PERFORMANCE EVALUATION OF OPTICAL CODING TECHNIQUES FOR OPTICAL PON NETWORK

MAJOR PROJECT II

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE AWARD OF THE DEGREE

OF

MASTER OF TECHNOLOGY

IN

MICROWAVE AND OPTICAL COMMUNICATION

Submitted by:

NAVYA SIRINGI

2K18/MOC/01

Under the supervision of

DR. GURJIT KAUR

ELECTRONICS AND COMMUNICATION ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

JUNE, 2020

ECE DEPARTMENT

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

CANDIDATE'S DECLARATION

I, NAVYA SIRINGI, Roll No. 2K18/MOC/01 student of M.Tech (Microwave and Optical Communication), hereby declare that the Dissertation "PERFORMANCE EVALUATION OF OPTICAL CODING TECHNIQUES FOR OPTICAL PON NETWORK " is submitted by me to the Department of Electronics and Communication, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

Place: Delhi **NAVYA SIRINGI**
Date: 29th October, 2020

ECE DEPARTMENT

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

CERTIFICATE

I hereby certify that the Dissertation titled "PERFORMANCE EVALUATION OF OPTICAL CODING TECHNIQUES FOR OPTICAL PON NETWORK" which is submitted by NAVYA SIRINGI, Roll No 2K18/MOC/01 to the Department of Electronics and Communication, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi
Date: 29th October, 2020

DR. GURJIT KAUR
SUPERVISOR
ASSOCIATE PROFESSOR
Department of Electronics and Communication
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

ACKNOWLEDGEMENT

Apart from my efforts, the success of any research work depends largely on the encouragement and guidelines of many others. I take this opportunity to express my gratitude to the people who have been instrumental in the successful completion of this project.

I extend my thanks and gratitude to my supervisor Dr. Gurjit Kaur for her careful and precious guidance which was extremely valuable for my task to go on smooth pace. The guidance and support received from her was vital for the success of the project. I am grateful for her constant support and help.

I perceive this opportunity as a big milestone in my career development and a great experience. I will strive to retain gained skills and knowledge and use it in the best possible way, to attain desired career objectives.

Navya Siringi

2K18/MOC/01

ABSTRACT

In this dissertation, the two 2-D coding techniques has been designed for OCDMA system and their performance has been compared for passive optical network. The first coding technique i.e. Hadamard coding is designed for OCDMA system. In the first phase of this dissertation, two-dimensional Optical Code Division Multiple Access System (2D-OCDMA) has been designed by using wavelength/phase Hadamard encoding technique. Usually Hadamard encoding technique is used in single domain i.e. wavelength domain. In this research work, 2D encoding technique is designed for OCDMA system in spectral as well as phase domain which will further improve the security. The proposed 2-D OCDMA increases the number of users by splitting the optical source to two orthogonal phase signals without the requirement to increase the code length as well as wavelengths. The proposed system requires a smaller number of LEDs as well as improves the security. The performance of the proposed system is analyzed by designing an OCDMA system for six users. The performance is analyzed in terms of Bit Error Rate (BER) and Quality Factor by increasing the number of users and for different distance range.

In the second phase of this dissertation, Cyclic Shift (CS) coding technique is implemented for two dimensions i.e. wavelength and phase for Optical Code Division Multiple Access System (2D-OCDMA). Previously this cyclic shift encoding was done in spectral domain but in this dissertation the encoding technique has been proposed for spectral as well as phase domain. The proposed 2-D Cyclic shift code with spectral as well as phase domain increases the number of users by splitting the optical source to two orthogonal phase signals without the requirement to increase the code length as well as number of LEDs. Thus, the wavelength required for this proposed encoding structure is also reduced. In this paper, this encoding technique has been tested for four users. The performance is analyzed with increase in number of users. The proposed 2D is compared with the previously implemented 1D CS SAC-OCDMA code. Performances of the system designed show better result than the previously designed SAC-OCDMA Cyclic Shift code. The results of the proposed system in terms of parameters like bit error rate is within the range of10^{-9}.

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CHAPTER 1

1.1 INTRODUCTION

OCDMA is a spread spectrum multiple access technique in which we use orthogonal codes for several users to access the intersecting spectral band without any intersession. Spread spectrum allows several users to access the local network at the same time without any delay. OCDMA is increasingly is finding application in expanding passive optical network. Several codes are being developed for higher capacity of data, users, and access of the network. CDMA are intensity modulated with direct detections (IM-DD). It can be achieved by multiplying every user signal with a unique code. OCDMA channels can be either fiber-optic wireless or with fiber. Users are provided all the available bandwidth. Spectral amplitude coding (SAC) a family in OCDMA have gained attention in comparison with the spatial and temporal coding family.

The idea of OCDMA has come from Code Division Multiple Access (CDMA). OCDMA is similar to the concept of CDMA, based on sharing of allocated bandwidth among users. The advantages of using CDMA is

I. Simultaneous network access
II. Increased system capacity
III. Enhanced security

OCDMA can be of synchronous where users transmit signals at predetermined intervals or asynchronous transmission where users are allowed to transmit at any given time. Signals from users are passing through encoders, where the signals are intensity modulated are coupled and transmitted. Decoders receive the sum of all the encoded signals. At receiver section signal can be detected directly. Each decoder can decode the transmitted signal if it has the same code as was transmitted. At the receiver several signals appears in the form of noise to the decoder this is known as multiple-access interference (MAI). The intensity Detection and Direct Detection use unipolar codes because it gives low error OCDMA systems. OCDMA technologies have both advantages and disadvantages. It has a tradeoff when LEDs as broadband source are used. A broadband light reduces the overall system cost but limits in areas like range, bit error rate, and quality. MAI is one of the prominent sources of noise in OCDMA which affects the system performance. MAI can be overcome by using suitable coding technique like subtraction techniques.

Hence Code design generally aims at low cross-correlation and high auto-correlation properties.

In CDMA the bits 1 and 0 are transmitted with a code. The code lengths are determined by correlation coefficient. Number of ones is the code weight.

OCDMA USES

OCDMA is a viable option of future PON network technologies. An OCDMA PON is designed with topologies like tree with passive optical power splitters. The network has all encoder-decoder pairs for communication between optical line terminal (OLT) and Optical Network Unit (ONU). However, since the signal transmitted by one ONU does not reach other ONU, OCDMA PON are slightly different from broadcast systems like LAN. More contributions include assigning OCDMA codes with universal IP addresses.

OCDMA does not require control mechanism to avoid collisions or allocate bandwidth. There is no need for synchronization between ONU and OLT as they do not require instantaneous bandwidth allocations to OLT, this reduces round trip delay.

a) OCDMA can support higher users than WDMA or TDMA or 1D-OCDMA. 2D-OCDMA systems can be implemented with combinations of time, space, phase and wavelength dimensions. Using an access protocol it is possible to assign even larger number of users in OCDMA.
b) OCDMA offers a virtual point-to-point topology over physical tree architecture with simple network configuration. WDMA requires WDM multiplexer at the ONU whereas OCDMA needs the low cost optical power-splitter but also suffers power loss.
c) With OCDMA it is possible to accommodate more users with complexity and less cost. In OCDMA, the addition of extra users do not affect the bandwidth availability of other users where as in WDMA or TDMA bandwidth allocations need to be changed with addition of users. OCDMA does not require being control or synchronized.
d) OCDMA, like WDMA, ONU and OLT can operate with different upstream and downstream bit rates, protocols, and can be upgraded individually. In TDMA, ONU

needs high-speed transceivers and line them up to communicate with the OLT, irrespective of their input data rate.

e) OCDMA can accommodate users with low and high bit rate in the same optical system. This allows different traffic patterns which are highly desired.
f) OCDMA provides higher security, Special orthogonal codes can be designed to make OCDMA secure without additional equipment [1] but TDMA and WDMA requires encryption at the electrical level.

Several coding techniques have been proposed meet the required properties. For a system designed code length is critical as it should be minimal. There is tradeoff between the code length and correlation properties. Large code length improves correlation property of the codes, therefore improves the system performance.

Even with the use of orthogonal codes, the Signal to Noise ratio is still affected with the number of users transmitting and receiving at a given instance, which is known as Multiple Access Interference (MAI). The LAN/MAN optical networks can be of EOE CDMA, hybrid CDMA and WDM, WDMA, or OTDMA.

1.2 CODING TECHNIQUES

Spectral amplitude coding (SAC) which is one of the most widely used optical code division multiple access (OCDMA) techniques. In SAC-OCDMA coding is done in the amplitude of light spectrum where each user is allocated a distinct code word in spectral domain. Codes with low cross-correlation and high auto correlation are used. Several SAC-OCDMA codes like Optical Orthogonal Code (OOC) [2], Hadamard, Modified Frequency Hopping (MFH) [3], Random Diagonal (RD) [4], Multi-Service (MS) [5], Khazanis-Syed (KS) [6], Dynamic Cyclic Shift (DSC) [7], Modified Quadratic Congruence (MQC) [8] are proposed having low cross correlation and high correlation. These codes are characterized by code length, code weight, number of users. As the users raises, the code length gets to increase making the system more complex.

1.2.1 CLASSIFICATION OF ENCODING:

I SPECTRAL ENCODING

It uses a broadband optical source which has low cost. It can be of two types that is encoding van be done in amplitude and phase. A grating is used to diffract light into several spectral components that are focused into lens with amplitude mask or phase mask. As per Park et al. (2004) publication multiple access interference can reduce the differential detection using spectral coding.

II SPATIAL ENCODING

In optical CDMA spatial encoding systems uses multiple fibers as space channels for encoding in systems. spatial optical CDMA by Hui (1985). Park et al. (1992) have proposed Temporal/Spatial code.

III MATRIX ENCODING

Zhang and Pichhi (1993a) have proposed a tunable encoder/decoder using splitter, combiner, switches and fiber delay lines. In a wavelength-time system the broadband light pulse is used with a super-structured fiber Bragg grating (SSFBG) so that wavelengths at the output of the encoder is a coded signal. The spectral components are time-shifted because of the positions of the fiber gratings. The receiver conjugate SSFBG to decode the signal. Fathallah et al. (1999) used identical gratings which can be strain-tuned to different wavelengths.

TYPES OF OCDMA CODING:

[1] ONE DIMENTIONAL:

One-dimensional (1D) OCDMA are constructed using prime sequence codes given by Kwong and Prucnal. In one dimensional OCDMA higher the number of users the code sequence length also increases rapidly in other words the code weight increases, which are bandwidth requirement increases if a more users are required to be accommodated.

I. PULSE AMPLITUDE ENCODING

It generally uses broadband incoherent light source and optical delay lines for encoding the incoming data signal. The intensity of optical are summed up at the receiver to detect the signal. It generally uses unipolar pseudo random signals, characterized with some cross-correlation. The light sources are subjected to dispersion and non-linearity. Some characteristics of these encoding techniques are:

- Unipolar
- Incoherent
- Examples based on this code OOC, QCC, PC, HCC.

