function. In every scheme in this thesis, butterworth filter is set to has order value equal to 4. Figure 4.13 shows the component in OptiSystem software.

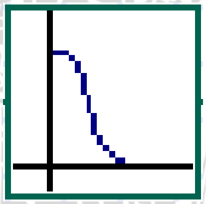


Figure 4.13 Butterworth Filter

(Source: OptiSystem 13 User Manual)

14) **3R Regenerator**

This component has a function to regenerates an electrical signal. It generates the original bit sequence, and a modulated electrical signal to be used for BER analysis. Figure 4.14 shows the component in OptiSystem software.

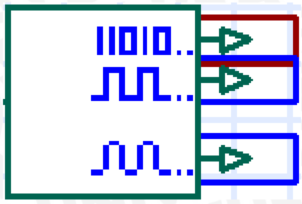


Figure 4.14 3R Regenerator

(Source: OptiSystem 13 User Manual)

15) **Fork 1 x 2**

This component has a function to copies the input signal into two output signals. This tool allows you to duplicate component output ports. Figure 4.15 shows the component in OptiSystem software.

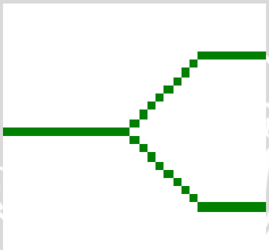


Figure 4.15 Fork 1 x 2

(Source: OptiSystem 13 User Manual)

16) **Clock Recovery**

This component has a function to compensates the time delay between the original signal at the reference port and the signal that is received at the input port. Figure 4.16 shows the component in OptiSystem software.

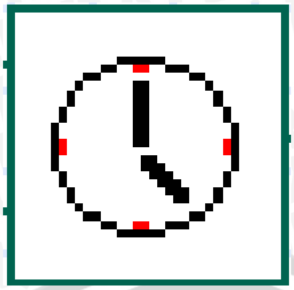


Figure 4.16 Clock Recovery

(Source: OptiSystem 13 User Manual)

17) **Electric Rescale**

This component has a function to scales the minimum and maximum values of the input signal to user-defined minimum and maximum values. Figure 4.17 shows the component in OptiSystem software.

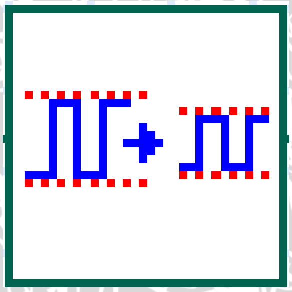


Figure 4.17 Electric Rescale

(Source: OptiSystem 13 User Manual)

18) **BER Analyzer**

This component has a function as a BER visualizer. The input of BER are bit sequences, encoded signal, and modulated signal. Figure 4.18 shows the component in OptiSystem software

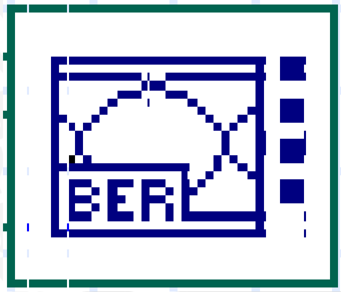


Figure 4.18 BER Analyzer

(Source: OptiSystem 13 User Manual)

The configuration of each line coding is shown as follow :

4.2.1 Non Chirped NRZ Transmitter

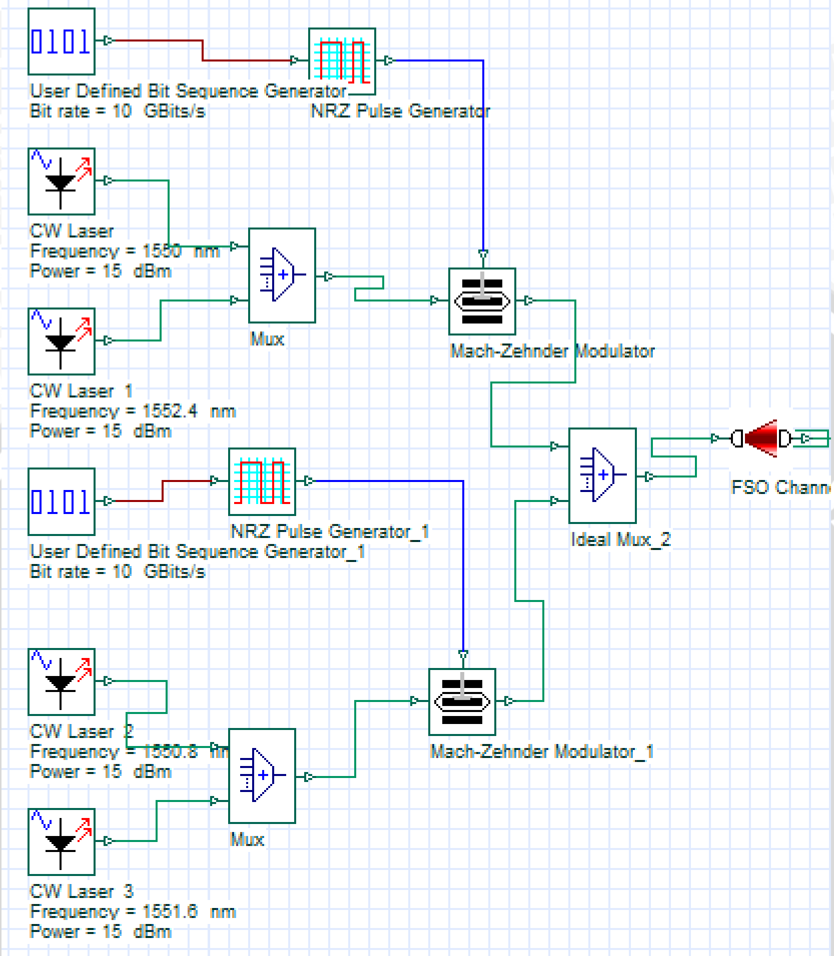


Figure 4.19 Non Chirped NRZ Transmitter Scheme

(Source: Design Configuration)

As described in chapter III, each subscriber has a bandwidth 10 Gigabits. All of them are encoded by NRZ Pulse Generator. The output signal from NRZ Pulse Generator is modulated by each codeword from each subscriber in intensity modulator called Mach-Zehnder Modulator. Then output from each Mach-Zehnder Modulator is multiplexed in order to transmit them in one FSO channel.