II. PULSE PHASE ENCODING

In the phase encoding technique, phase modulated signals are superimposed with optical delay lines. The cross-correlation are nearly zero. Bipolar techniques used in CDMA can be employed here. Even this technique is subjected to dispersion and non-linearity. Characteristics of the used coding techniques are summarized below:

- Bipolar
- Coherent
- Examples of this codes are m-sequence, Walsh-Hadamard, gold codes

III. SPECTRAL AMPLITUDE ENCODING

Here broadband light source is scattered into multiple wavelengths. Encoding is done in wavelength domain. Spectral encoding is done by passing the wavelength through an amplitude mask. The spectral components are recombined at receiver for decoding. Code length is determined by the length of mask, also increases with increase in no of users. Multiple Access Interface is reduced by the use of bipolar codes. Some characteristics are summarized below:

- Bipolar
- Incoherent
- Examples of this codes are m-sequence, Walsh-Hadamard, gold codes

IV. SPECTRAL PHASE ENCODING

Here broadband light source is scattered into multiple wavelengths. Encoding is done in wavelength domain. Spectral encoding is done by passing the wavelength through a phase mask. The spectral components are recombined at receiver for decoding. Code length is determined by the length of mask, also increases with increase in no of users. Multiple Access Interface is reduced by the use of bipolar codes. Some characteristics are summarized below:

- Bipolar
- Coherent
- Examples of this codes are m-sequence, Walsh-Hadamard, gold codes

[2] TWO DIMENTIONAL OCDMA

Two-dimensional OCDMA, any two domains among, wavelength, phase for spreading, polarization, time and space can be utilized.

I. WAVELENGTH/TIME SPREADING ENCODING

Encoding is done with wavelength and time domain. Two dimensional codes enhance the scalability of the system with enhances security. Generally employed in physical layer where the signal transmission is time sensitive. Requirement of short pulses is reduced. These codes are less susceptible to dispersion. Encryption delays are important in these system designs. Some characteristics of this coding are summarized below:

- Unipolar
- Incoherent
- Examples of its codes using wavelength/time systems are 2DWH/TS OOCs

II. SPACE ENCODING

It explores two dimensional optical codes in space domain and wavelength domain. It was initially used for two dimensional spatial codes. Some characteristics of this coding are summarized below:

- Unipolar
- Incoherent
- Examples: 2-D space codes

[3] THREE DIMENTIONAL ENCODING

Encoding is done in polarization, time, wavelength domains or time, wavelength, space domains. 3-D codes improve the performance, reduce the code length along with increase in the number of users. They use incoherent and unipolar codes.

1D SACOCDMA

Spectral Amplitude Coding (SAC) is a coding technique developed for OCDMA systems that are most widely used due to the reduction of the MAI effects, simplicity and low cost of system components [10,11].

One-dimensional nature of SAC-OCDMA codes have certain limitation their performance through several problems like

- limited number of available frequency bins
- spectral width of the encoded chips
- Limited number of users etc.

1.3 PROBLEM IDENTIFICATION

- The performance of OCDMA is often affected by noise. Shot noise is one such noise that affects the network performance. It is the optical root square of the power at the receiver, which is directly proportional to users in the system. Scalability of the designed OCDMA system is reduced because of this type of noise. Another type of noise that affects the system is beat noise. Beat noise occurs because of the interference of signals of different wavelength's or frequencies. The signal and the multiple user interference are known to be affected by beat noise in 2-D wavelength/ time spreading CDMA [11].
- The Transmission of signals in electrical domain is different from optical domain as the data capacity and rate are different. The encoding and decoding of signals in optical domain require coding techniques characterized with low cross correlation and high autocorrelation to reduce the error. The coding techniques are again characterized with code length and code weight.

- The process of encoding and decoding requires more wavelengths so there is a need of source that can produce these wavelengths. Source like lasers can be used as a source but use of large number of lasers can make the system costly. So generally, LEDs are used as source which can transmit the data for longer distances.
- Spreading in one dimensional (1D) spectral domain optical codes require ultra-short optical pulses for long code lengths, this makes such systems practically difficult. Therefore, 2D codes have been introduced to overcome the mentioned problems. Many 2D OCDMA coding schemes have been proposed like hybrid WDM/OCDMA increase the bandwidth and number of users. Two dimensional systems essentially employees the combination of two coding schemes, where one is encoded in spectral domain and another is encoded using spatial domain respectively [III, IV].

1.4 OBJECTIVE

There are several advantages attained by using 2-D coding that is reduced cross-correlation, are nonexistent of auto-correlation side lobes, the scalability of the code family is greatly increased along with enhanced security. The objective of the proposed system is described below:

- To design a secure and simple two-dimensional Optical CDMA system for low BER and high Q-Factor.
- To design an improved Cyclic Shift code by using wavelength and phase as two dimensions for a secure OCDMA system.
- To design an improved OCDMA by using wavelength and phase as two dimensions using Hadamard coding technique for a secured system.
- To compare the performance of above coding technique with respect to BER, Q Factor, number of users and fiber length.
- To stimulate above coding technique for OCDMA system and compare its performance.

1.5 ORGANIZATION OF THE THESIS

First chapter gives a brief introduction of OCDMA, details of different coding techniques used in ocdma, types of coding in ocdma and uses of ocdma. Second Chapter is literature survey that details previous work done in the field of ocdma. Chapter Three discusses the Two-Dimensional OCDMA using Hadamard coding technique in detail along with components used in the software like LED, power splitter, FBG filters, power combiner, photo detector are the components described. Forth chapter details the Two-Dimensional OCDMA using Cyclic Shift coding technique.

CHAPTER 2

2.1 LITERATURE SURVEY

1. A spectral amplitude optical coded multiple access (SAC-OCDMA) system has been designed with two orthogonal polarization states of the same 1D optical code has been used [12]. This can increase the number of simultaneous users who can be accommodated in a network, and it can double the number of users against the 1-D code. The results obtained showed that optical zero cross-correlation code could accommodate more users simultaneously for the bit error rate of 10− 9 in optical communication system.
2. This problem deals with the employment of several optical fiber paths between the transmitter and receiver modules for the implementation of spatial encoding as shown in Fig. 2. This significantly elevates the complexity and cost of deployment for such systems. In order to overcome this problem, another family of 2D codes is proposed that replaces spatial encoding with temporal encoding to mitigate the extensive use of long span optical fiber media [V, VI]. Fiber media [V, VI]. Figure 2: Conventional spectral/ spatial OCDMA system.

   In quest to develop such a scheme, this paper utilizes the combination of diagonal eigenvalue unity (DEU) code along the spectral domain and zero cross correlation (ZCC) code along the temporal domain to develop a 2D code called 2D-DZ code. The proposed code is analyzed in terms of cross correlation properties in order to determine the improvement offered by the selected combination. Mitigation of cross correlation is of primal importance as it can reduce the contribution of interfering noise sources along with the simplification of network architecture that can facilitate the deployment as PON.
3. Cyclic Shift (CS) code has been proposed to overcome the drawbacks in Spectral Amplitude Coding- Optical Code Division Multiple Access (SAC-OCDMA) codes that have been previously explored [14]. The proposed code has a simple construction, large cardinality while choosing the number of users and code weight. It has reduced zero cross correlation that allows suppressed MAI (Multiple Access Interference) and PIIN (Phase Induced Intensity Noise). Additionally, the frequency bins of the code proposed exist beside each other this reduces filters required in encoder and decoder. Hence the receiver

construction design becomes simple, easy and cost efficient. Performance of the proposed code has been compared with the traditional codes. Results showed that the proposed code gave better performance than the traditional SAC-OCDMA codes. Mathematical analysis of the proposed CS code has been derived and Simulation has been done using Opti-system version13.

4. Zero Cross-correlation (ZCC) code has been proposed in OCDMA. The system is based on amplitude spectral encoding using broadband sources like Light Emitting Diode (LED) [15]. The system is designed with easily available optical elements and simple direct-detection receivers. It has been shown that for weight = 4, nearly 100 users can transmit data asynchronously with an average bit error rate of 10-9. This can be achieved with the minimum received power of -25.5 dBm.
5. OCDMA code optical Zero Cross Correlation (ZCC) has a flexible code construction design and the number of user and weight can be increased easily using mapping and transformation techniques respectively [16]. The performance of the designed system was analyzed using Opti system version5. The demonstrated ZCC code had excellent performance of BER because it had no cross correlation between the users. element of Phase Induced Intensity Noise (PIIN) was eliminated. The results showed acceptable BER up to a distance of 100kmcan be achieved using ZCC code.
6. Hybrid system has been designed with OCDMA over wavelength division multiplexing (WDM) with differential phase shift keying (DPSK) modulation using complementary and direct subtraction detection techniques. Here two different technologies, OCDMA and WDM were combined as a hybrid system aimed to increase the transmission capacity, enhance security and reliability of the network [17]. Most of the OCDMA systems suffer from multiple access interference (MAI that degrades the overall performance of the designed hybrid system. modified double weight (MDW) code was used as a signature code for the system. The results of direct and complementary subtraction detection techniques with data bit rate of 1Gbps were compared. Simulation showed the complementary subtraction technique provided better BER vs distance performance than the direct detection technique.
7. A survey of the recent trends in OCDMA codes and their applications are detailed. Optical coding distinguishes itself from OCDMA where codes are not applied to data,

network carry information other than user identity. Here principles of coding, their applications, OCDMA PON are discussed [18].

8. The performance of a PON has been compared with OCDM PON to determine a system for NGOA networks [19]. A Passive optical network (PON) has high bandwidth and economical was designed. Time division multiplexed passive optical networks (TDM PONs) and Wavelength division multiplexed passive optical networks (WDM PONs) are considered good option for next-generation optical access (NGOA) networks. These systems are limited in areas like transmission capacity, broad bandwidth, and dispersion tolerance. This paper uses two parameters that are fiber length and bit rate. Performance was analyzed using Opti-system. Results showed the performance parameters that is bit error rate (BER) less than 10-9 and quality factor (Q) more than 6, for a distance up to 50 km with data rate of 10 Gbit/s per ONU.
9. The RD code has receiver's flexibility that makes its implementation easy. The simulation was carried out in Opti-System software. The designed system with four users in WDMA system with bit rate of 10Gbps coupled with users of OCDMA with bit rate of 1.25Gbps. It has been compared to hybrid SAC-OCDMA /WDMA using KS code, the system had better performance with requirement of less code length and desired bit error rate (BER) but required of a greater number of filters [20].

CHAPTER 3

DESIGN AND IMPLE MENTATION OF TWO DIMENTIONAL OCDMA USING HADAMARD CODING TECHNIQUE

3.1 INTRODUCTION

Code Development depends upon parameters like code weight, the cross-correlation, and code length. Several 2-D codes have been proposed previously. In some cases, 1-D have been mapped to into 2-D and 3-D codes sequences, some are based on algorithm while some use different combinations of 1-D sequences to construct a new 2-D codes.

In this dissertation we have worked on two dimensional OCDMA using cyclic codes and Hadamard code. The used coding techniques have simple code construction. The performance of the proposed system using Hadamard coding technique is analyzed by designing a 2D OCDMA system for six users for a range of 20Km. The system is designed for transmission at the rate of 200Mbps. The performance of this system is examined in terms of Bit Error Rate (BER) and Quality Factor by increasing the users and for distinct distance range.

Hadamard code is an error-correction code titled after Jacques Hadamard. It is generally used for fault detection and their correction. It is used mostly in noisy communication channels because of cross-correlation properties. Hadamard is limited in its cardinality.

Hadamard codes are one among the most widely used SAC- OCDMA. They are easy to implement hence are widely used. They are bipolar code generally used in wireless communication but have also been used in OCDMA. Hadamard codes are orthogonal in nature which gives low cross correlation that is used in communication.

It exists at matrix sequence n only, where $n \geq 2$. It is characterized by: (N, w, K, λc), where

- user number $K=2n - 1$
- code weight (W), $W= 2n-1$
- code length (N), $N= 2n$
- $\lambda c= 2n-1$ cross correlation
- $n=4$ message length (for all integer)

The code structure of Hadamard code is described below:

The basic 2×2 matrix of Hadamard code is

$$H_{2\times2} = \begin{bmatrix} 1 & 1 \\ 1 & 0 \end{bmatrix}$$

For a 4×4 matrix expansion the following method is used

$$H_{n\times n} = \begin{bmatrix} H_{2\times2} & H_{2\times2} \\ H_{2\times2} & H_{2\times2}* \end{bmatrix}$$

For example, 4×4 matrix is given as:

$$H_{4\times4} = \begin{matrix} 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 \\ 1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 1 \end{matrix}$$

For further expansion the same process can be repeated. As the number of users increases the bandwidth requirement increases as the wavelength assignment increases. In this project 2D OCDMA is designed for 6 users using Hadamard code and phase shift. So, reference is taken for designing the SAC-OCDMA using Hadamard code [15]. Then by using polarization of optical source the number of users are increased to six [10].

The wavelengths assigned for three users using Hadamard code is described below

$$H_{4\times4} = \begin{matrix} 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 \\ 1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 1 \\ \downarrow & \downarrow & \downarrow & \downarrow \\ 1548.5 & 1550.1 & 1551.9 & 1552.5 \end{matrix}$$

The same set of wavelengths is used for encoding with different phases of optical sources. Here each row represents a user and each column is assigned a wavelength. The number of 1's is code weight. The code length for 4 users for Hadamard code is 4. Hence for increasing the number of users using Hadamard code requires more code length which requires makes the implementation of receiver section difficult. So, making them Two Dimensional in the phase domain makes the system work efficiently.

Let $C_K(i)$ is the i^{th}item of the K^{th}CS code sequence. For two sequences the code is presented as

$$\sum_{i=1}^{L} C_K(i)C_N(i) = \begin{cases} W, for\ \ K = N, \\ 0\ , \qquad\qquad else \end{cases} \tag{3.1}$$

The non-polarized optical source with flat spectrum over the range of $\left[v_O - \frac{\Delta V}{2}, V_O + \frac{\Delta V}{2}\right]$ where Δv is the bandwidth f source and v_O is central frequency.

After the encoding of optical signals, the binary data signal is transmitted is converted into electrical RZ signal which is then modulated. At the receiver section, the Power Spectral Density (PSD) is given with the expression

$$r(v) = \frac{P_{sr}}{\Delta v} \sum_{k=1}^{K} d_k \sum_{i=1}^{L} C_K\,(i) \left\{u\left[v - v_O - \frac{\Delta v}{2L}(-L + 2i - 2)\right] - u\left[v - v_O - \frac{\Delta v}{2L}(-L + 2i)\right]\right\} \tag{3.2}$$

Photocurrent at the receiver for the polarized states, is given as:

$$\mathrm{I} = \frac{\mathrm{ne}}{\mathrm{hv}} \int_0^{-\infty} \mathrm{G(v)dv} = \frac{\mathrm{ne}}{\mathrm{hv}} \cdot \frac{\mathrm{P_{sr}}}{\mathrm{L}} \text{ if } \theta = 90° \text{ or } \theta = 0 \tag{3.3}$$

The Signal to Noise Ratio (SNR) and Bit Error Rate (BER) is given as

$$\mathrm{SNR} = \frac{\mathrm{I}^2}{\sigma^2} = \frac{\left(\frac{\mathrm{RP_{sr}w}}{\mathrm{L}}\right)^2}{\mathrm{eBR}\frac{\mathrm{P_{sr}w}}{\mathrm{L}} + \frac{4\mathrm{KT_nB}}{\mathrm{R_L}}} \tag{3.4}$$

$$\mathrm{BER} = .5\ \mathrm{erfc}\left(\sqrt{\mathrm{SNR}/8}\right) \tag{3.5}$$

Where K is the Boltzmann's constant, e is the electronic charge, T_n is the absolute temperature in kelvin, B denotes the electrical bandwidth, R_L is the load resistance and P_{ST} is the power received.

3.2 SYSTEM DESIGNED

In this dissertation 2D-SAC OCDMA is explored. 2-D encoding is done to overcome the drawbacks in 1-D codes as they require more wavelengths, longer code lengths. 2-D encoding is done to overcome the drawbacks in 1-D codes as they require more wavelengths, longer code lengths. For enabling the 2-D encoding spectral and polarization domain is used. For spectral encoding Hadamard code is used. The transmitter section of system designed for single user is shown in figure 3.1.

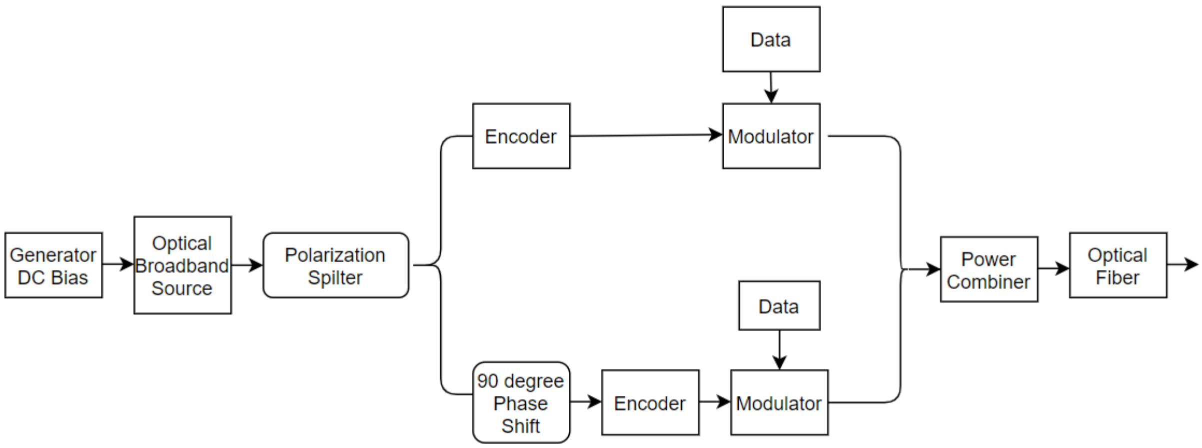

Figure 3. 1: Schematic of Transmitter for 2-D Encoding for single user.

In the transmitter section LED is used as a broadband source. LED as a source can be split into different spectral components of different phase this enables coding each user as per the coding requirements. Encoding and decoding is done through fiber Bragg gratings (FBG) filters. Each user is coded with a unique code generated using Hadamard coding technique. The encoded signals are electro-optically modulated. The modulated optical signals are mixed using a power combiner and transmitted through fiber.

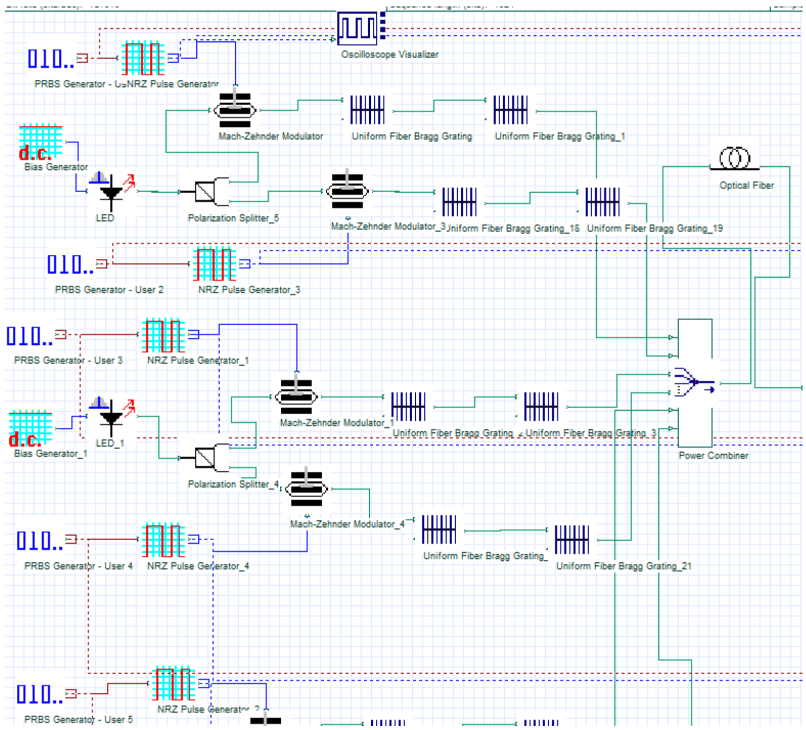

Figure 3. 2: Transmitter for 2-D Encoding for single user in OptiSystem.

The system has been designed in OptiSystem. The system designed in OptiSystem 17 is shown in figure 3.2.

AT RECEIVER

The block diagram and schematic diagram of receiver is shown in figure 3.3 and figure 3.4. At the receiver the received signal is split using power splitter. Then signal is first split into different polarizations. After splitting the phase of received signal the signals are decoded subtraction technique with FPG filters. The decoded signals are passed through low pass filter (LPF). The received signals are analyzed through BER analyzer.

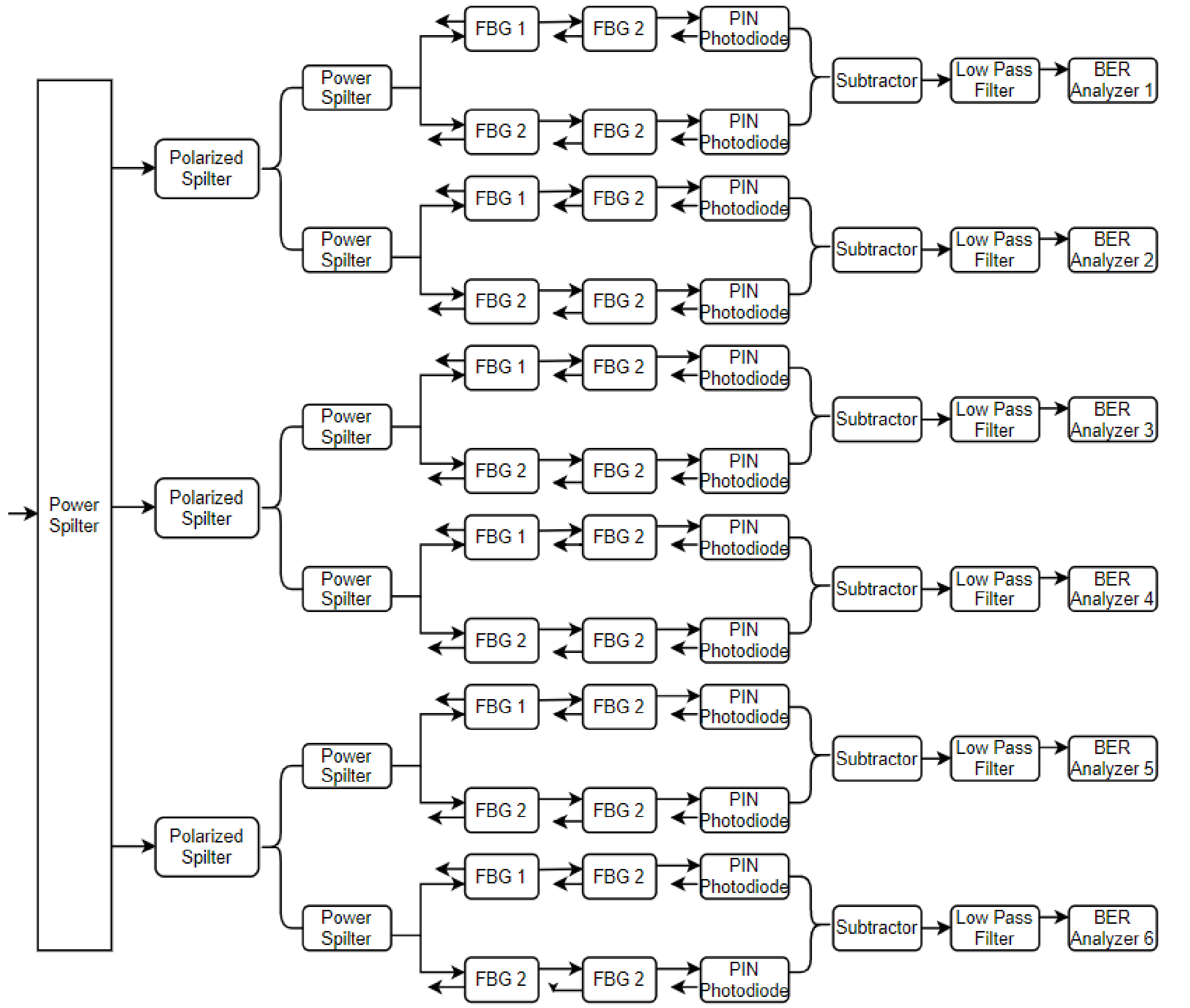

Figure 3. 3: Block Diagram of Receiver Section.