4.2.2 Chirped NRZ Transmitter

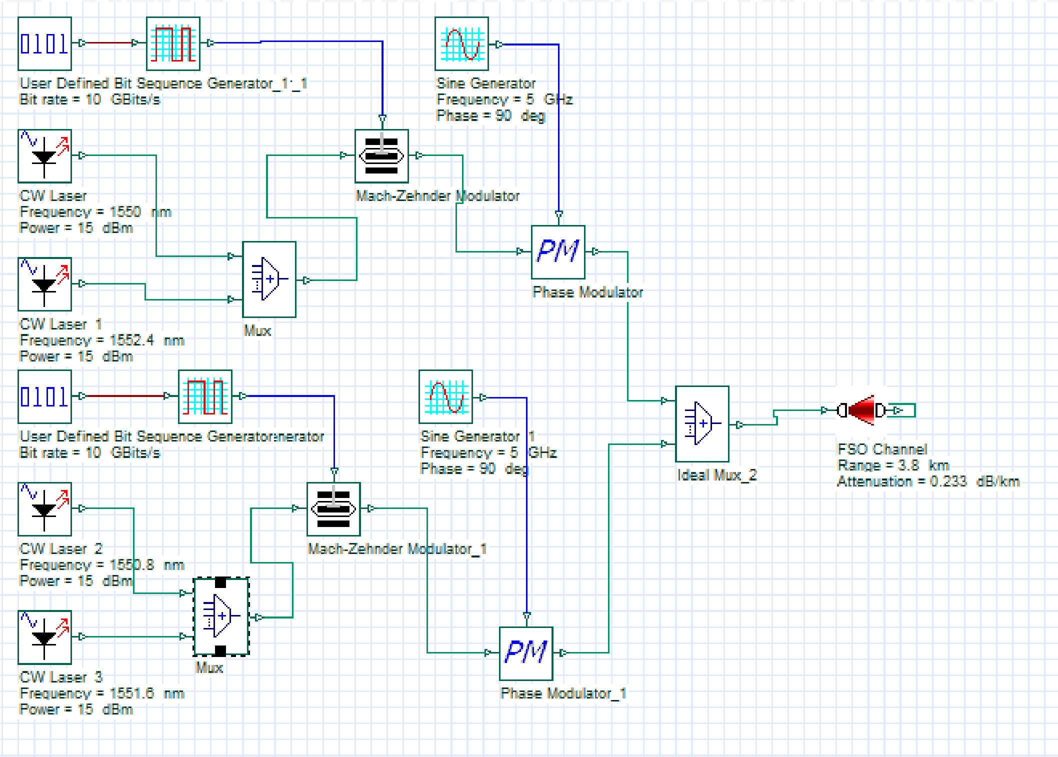


Figure 4.20 Chirped NRZ Transmitter Scheme

(Source: Design Configuration)

As described at subchapter 2.6.3, the chirped NRZ pulses are generated by modulation between Mach-Zehnder Modulator output signal and optical phase modulator, which is driven by the cosine-clock signal at the half bit-rate. Because the bandwidth of the system is 10 Gbps, then the frequency of sine generator have to be 5 GHz (half of bandwidth system). To set output from Sine Generator to cosine signal, the value of phase parameter has to be 90, which means the signal lead by 90 degrees from sine signal.

4.2.3 RZ Transmitter

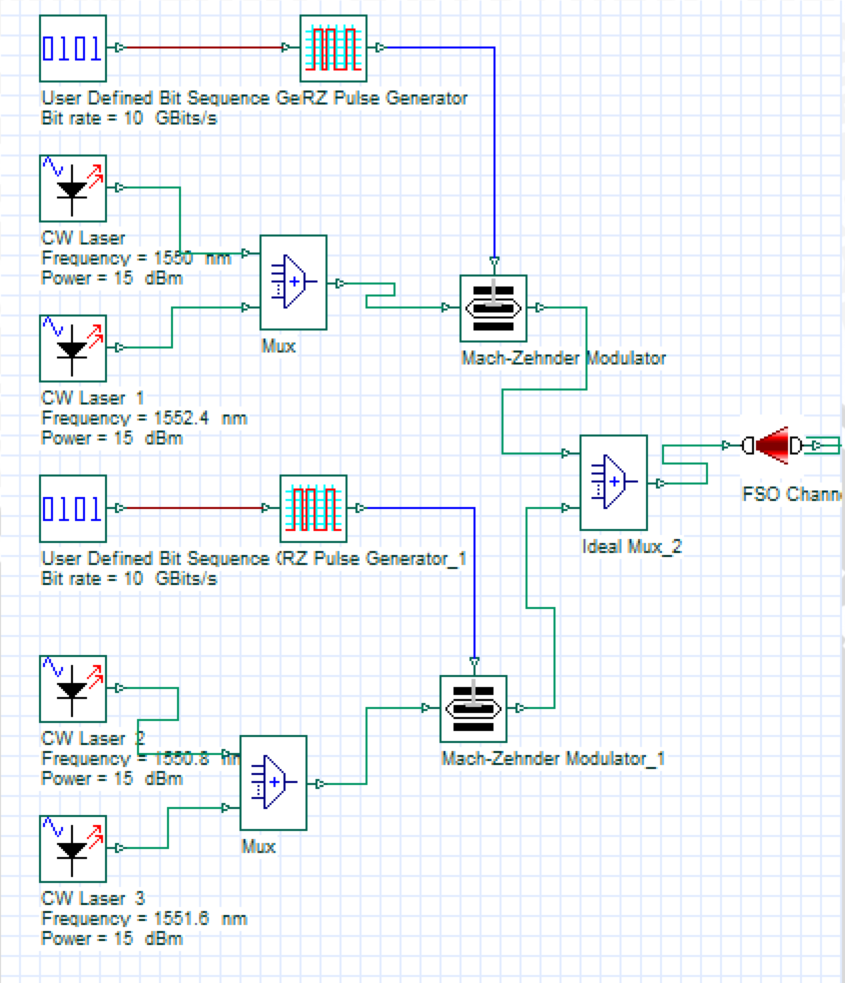


Figure 4.21 RZ Transmitter Scheme

(Source: Design Configuration)

The main idea from RZ transmitter scheme is like an NRZ transmitter scheme, the difference is just at the line coding block. If in the NRZ transmitter scheme the bits are encoded by NRZ Pulse Generator, in RZ transmitter scheme the bits are encoded by RZ Pulse Generator.