At receiver OCDMA experiences different kinds of commotions like intrinsic noise sources due to impacts on the physical structure of the system, for example, relative intensity noise (RIN), phase induced intensity noise (PIIN), thermal noise, beat noise and shot noise [15,19]. PIIN is firmly identified with the MAI. Here we use subtraction technique for detecting the signal.

During AND subtraction [9], the cross correlation $\theta_{\overline{XY}}(k)$ is replaced by $\theta_{(X\&Y)Y}$, where $\theta_{(X\&Y)}$ denotes the AND operation between X and Y sequences.

If X = 1011 and Y = 0110 then (X AND Y) = 0010.

At the receiver,

$$Z_{AND} = \theta_{XY}(k) - \theta_{(X\&Y)Y}(k) = 0 \qquad (3.6)$$

Subtraction of the received signal from selected signal is done through above equation. The MAI can be reduced with AND subtraction as interference from several other channels can be removed by cancelling out. This subtraction technique can implement in any OCDMA codes. The receiver section designed in the software is shown in figure 3.4.

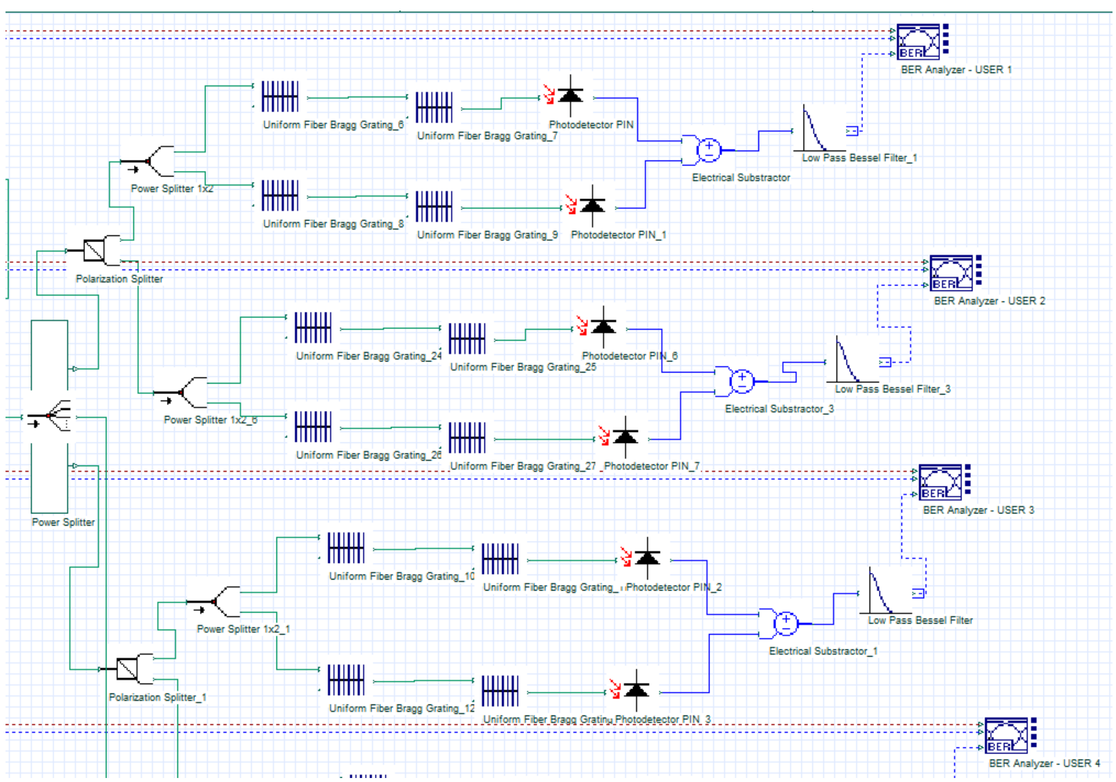

Figure 3. 4: Receiver for 2-D Decoding for single user in OptiSystem.

For decoding the signals one set of filters, filter out the wavelengths same as the transmitted one that is 1550.1nm and 1552.5nm. Another set of wavelengths that are assigned to '1' are filters out that is 1548.5nm and 1550.9nm

3.3 COMPONENTS USED

I. PHOTODETECTOR PIN

At receiver the optical signal and noise bins are filtered by an ideal rectangular filter for reducing the quantity of samples of electrical signals. A new sampling rate is defined using Sample rate. The center frequency can be defined or calculated by centering the filter at the maximum powered optical signal. Optical noise is converted to Gaussian noise within the signal bandwidth.

If the parameter Add shot noise is enabled and Shot noise distribution parameter is Gaussian, the optical power is converted to electrical current.

$$i(t) = i_s(t) + i_{th}(t) + i_d + i_{sh}(t) \quad (3.7)$$

Where $i_s(t)$ is the optical signal calculated from the responsively, $i_{th}(t)$ is the thermal noise and i_d is the dark current noise and i_{sh} is the shot noise.

II. 3R REGENERATOR

This is an electrical signal generation component. It regenerates the original bit sequence, the corresponding electrical signal and the modulated electrical signal that is used for BER analysis. It is a subsystem based on the Data Recovery component and an NRZ Pulse Generator. The type of Signal coming in input and output Port w.r.t 3R Regenerator is shown in table 3.1.

Table 3. 1:3R Regenerator Ports.

Name	Type of Port	Type of Signal
Input	Incoming	Electrical
Bit Sequence	Outgoing	Binary
Reference signal	Outgoing	Electrical
Output	Outgoing	Electrical

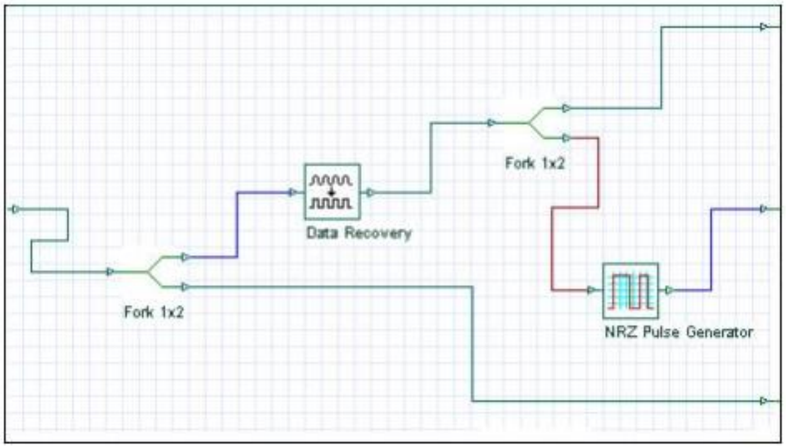

Figure 3. 5: The inside diagram of 3R Regenerator.

III. BER ANALYSER

This visualizer allows the user to calculate and display the bit error rate (BER) of an electrical signal automatically. It can estimate the BER using different algorithms such as Gaussian and Chi-Squared and derive different metrics from the eye diagram, such as Q factor, eye opening, eye closure, extinction ratio, eye height, jitter, etc. It can also take in account Forward Error Correction (FEC), plot BER patterns and estimate system penalties and margins. The type of Signal coming in input and output Port w.r.t BER is shown in table 2.

Table 3. 2: BER Analyzer Ports.

Name	Type of Port	Type of Signal
Bit Sequence	Incoming	Binary
Reference	Incoming	Electrical
Input	Incoming	Electrical

The Q-Factor from BER is calculated numerically by:

$$P_e = \frac{1}{2}\operatorname{erfc}\left(\frac{Q}{\sqrt{2}}\right) \tag{3.8}$$

IV. POLARIZATION SPLITTER

Optical domain polarization splitter has been used in the system designed. It splits the input signal into two output ports. The polarization splitter selects the appropriate polarization component of the input at input port and the respective polarization component for one of two output ports. The working of polarization is shown in figure 3.6.

Polarizer Splitter

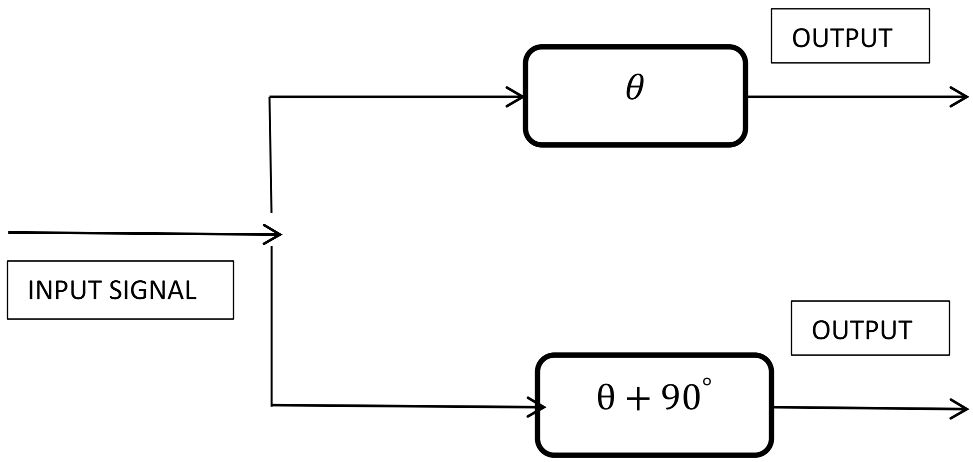

Figure 3. 6: Polarization Splitter

V. UNIFORM FIBER BRAGG GRATING

Table 3. 3: FBG Input and Output Signal Port.

Name	Type of Signal	Type of Port
Input	Optical	Incoming
Transmission	Optical	Outgoing
Reflection	Optical	Outgoing

FBGs are used as a filter. The uniform grating reflects back a wavelength based on reflectivity of medium, while the remaining wavelengths are transmitted. For the calculation of the reflection and transmission wavelengths, coupled mode equations for a uniform grating are used. The type of Signal coming in input and output Port w.r.t. FBR is shown in table 3.3.

VI. LED

It converts the input electrical signal to optical signal. The current flowing through LED gives light. The mean of the optical power is a function of the modulation current. Responsivity of LED or the Slope efficiency gives the conversion of the current into optical power. The type of Signal coming in input and output Port w.r.t LED input is shown in table 3.4.

Table 3. 4: LED Input and output signal port type.

NAME AND DESCRIPTION	SIGNAL TYPE	PORT TYPE
Modulation	Electrical	Input
Output	Optical	Output

Responsivity is calculated as follows:

$$P = \eta * h * f * \frac{i(t)}{q} \tag{3.9}$$

Where

η is the quantum efficiency

h is the planks constant

f is emission frequency

q is the electron charge

$i(t)$ is modulation intensity

VII. POWER COMBINER

Optical power combiner combines a user-defined number of input signals. Its input-output parameters are shown in table 3.5.

Table 3. 5: Power combiner input and output signal port type.

NAME AND DESCRIPTION	SIGNAL TYPE	PORT TYPE
Input 1	Optical	Incoming
Input 2	Optical	Incoming
Output	Optical	Outgoing

The power combiner combines the input fields of every frequency mode ω, when there is more than one mode present, outputs field at frequency modes ω.

The total output field at each mode is given by:

$$E_{O,\omega,X,Y}(t) = 10^{\frac{-\alpha}{20}} N(\omega) \sum_{i=1}^{n} E_{O,\omega,X,Y}(t) \quad (3.10)$$

VIII. POWER SPLITTER

An Ideal power splitter splits an optical input signal into number of output signals as required in the system. The type of Signal coming in input and output Port is shown in table 6.

Table 3. 6: Type of Input and Output signals ports in Power Splitter.

Name	Type of Signal	Type of port
Input	Optical	Input
Output 1	Optical	Output
Output 2	Optical	Output

The signal output for each port is attenuated by:

$$E_{out\,X,Y}(t) = \frac{E_{IN\,X,Y}(t) 10^{\frac{-\alpha}{20}}}{\sqrt{N}} \quad (3.11)$$

Where α is the power attenuation and N is the number of output ports.

IX. POLARIZATION METER

The polarization is a visualizer that shows the calculated the average polarization state of the optical signal, the degree of polarization (DOP), differential group delay (DGD), Stokes parameters, azimuth and elasticity. It also shows the total signal power at a defined frequency and bandwidth.

3.4 WORKING

The system is designed for 6 users. Data is transmitter at a 200Mbps. Incoming data bits is converted to electrical NRZ which is then optical modulated. An optical signal is initially split into two polarizations. The optical signals are further transmitted to fiber Bragg grating (FBG). FBG enables the spectral coding. The wavelength assignment is done through Hadamard codes. Each bit of '1' is assigned a wavelength. At first FBG one wavelength is filtered out and the reflected to be passed to second FBG, this compensates the delays involved. At second FBG another wavelength is filtered out. Parameters assigned for Hadamard code of 2D OCDMA are listed out in table 7.

Table 3. 7: The parameters assigned for 2D OCDMA using Hadamard coding technique.

S.No.	**Parameters**	**Values**
1	Data rate	200Mbps
2	No of users	6
3	Wavelengths used	1548.5-1552.4
4	Wavelength spacing	0.8nm
5	LED source wavelength	1551nm
6	Fiber optic length	20km
7	Attenuation	25dB/Km
8	Geometric attenuation	enabled
9	Photo detector gain	3
10	Uniform FBG bandwidth	0.3nm
11	Polarization device angle	0°
12	Photo detector gain	3
13	Responsivity	1A/w
14	Low pass filter cutoff	130Mhz

The encoding for three users is specified below

$$H_{4\times4} = \begin{array}{cccc} 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 \\ 1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 1 \\ \downarrow & \downarrow & \downarrow & \downarrow \\ 1548.5 & 1550.1 & 1551.9 & 1552.5 \end{array}$$

Each row depicts a user. Leaving the first row, the first user is assigned with code of 1010. FBG filters are used to filter the selected wavelengths; the corresponding wavelengths 1550.1nm and 1552.5nm are filtered out. The output is shown in figure 3.7.

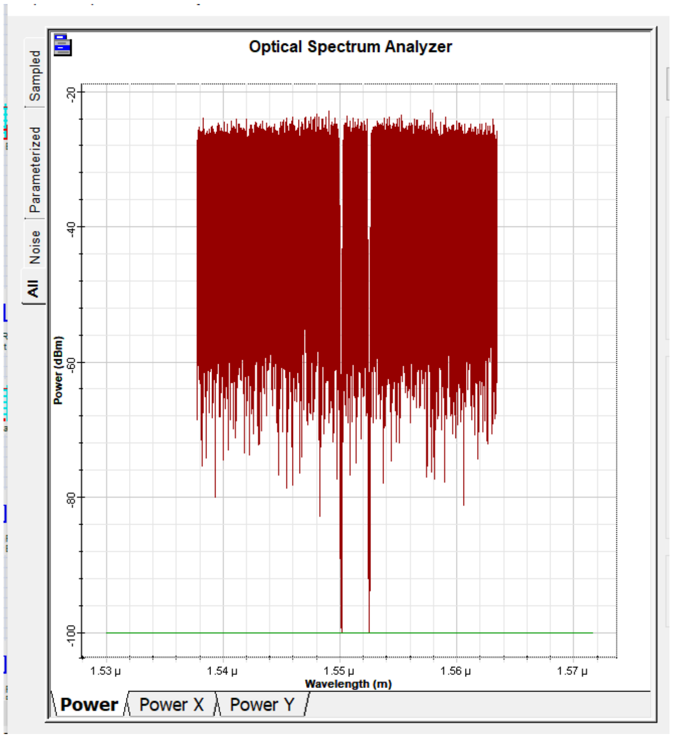

Figure 3. 7: Optical encoded signal for user1

The first and second set received signal at the subtraction is shown in figure 3.8 and figure 3.9 respectively.

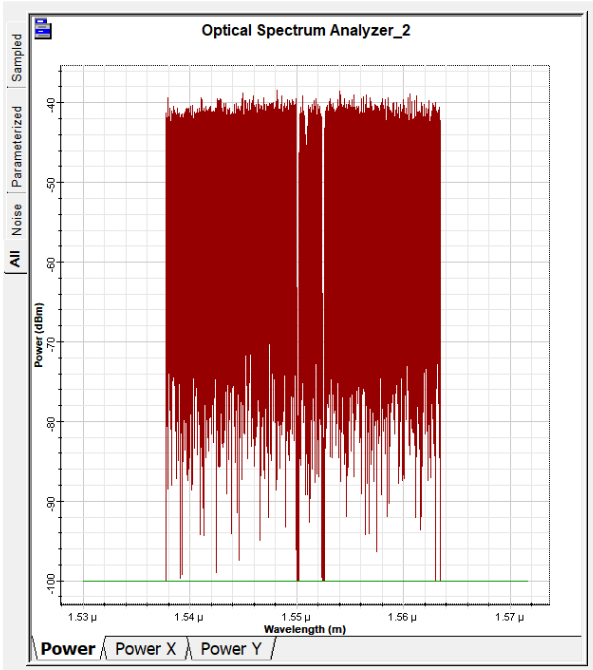

Figure 3. 8: First set of Optical spectrums obtained after subtraction for user1.

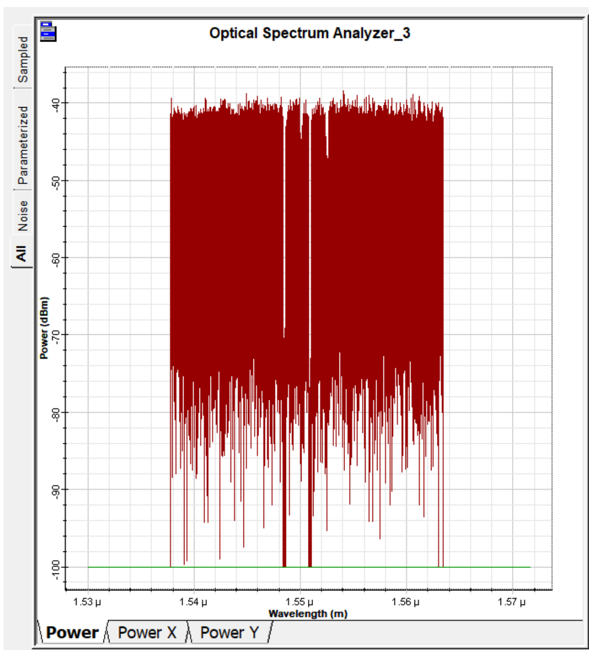

Figure 3. 9: Second set of Optical spectrum obtained at subtracted for user1.

The second set of signals is subtracted from first set of signals and the signal obtained is passed through low pass filter and finally the signals are detected.

The optical CDMA depends on similar fundamental ideas as the CDMA radiofrequency. Assigning out to every user through the transmission medium, which is comprised by an optical fiber recognizes the objective recipient.

3.5 RESULTS AND DISCUSSION

The Performance of the system designed for six users is studied in terms of the transmitted and received signals in optical and electrical domain through Optical spectrum analyzer and oscilloscope visualizer respectively. The system designed studies the performance with increase in number of users and for different distance of 10Km, 20Km, and 30 Km of the in terms Q-Factor. The results obtained in this system for six users are compared with system designed for three users.

At the transmitter section, for encoding process the optical spectrum is passed through two FBG filters. Each FBG filters out one wavelength. Since the coding weight for four users in Hadamard code is two, therefore two wavelengths are filtered. For the first user wavelengths filtered are 1550.1nm and 1552.5nm. The optically encoded signal transmitted by user one is shown in (Fig. 3).

The transmitted and receiver signal for first and second user as shown by oscilloscope is shown in figure 3.10 and figure 3.11.

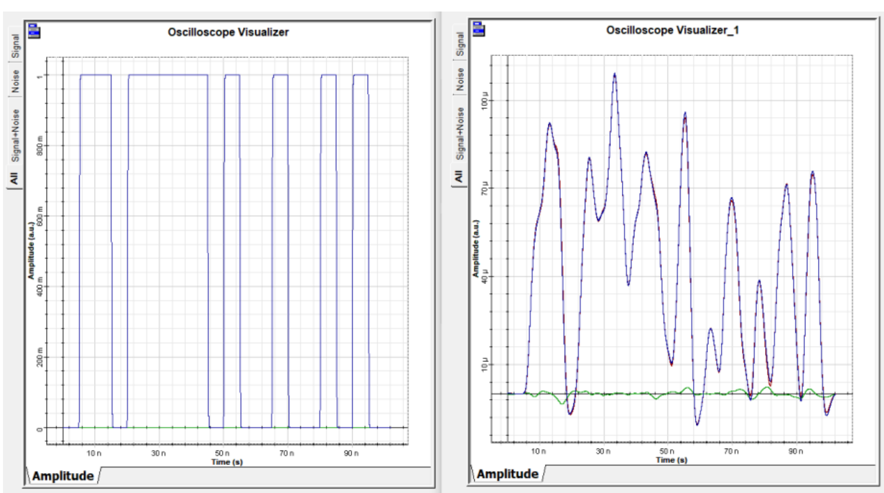

Figure 3. 10: Transmitted and received signal for user1.