4.2.4 Receiver for Non Chirped NRZ, Chirped NRZ, and RZ

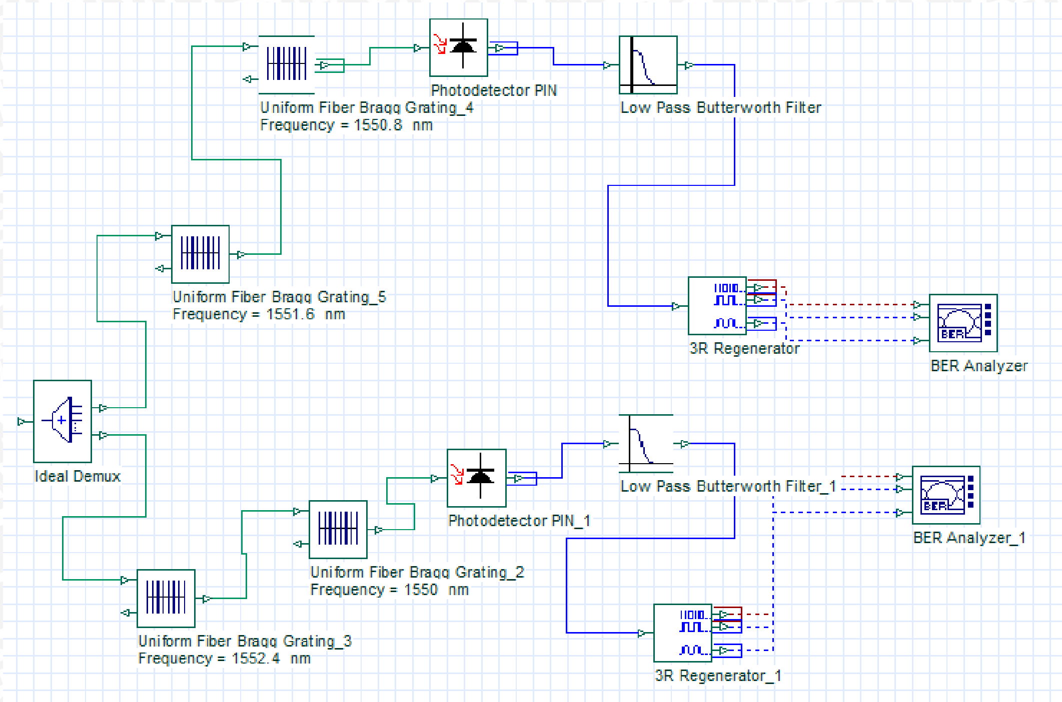


Figure 4.22 Receiver Scheme for Non Chirped NRZ, Chirped NRZ, and RZ

(Source: Design Configuration)

Signals from FSO channel are demultiplexed by demultiplexer in order to transmit desired signal to each subscriber. Then the signals will pass two Fiber Bragg Gratings. Two Fiber Bragg Gratings are used because it is efficient to eliminate undesired signal from another subscriber. The output from last FBG is received by Photodetector PIN to be converted to electrical signal, then filtered by Low Pass Butterworth Filter.

4.2.5 Manchester Transmiter

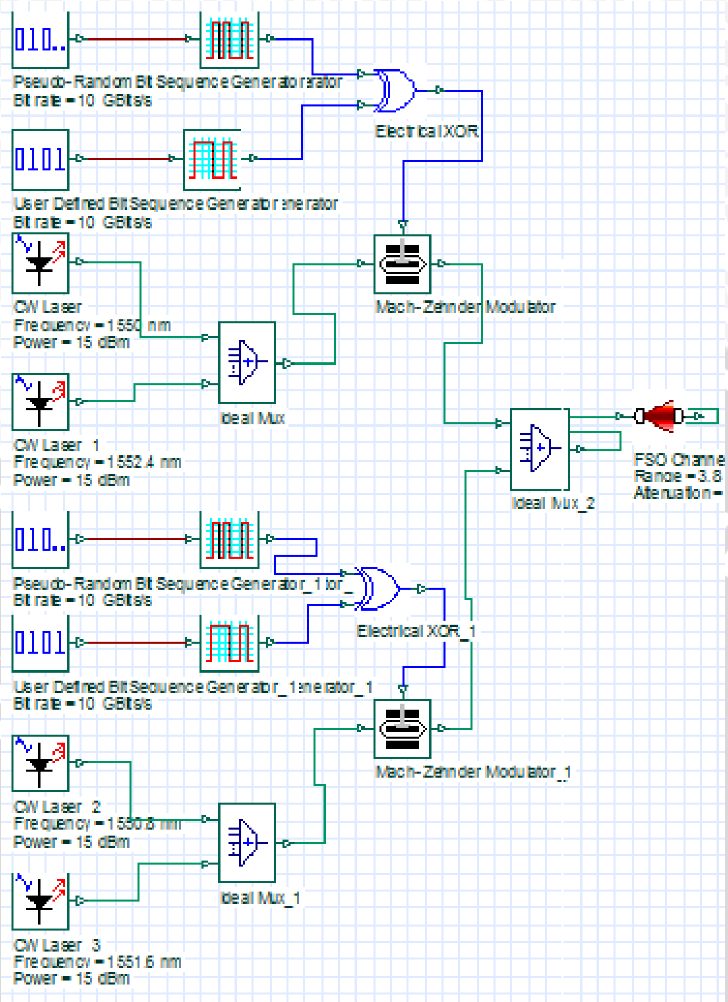


Figure 4.23 Manchester Transmitter Scheme

(Source: Design Configuration)

The idea of Manchester and another line coding scheme is closely similar, the difference is only at bits are encoded by Manchester line coding. The Manchester line coding is generated by the result of XOR gate between RZ and NRZ signal. The transmitter clock is generated by Pseudo Random Bit Sequences (PRBS) generator (http://optiwave.com/resources/applications-resources/optical-system-manchester-and-pam-codingdecoding/).

4.2.6 Receiver for Manchester

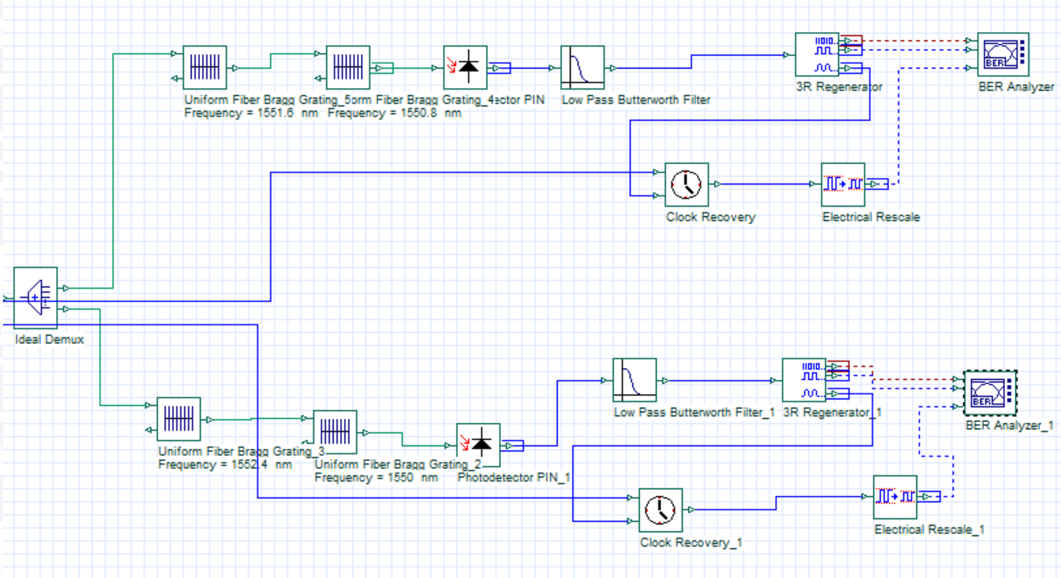


Figure 4.24 Manchester Receiver Scheme

(Source: Design Configuration)

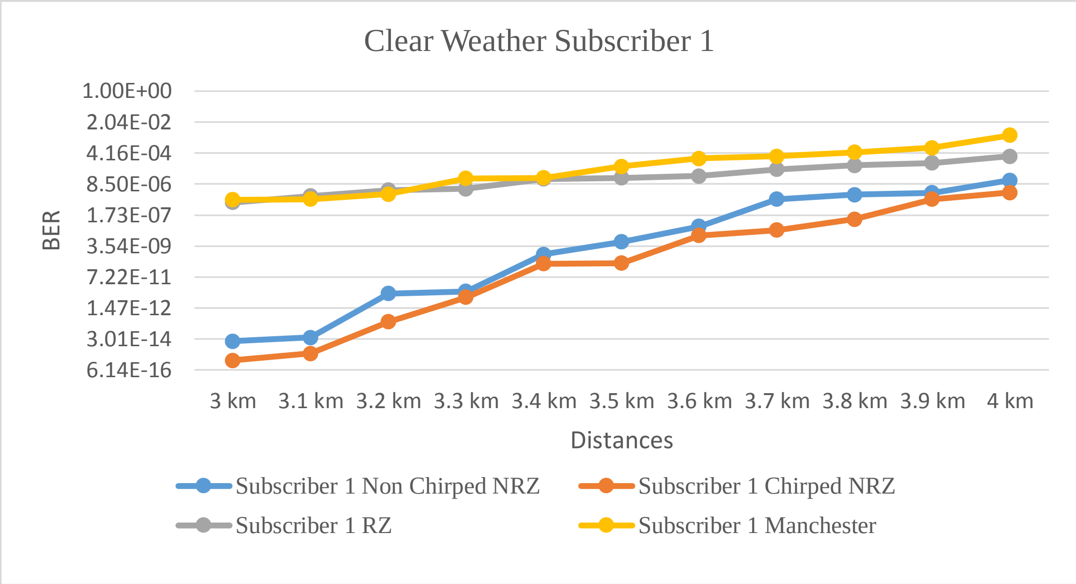
The receiver for Manchester line coding was designed based on research which has been done by S.Rajalaksmi (Rajalaksmi *et al*, 2012:3). There is the difference between Manchester line coding receiver to NRZ, chirped NRZ, and RZ receiver. In Manchester line coding receiver we need to put clock recovery and electrical scale to help 3R regenerator for decoding process. The input of clock recovery is from the output of low pass butterworth filter and the Manchester signal from transmitter side.

4.3 Result and Analysis

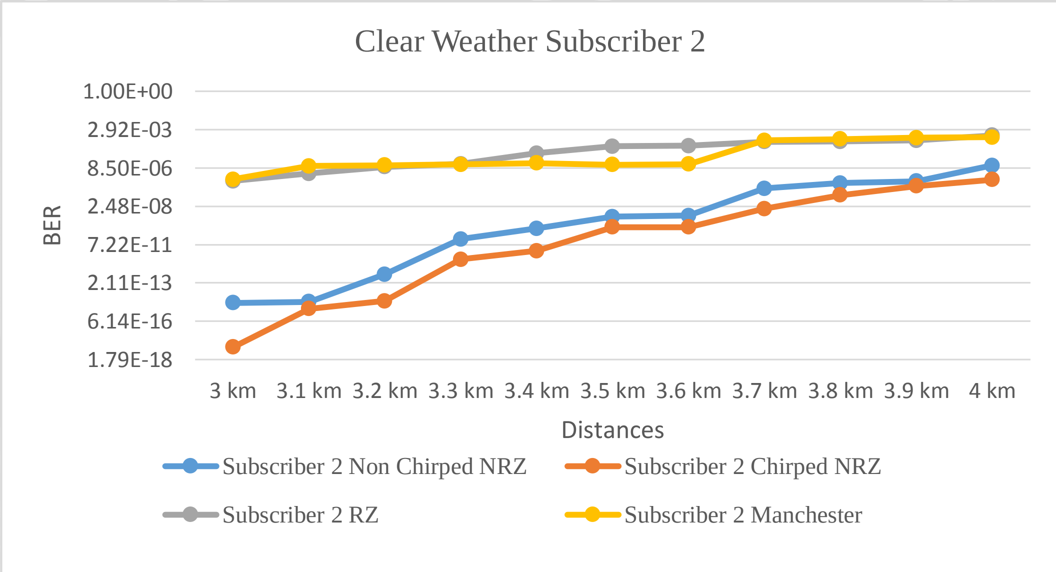
This sub section discuss about comparison of NRZ, chirped NRZ, RZ, and Manchester line coding performance for MD-SAC OCDMA with distance variations in FSO communication system.

4.3.1 The Effect of Distance Variations in MD-SAC OCDMA with Variation of Line Coding in FSO Communication System

In this thesis, the attenuation from each weather refers to research which has been done by Fadhil (Fadhil *et al*,2013. The attenuation for clear weather is 0.233 dB/km, haze is 2.37 dB/km, light rain is 6.27 dB/km, medium rain is 9.64 dB/km, and 19.28 dB/km for heavy rain.



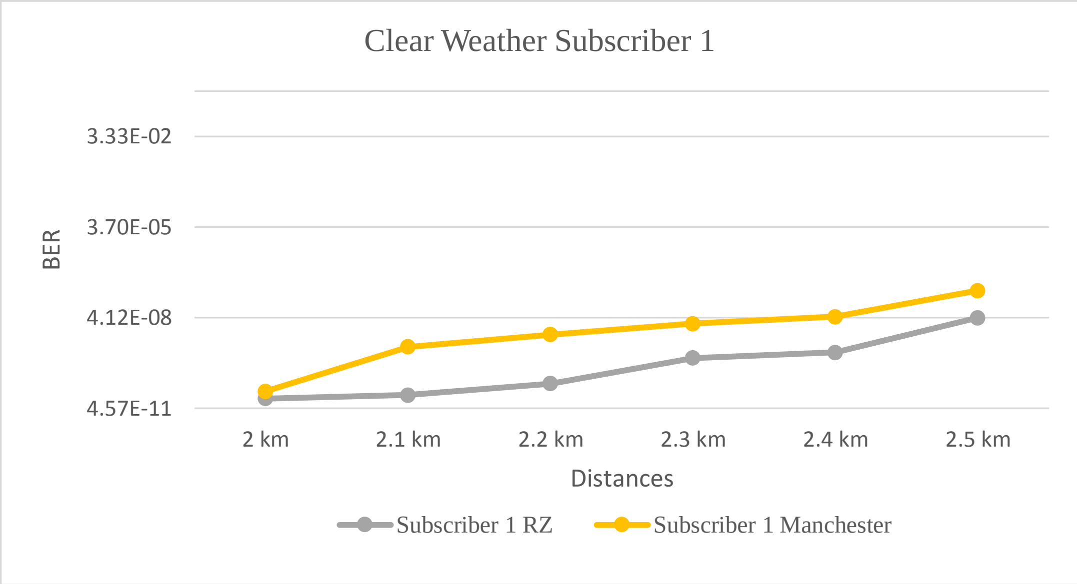
(a)