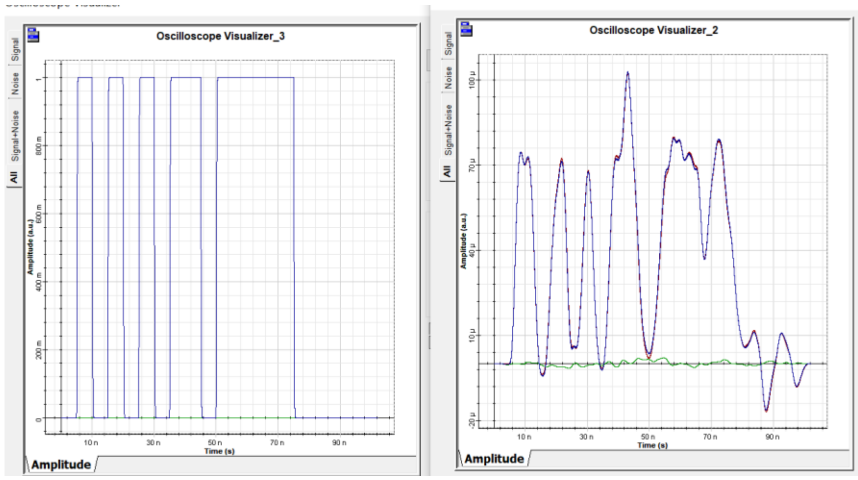

Figure 3. 11: Transmitted and received signal for user2.

As the number of users are increased the performance in terms of the system is affected. The variation in terms Quality Factor with increasing number of users is shown in the form of a graph in figure 3.12.

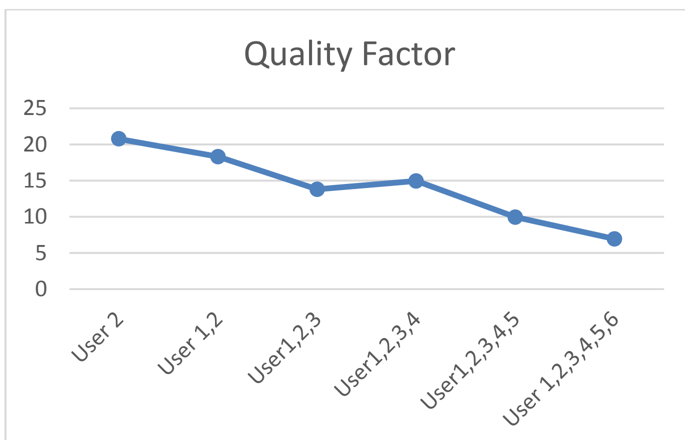

Figure 3. 12: Variation in with increase in number of users.

The performance the proposed 2D OCDMA is analyzed for distances of 10Km, 20Km and 30Km in terms of the Q factor. The results obtained are shown in figure 3.13.

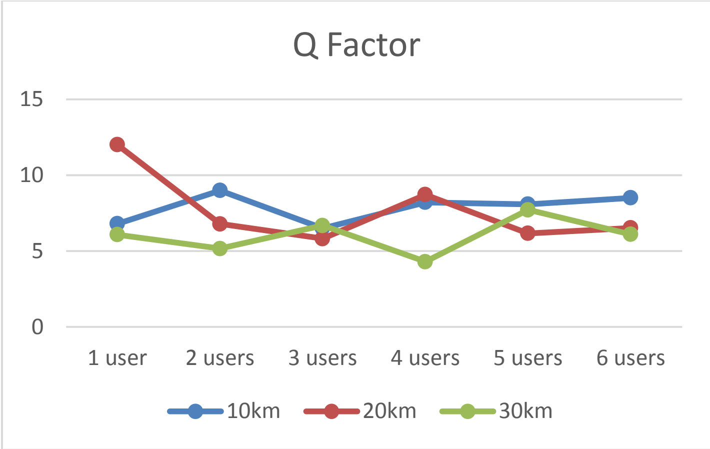

Figure 3. 13: Performance of the proposed system for varying distance.

The performance of the system for distance of 10Km and 20Km show quality factor above 5, but for range of 30Km it is below 5 hence not very suitable for implementation of the system for 30Km range.

The bit error rate and quality factor of proposed 2-D SAC-OCDMA for users is presented below in figures 3.14, 3.15 and 3.16.

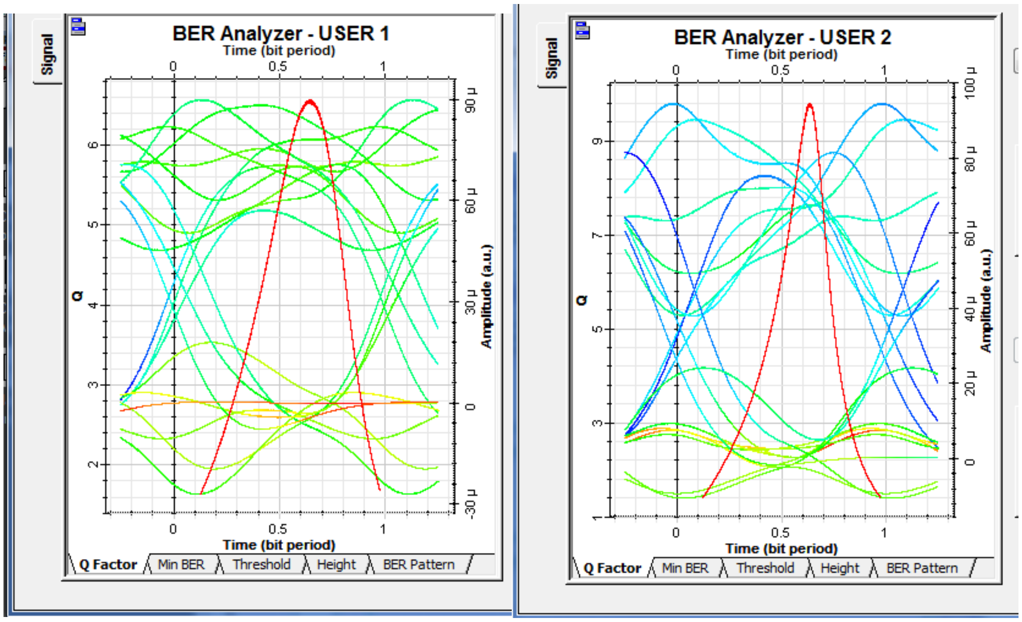

Figure 3. 14: Proposed 2-D SAC-OCDMA using Hadamard code for user1 and user2.

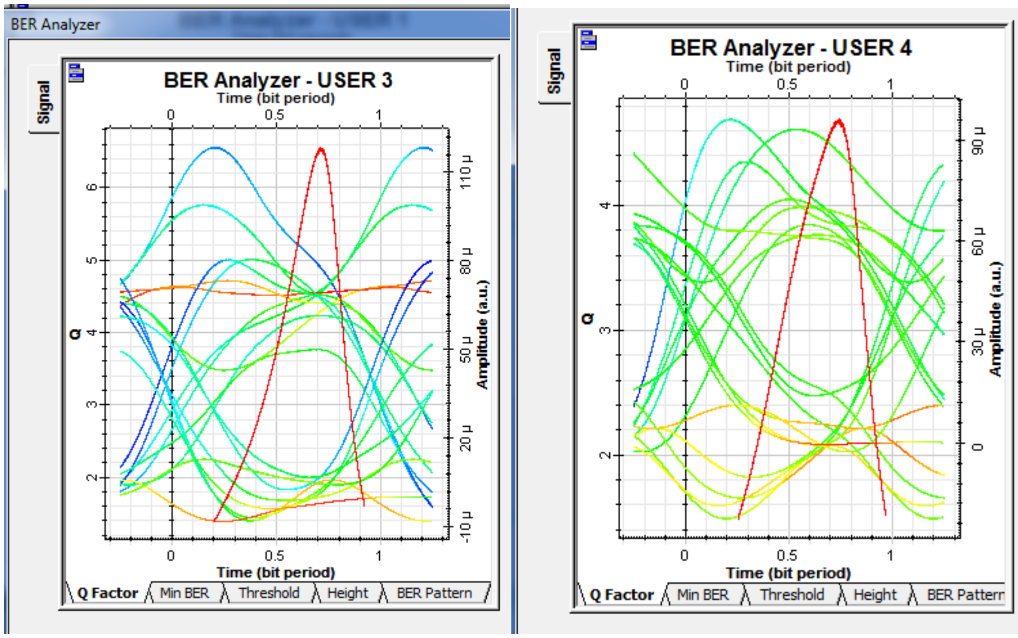

Figure 3. 15: Proposed 2-D SAC-OCDMA using Hadamard code for user3 and user 4.

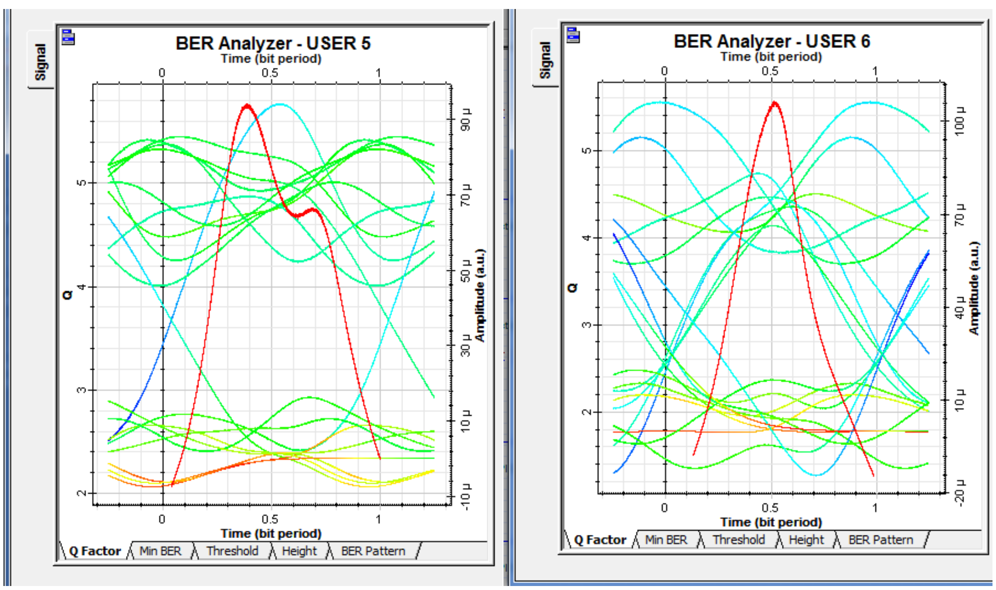

Figure 3. 16: Proposed 2-D SAC-OCDMA using Hadamard code for user5 and user6.

The performance in terms of the bit error rate and quality factor of 1-D SAC-OCDMA available in the software and the proposed 2-D SAC-OCDMA for a distance of 10Km and 20Km respectively is presented below in a tabular form.

Table 3. 8: Performance of SAC-OCDMA.

	2-D SAC-OCDMA using Hadamard code for 6 users (Range 20Km)		SAC-OCDMA using Hadamard code for 3 users (Range 10Km)	
	Min. BER	Max. Q Factor	Min. BER	Max. Q Factor
USER 1	3.4616e-010	6.14733	9.46773e-005	3.73085
USER 2	7.79093e-011	6.33365	4.8553e-008	5.31591
USER 3	6.84561e-016	7.98757	1	0
USER 4	3.74161e-011	6.49579	-	-
USER 5	3.82505e-009	5.71186	-	-
USER 6	1.36499e-009	5.65753	-	-

The average bit error rate for the proposed system of 2-D SAC-OCDMA using Hadamard code for 6 users for a distance of 20Km is 3.506885e-009 which meets the standards of telecommunication.

CHAPTER 4
DESIGN AND IMPLEMENTATION OF TWO DIMENTIONAL OCDMA USING CYCLIC SHIFT CODING TECHNIQUE

4.1 INTRODUCTION

In the next part we constructed 2-D Cyclic shift code for 4 users by using polarization. For constructing the two dimensional we have used wavelength and polarization. By using the cyclic shift code in [13], the one-dimensional SAC-OCDMA is designed for 4 users and then compared with the proposed 2-D Cyclic shift code. The system is designed for transmission at the rate of 622Mbps Performances of both the systems have been studied in terms of factors like bit error rat and quality factor. Further the performance of the system with increase in number of users is also studied.