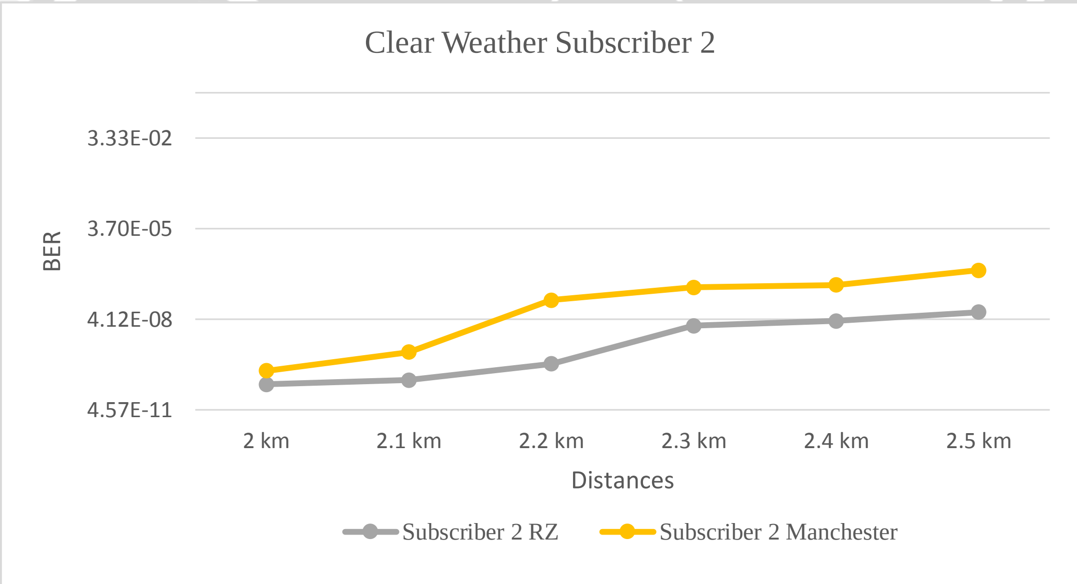
(b)

Figure 4.25 (a) Distance Versus BER in Clear Weather for Subscriber 1 (b) Distance Versus BER in Clear Weather for Subscriber 2

(Source: Research)



(a)

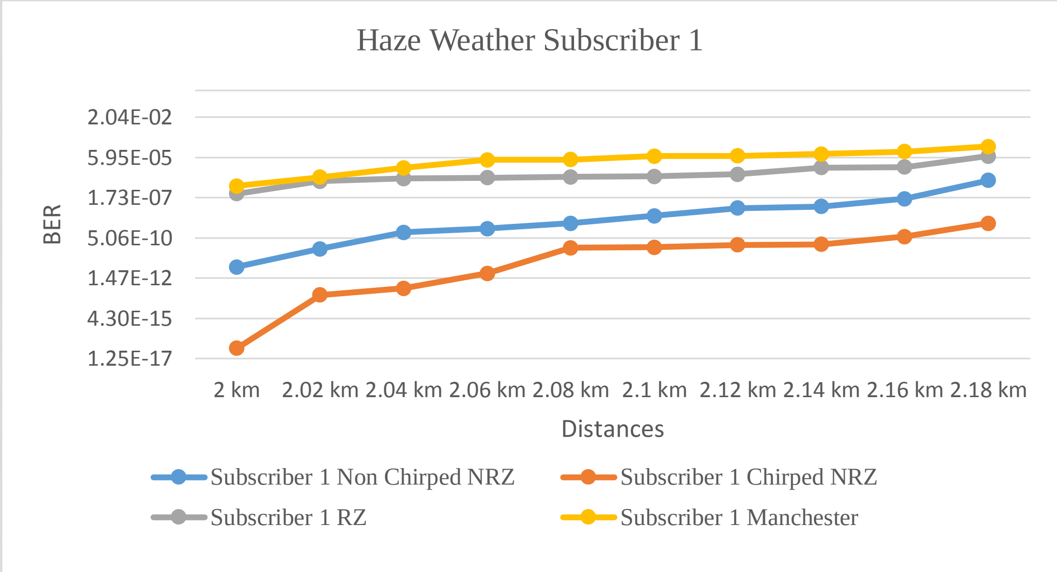


(b)

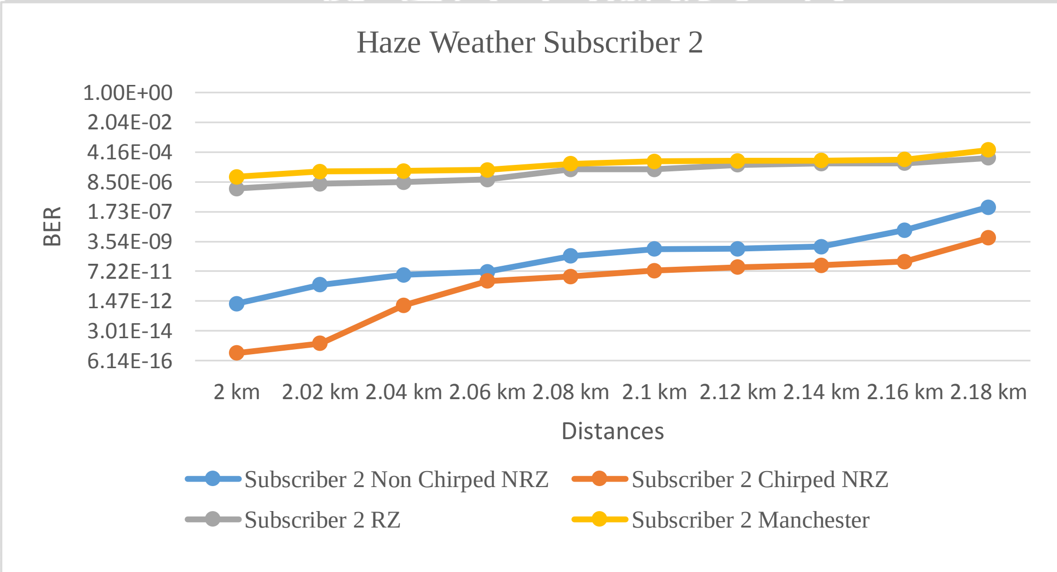
Figure 4.26 (a) Distance Versus BER in Clear Weather for Subscriber 1 (Only RZ and Manchester) (b) Distance Versus BER in Clear Weather for Subscriber 2 (Only RZ and Manchester)

(Source: Research)

Figure 4.25a and 4.25b shows the distances for FSO communication system which satisfied ber value 10^{-9} in clear weather. From the figures above we got 3.3 km and 3.4 km for non chirped NRZ subscriber 1 and 2 respectively and 3.5 km for both subscribers of chirped NRZ line coding . In the same distance comparasion with NRZ and chirped NRZ, RZ and Manchester did not meet the requirement of perfect BER for transmission which is 10^{-9}. Figure 4.26a and 4.26b shows the maximum distance of RZ and Manchester which are 2.2 km (subscriber 1), 2.3 km (subscriber2), and 2.1 km (for both subscribers) respectively.



(a)

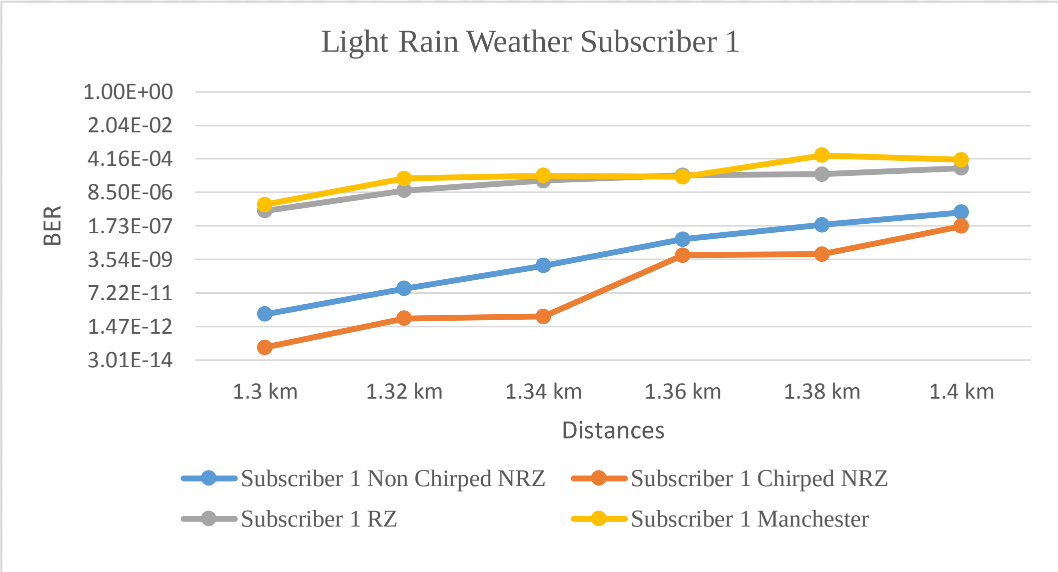


(b)

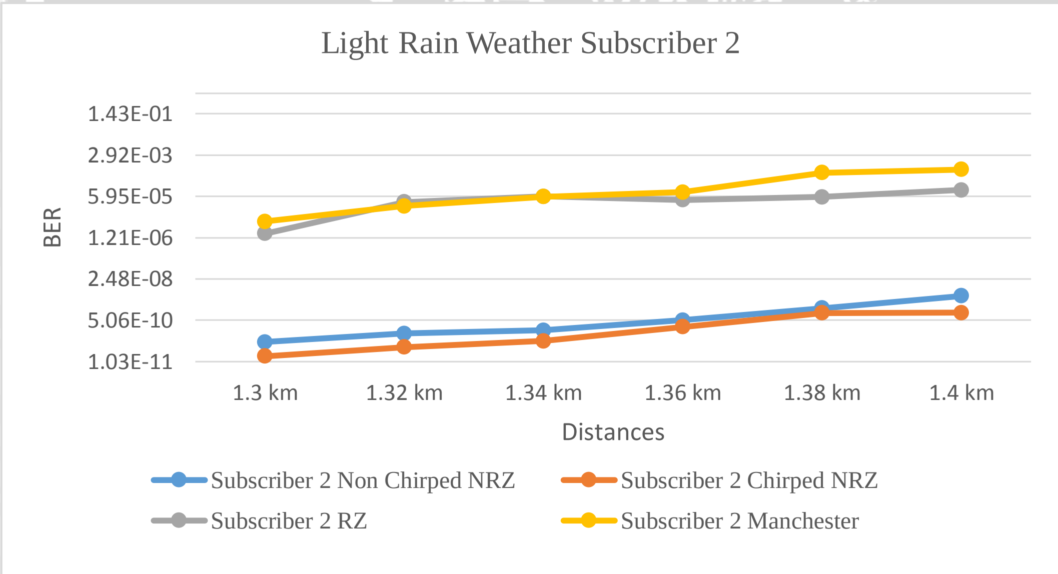
Figure 4.27 (a) Distance Versus BER in Haze Weather for Subscriber 1 (b) Distance Versus BER in Haze Weather for Subscriber 2

(Source: Research)

Figure 4.27a and 4.27b shows the distances for FSO communication system which satisfied ber value 10^{-9} in haze weather. From the figures above we got 2.06 km and 2.14 km for non chirped NRZ subscriber 1 and 2 respectively and 2.16 km for both subscribers of chirped NRZ line coding.



(a)

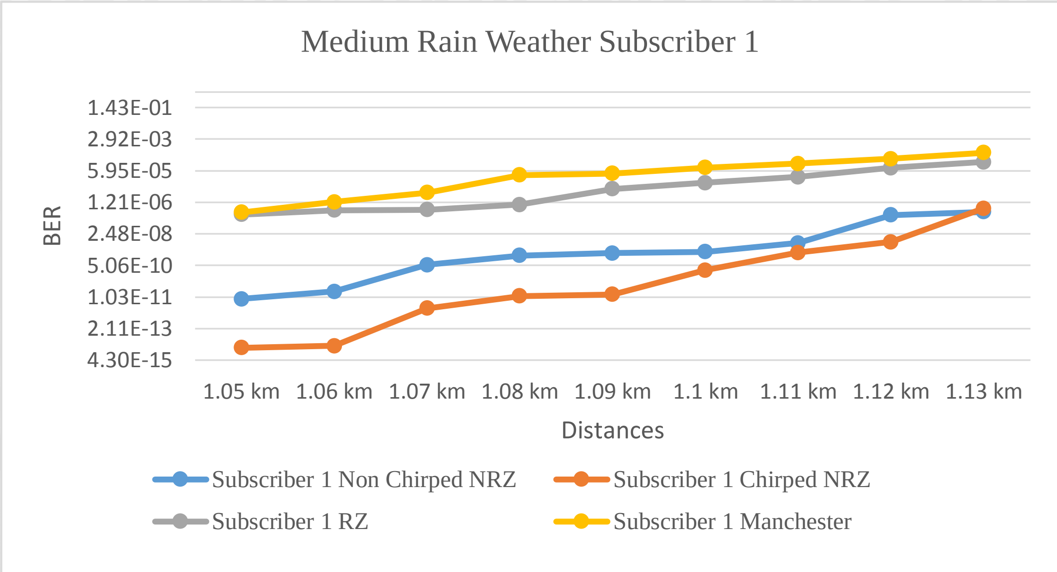


(b)