For the Cyclic Code construction consider two different code sequences $H_n = \{H_1, H_2, \dots H_r\}$ and $F_n = \{F_1, F_2, \dots . F_r\}$ whose cross-correlation can be written as equation [1].

$$\lambda_c = \sum_{i=1}^{r} H_n F_n \qquad (4.1)$$

The Cyclic Shift code is characterized by (L, w, K, λ_c), where L is the code length, w is the weight of the code, and K is the number of users. The code can be designed for any integer number of users and any code weight. The code can be constructed by following the steps:

i Select the number of users (K) the code weight (w) required for system

ii Calculate the code length r using the below formula

$$r = K * W \qquad (4.2)$$

iii Determine the code matrix dimension K × r

iv Determine the positions of ones (P) in the first code sequence by

$P = \{C_{1r}, \dots C_{1W}\}$

Where $r = \{1, \dots w\}$, C_{1r} is the column number in the first row of code matrix

v Fill the remaining positions by zeroes vi Cyclic Shift the pervious code sequence bits w bits to the right for the remaining code sequence.

vii Construct the code matrix.

The code has a zero cross correlation property. In this way, it suppresses both PIIN and MAI. It has a basic development, a viable code length, huge cardinality. OCDMA frameworks, encoder and decoder used as filters. The number of filters required is equivalent to the quantity of frequency bins in code sequence. Code frequency bins exist adjacent to one another. Therefore, one filter with enormous data transmission can be utilized as opposed to each frequency bins by a filter. Several codes have their frequency bins isolated from one another, which expands filters requirement. Subsequently, the receiver complexity and the expense are decreased.

4.2 SYSTEM DESIGNED

The application of polarization as the second domain along with spectral domain is proposed in the second part of this dissertation. In the first part the receiver is designed with AND subtraction technique. However, for cyclic SAC-OCDMA direct detection has been used in the receiver part. The block diagram of system designed is shown below in figure 4.1.

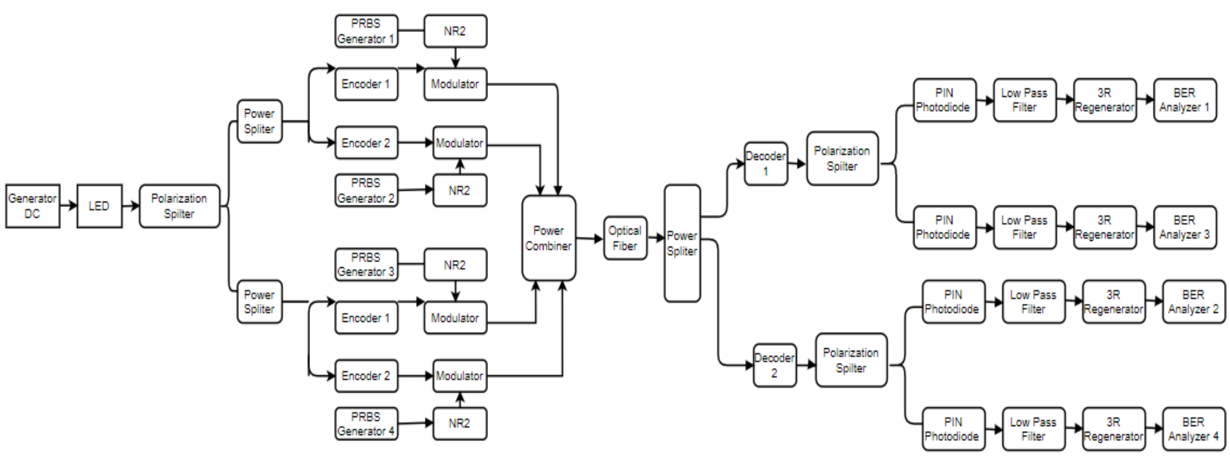

Figure 4. 1: Block diagram of 2D OCDMA for four users.

First we the transmitter part is shown and then the receiver part. Cyclic OCDMA is designed for 2 users then using polarization the system has been expanded to 4 users, that is the capacity has been doubled.

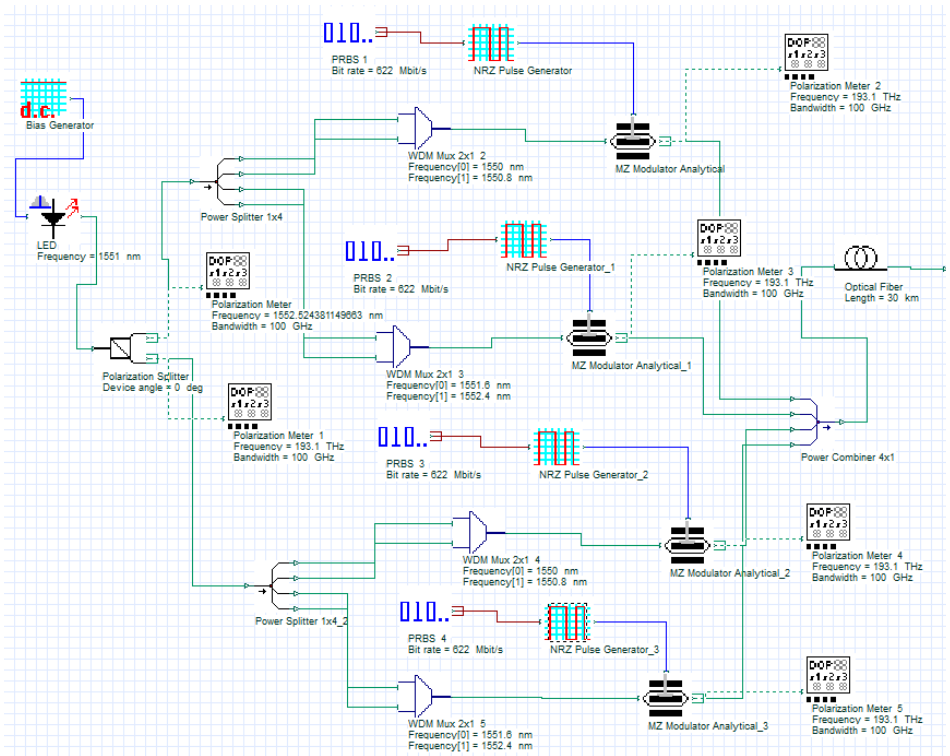

Figure 4. 2: Transmitter 2-D SAC-OCDMA using cyclic shift code.

The transmitter design for 2-D SAC-OCDMA cyclic shift code is shown in figure 4.2. The system is designed with data rate of 622Mbps for 4 users. It will be compared with 1-D code of 4 users, which will be covered in the latter part of this project. As shown above the broad band source is shifted to two polarizations.

The optical signal after polarization is passed through power splitter. The WDM mux are used as encoder instead of FBGs, each user is encoded with cyclic shift code for 2 users.

For detection of signal direct detection is used. At the receiver the signals are first decoded then they are phase shifted using polarizer. Then the optical signals are given to photo detector which converts the optical signal to electrical domain. The receiver system designed for 2-D SAC-OCDMA using cyclic shift code in optisystem is shown in figure 4.3.

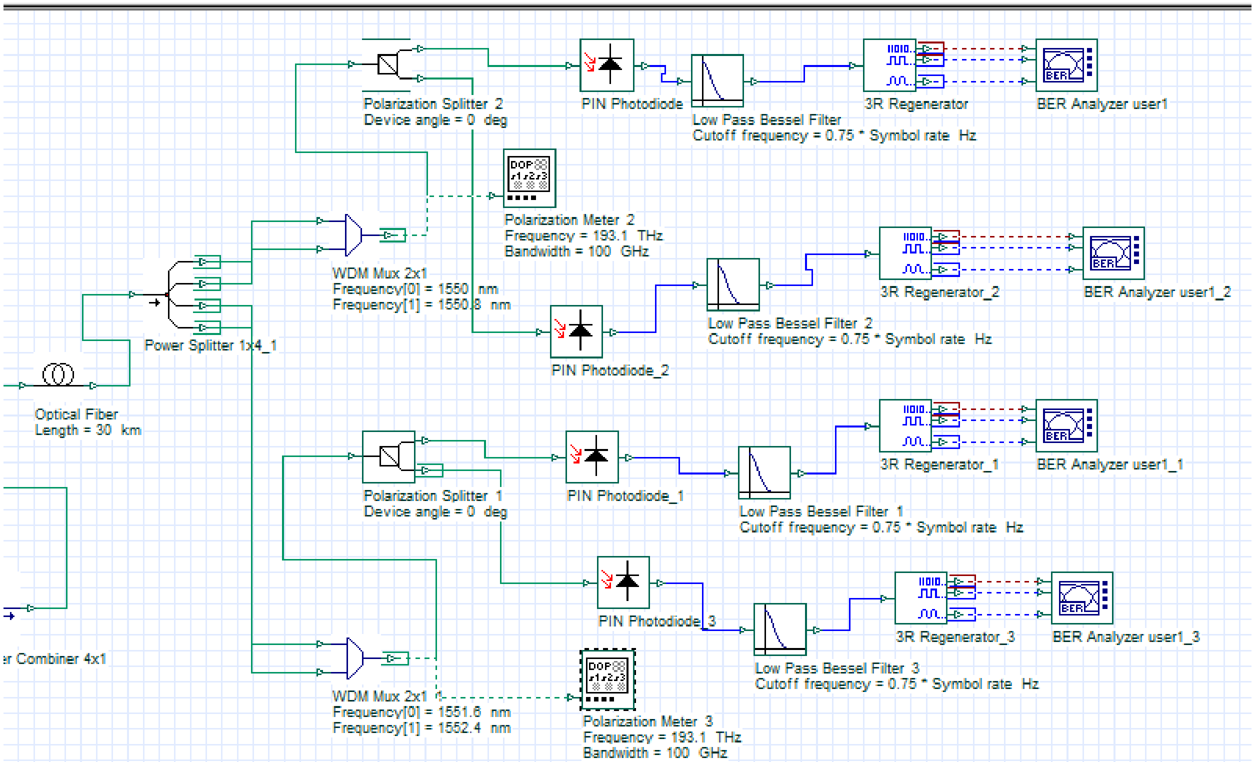

Figure 4. 3: Receiver 2-D SAC-OCDMA using cyclic shift code

4.3 WORKING

For two users we form a matrix of 2 × 4 as shown below:

User 1 = 1 1 0 0
User 2 = 0 0 1 1
↓ ↓ ↓ ↓
1550 1550.8 1551.6 1552.4

Each '1' is assigned a wavelength as shown in the above matrix. After the encoding of optical signals, the binary data signal is transmitted is converted into electrical NRZ signal which is then modulated. The modulated signals from different users are combined using power combiner and transmitted in optical fiber. The parameters used in the system are listed in table 9.

Table 4. 1: The parameters assigned for Cyclic Shift code of 2D OCDMA

S.No.	Parameters	Values
1	Data rate	622Mbps
2	No of users	4
3	Wavelengths used	1550-1552.4
4	Wavelength spacing	0.8nm
5	LED source wavelength	1551nm
6	Fiber optic length	30km
7	Attenuation	25dB/Km
8	Geometric attenuation	enabled
9	Photo detector gain	3
10	Uniform FBG bandwidth	0.3nm
11	Polarization device angle	0°
12	Photo detector gain	3
13	Responsivity	1A/w
14	Low pass filter cutoff	$7.5e^{+009}$

At first splitter the polarization parameters are given by polarization meter as shown in figure 4.4.