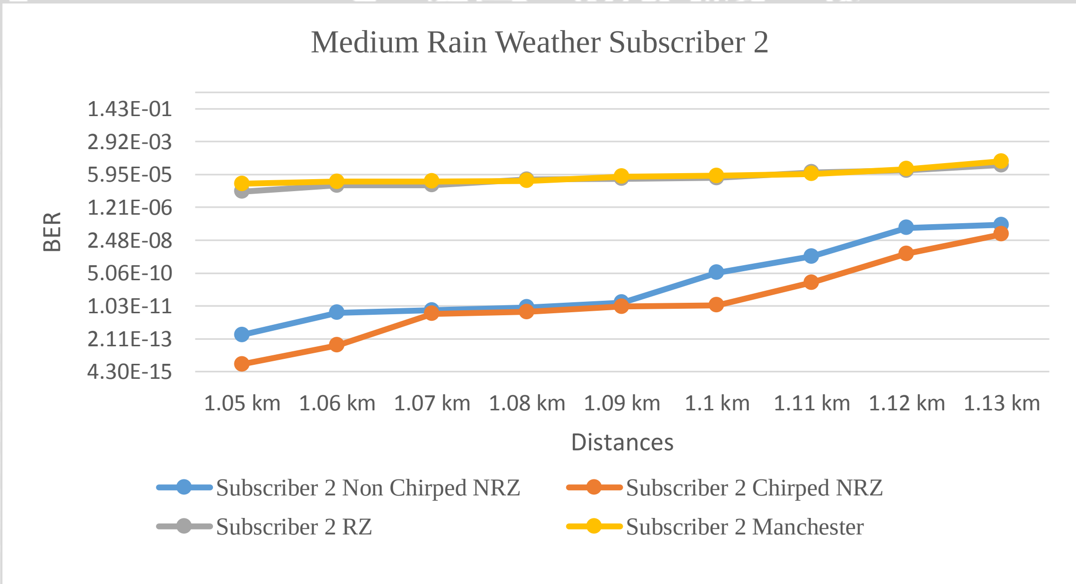
Figure 4.28 (a) Distance Versus BER in Light Rain Weather for Subscriber 1 (b) Distance Versus BER in Light Rain Weather for Subscriber 2

(Source: Research)

Figure 4.28a and 4.28b shows the distances for FSO communication system which satisfied ber value 10^{-9} in light rain weather. From the Figures above we got 1.34 km and 1.38 km for non chirped NRZ subscriber 1 and 2 respectively and 1.36 km and 1.38 km for chirped NRZ subscriber 1 and 2 respectively.



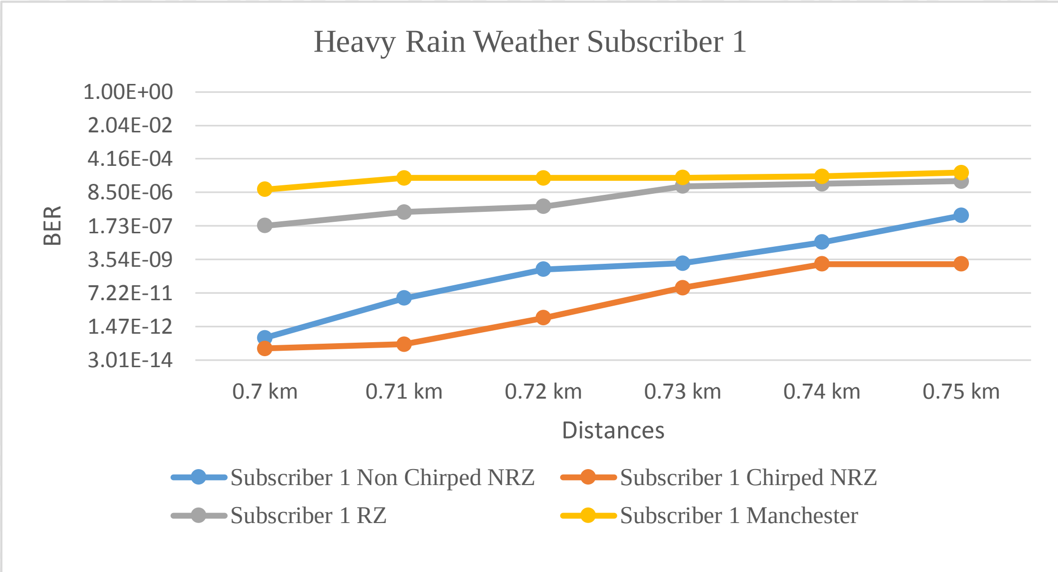
(a)



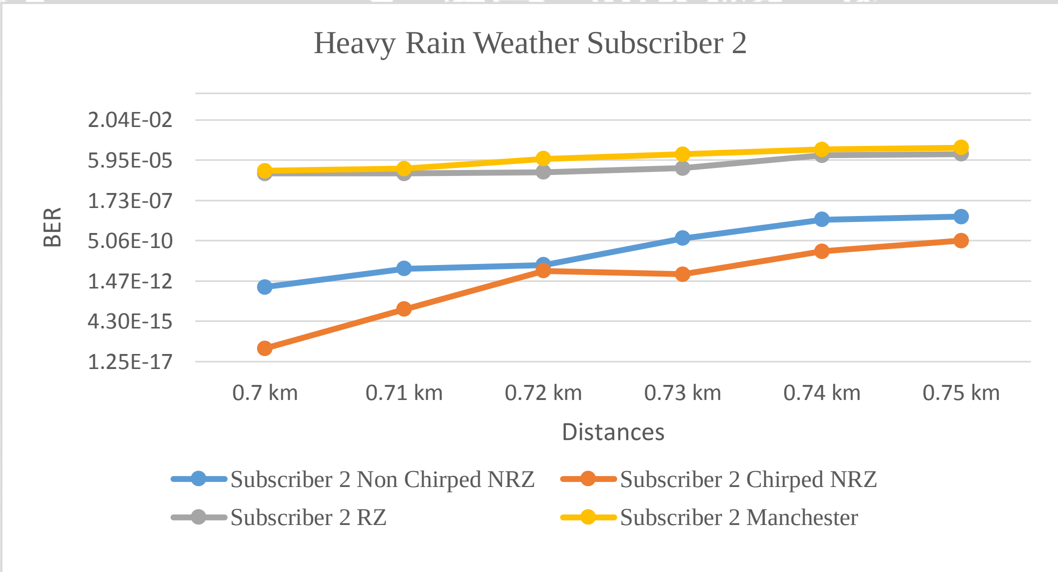
(b)

Figure 4.29 (a) Distance Versus BER in Medium Rain Weather for Subscriber 1
(b) Distance Versus BER in Medium Rain Weather for Subscriber 2
(Source: Research)

Figure 4.29a and 4.29b shows the distances for FSO communication system which satisfied ber value 10^{-9} in medium rain weather. From the Figures above we got 1.08 km and 1.1 km for non chirped NRZ subscriber 1 and 2 respectively and 1.11 km for both subscribers of chirped NRZ line coding.



(a)



(b)

Figure 4.30 (a) Distance Versus BER in Heavy Rain Weather for Subscriber 1 (b) Distance Versus BER in Heavy Rain Weather for Subscriber 2

(Source: Research)

Figure 4.30a and 4.30b shows the distances for FSO communication system which satisfied ber value 10^{-9} in heavy rain weather. From the Figures above we got 0.72 km and 0.73 km for NRZ subscriber 1 and 2 respectively and 0.75 km for both subscribers of chirped NRZ line coding. From Figure 4.7a to 4.12b it can be concluded that more attenuation in FSO communication system causes the maximum distance of the system become shorter, and the best line coding for Free Space Optical communication system is chirped NRZ.

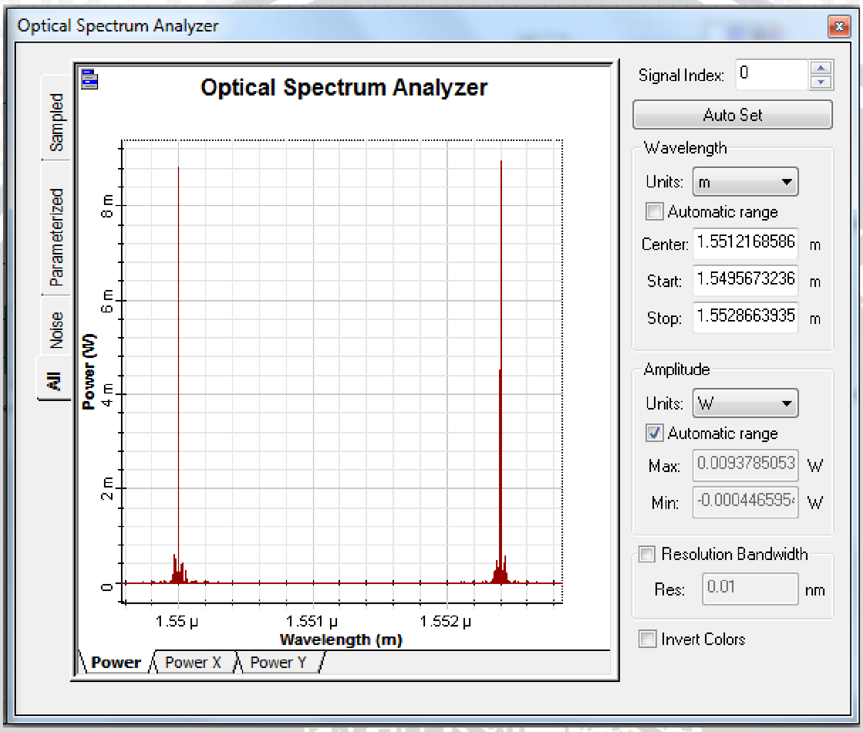


Figure 4.31 Mach-Zehnder Modulator Output From NRZ system
(Source: Research)

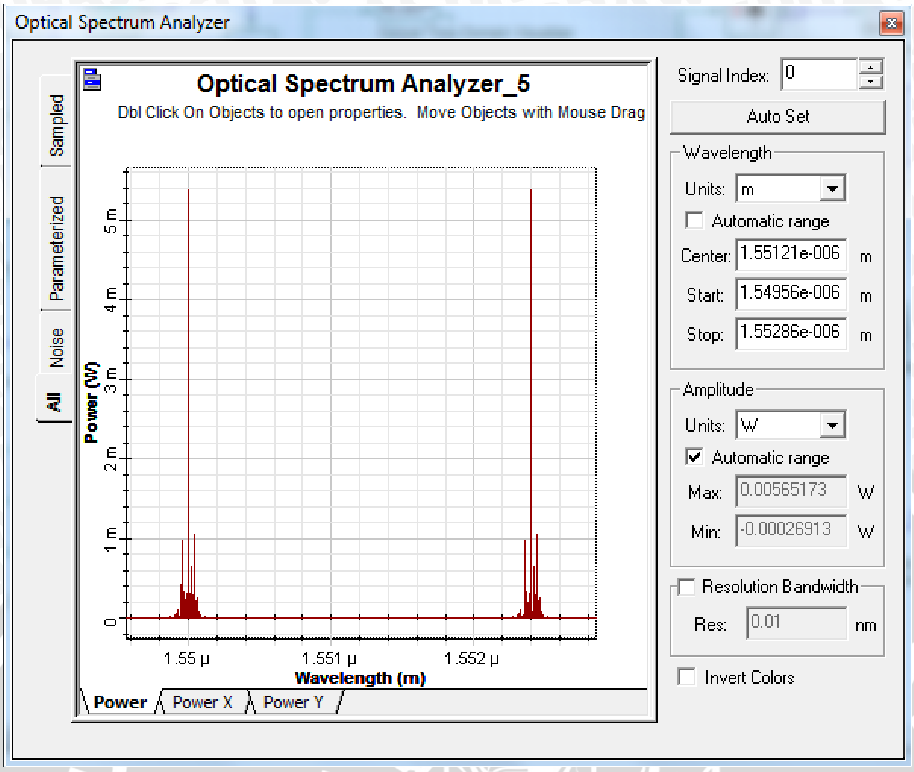


Figure 4.32 Optical Phase Modulator Output From Chirped-NRZ system

(Source: Research)

Figure 4.31 and Figure 4.32 show the optical spectrum of Mach-Zehnder Modulator output signal from NRZ and Optical Phase Modulator output from chirped NRZ system. From the figure 4.31 and 4.32, it can be concluded that implementation of the pre-chirp causes a broadening of the signal spectrum nevertheless, it can reduce nonlinear characteristics such as Single Phase-Modulation Group Velocity Dispersion (SPM-GVD), but the amount of pre-chirp has to be taken into account to get desired system performance. (Hodzig *et al*,2001:1). For RZ and Manchester line coding almost has same performance but RZ is little bit better. The reason why the performance of RZ and manchester are worse than NRZ and chirped NRZ is because the symbol rate of RZ and Manchester is twice from NRZ and chirped NRZ and it also make their bandwidth become twice.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

This chapter provides the conclusion of the project research based on the results and analysis which are obtained. The Suggestion also included for the improvement and speculating on the future research.

5.1 Conclusions

Based on the simulation results, this thesis has achieved its objectives of design and compare the performance parameters of NRZ, chirped NRZ, RZ, and Manchester line coding formats for MD-SAC OCDMA in Free Space Optical communication system. From the results obtained, the chirped NRZ line coding has the best performance, because it has the longest transmission distance in all weather than NRZ, RZ, and Manchester (The system will work properly when the reference BER at around 1×10^{-9} is obtained.). The worst performance is when the system use Manchester line coding, because beside the bandwidth of the system become twice, there are some additional components to decode the manchester, so it might add noise to the system

Chirped NRZ has a better performance than NRZ because the implementation of the pre-chirp can reduce nonlinear characteristics such as Single Phase-Modulation Group Velocity Dispersion (SPM-GVD) but the amount of pre-chirp has to be taken into account to get desired system performance.

5.2 Recommendations

There are many ways to make this thesis become better. First, the receiver diameter aperture can be set bigger to get the better performance of FSO. The second is choose more appropriate line coding formats, because there are many line coding formats like alternate-chirped NRZ and M-ary pulse. The last is choose another optical modulation scheme or add electrical modulator in electric side of the system, because in telecommunication, modulation format has a big role to determined the value of BER system.

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