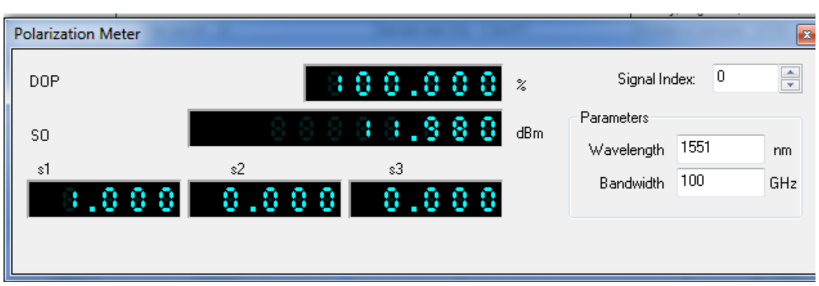

Figure 4. 4 : Polarization meter at input of User 1 and user 2

At second splitter the polarization parameters are given by polarization meter as shown in figure 4.5.

Figure 4. 5: Polarization meter at input of User 3 and user 4

Polarization at the output of the entire user 1, 2, 3 and 4, are given by the polarization meter as shown in figure 4.6, figure 4.7, figure 4,8, and figure 4.9 respectively.

Figure 4. 6: Polarization meter at input of User 1

Figure 4. 7: Polarization meter at input of User 2

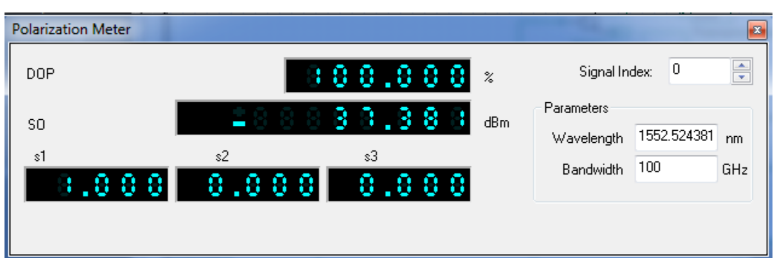

Figure 4. 8: Polarization meter at input of User 3

Figure 4. 9:Polarization meter at input of User 4

The optical spectrum of the encoded signal of user1, user2, user3, user4 are shown in figure 4.10 and figure 4.11.

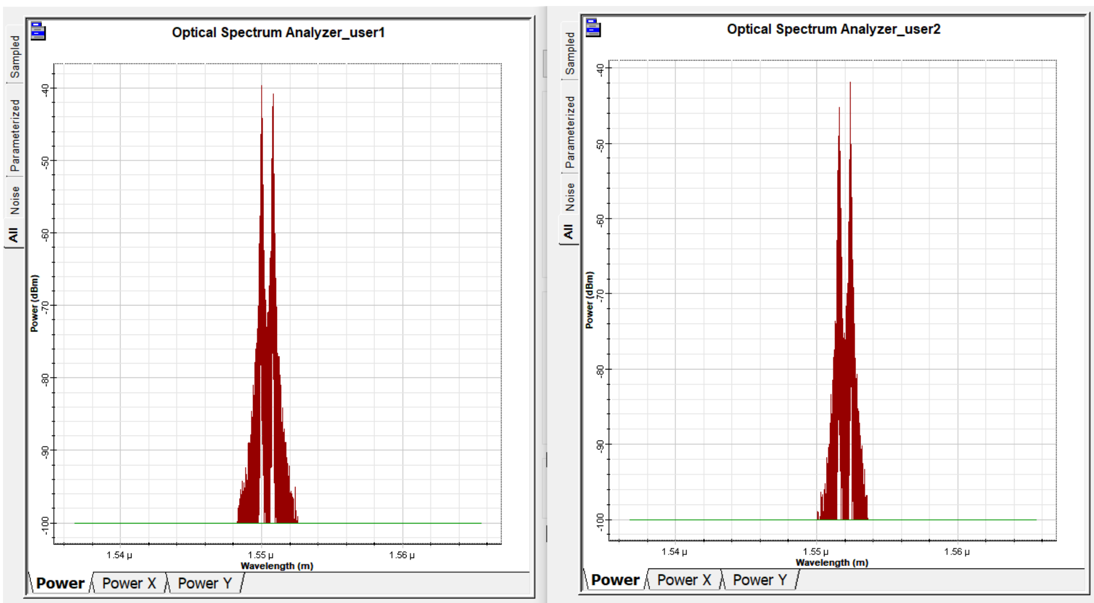

Figure 4. 10 Optical spectrum of modulated signal for 1st and 2nd user

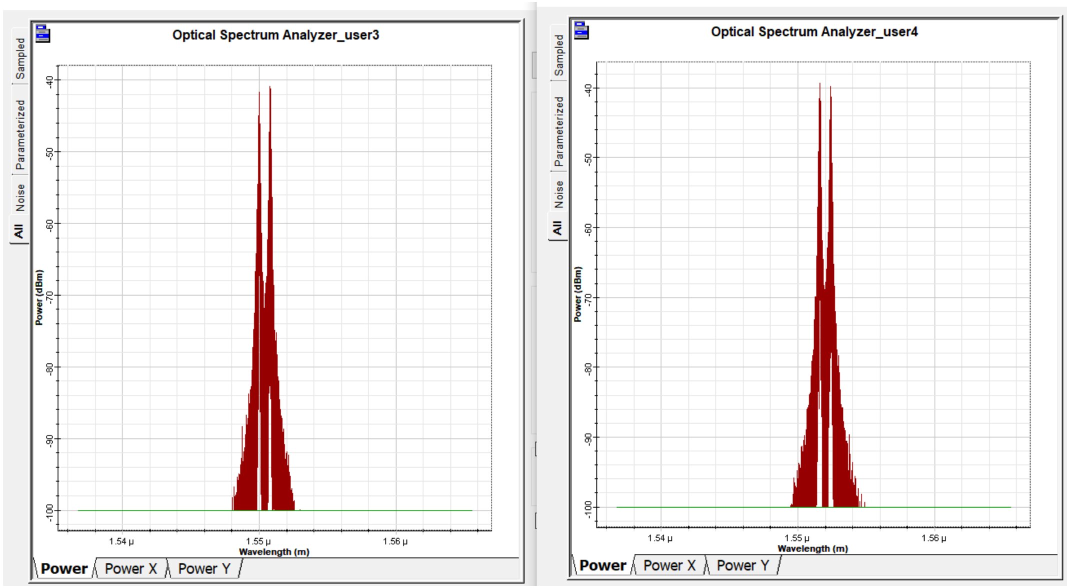

Figure 4. 11: Optical spectrum of modulated signal for 3rd and 4th user

As it can be seen user 1 and user3 are encoded with wavelengths of 1550nm and 1550.8nm respectively whereas user 2 and user 4 are encoded with wavelengths of 1551.6nm and 1552.4nm respectively. The finally transmitted optical spectrum of all users is shown in figure 4.12.

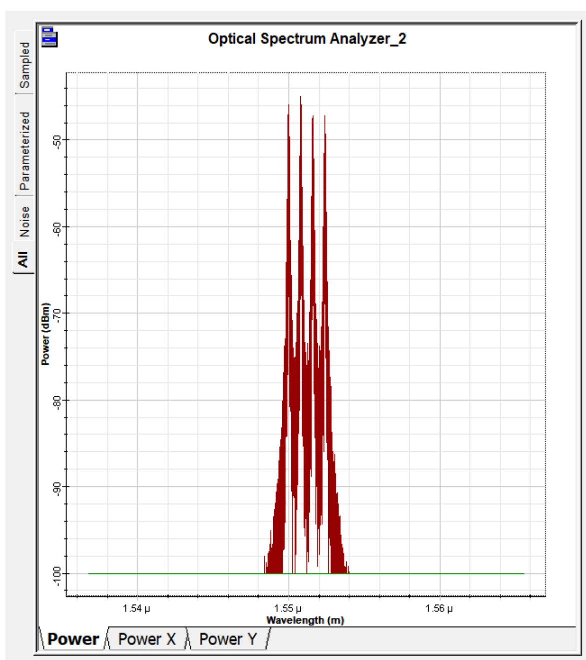

Figure 4. 12: Optical Spectrum at power combiner output.

4.4 ONE DIMENTIONAL SAC-OCDMA CYCLIC SHIFT CODE FOR 4 USERS

The cyclic shift code as proposed in paper [13] is designed for four users with the

- weight (W) = 2
- Number of users (K)= 4
- Code length (L)= $K \times W$, that is 4×2
- Matrix obtained is of order K$\times$ L, that is 4×8

Matrix:

$$\begin{matrix} User\ 1 \\ User\ 2 \\ User\ 3 \\ User\ 4 \end{matrix} = \begin{bmatrix} 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \end{bmatrix}$$

$$\begin{matrix} \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow \\ 1550 & 1550.8 & 1551.6 & 1552.4 & 1553.2 & 1554 & 1554.8 & 1555.6 \end{matrix}$$

The cyclic shift code has been implemented as per the above matrix. Each user is encoded with wavelengths as derived above. The schematic of implemented paper is shown in figure 4.13.

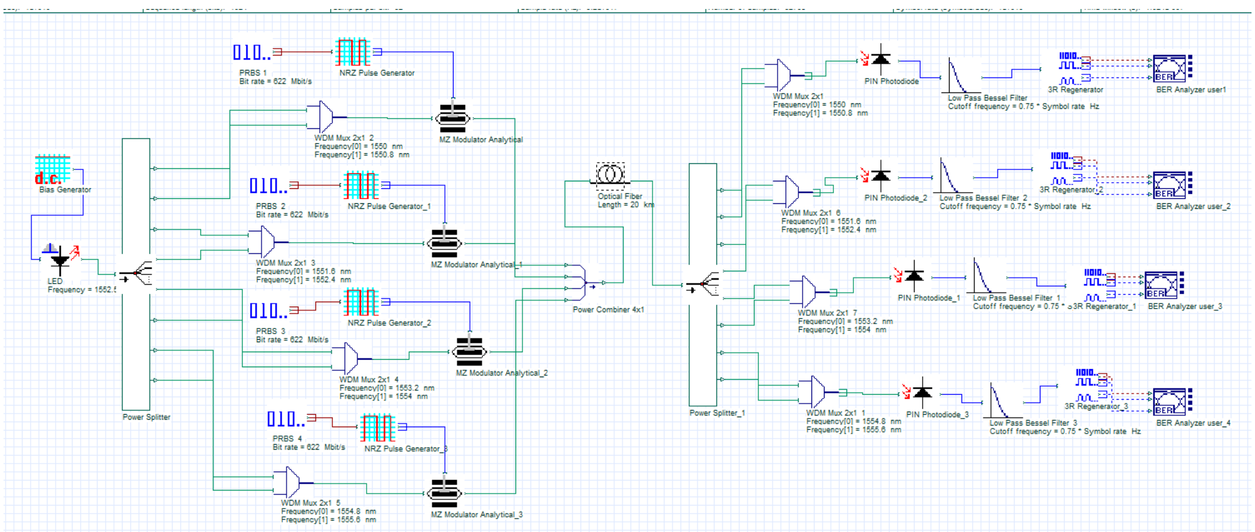

Figure 4. 13: Cyclic Shift Code for 4 Users.

The BER of all the users for the Cyclic Shift code [13] is shown in figure 4.14 and figure 4.15.

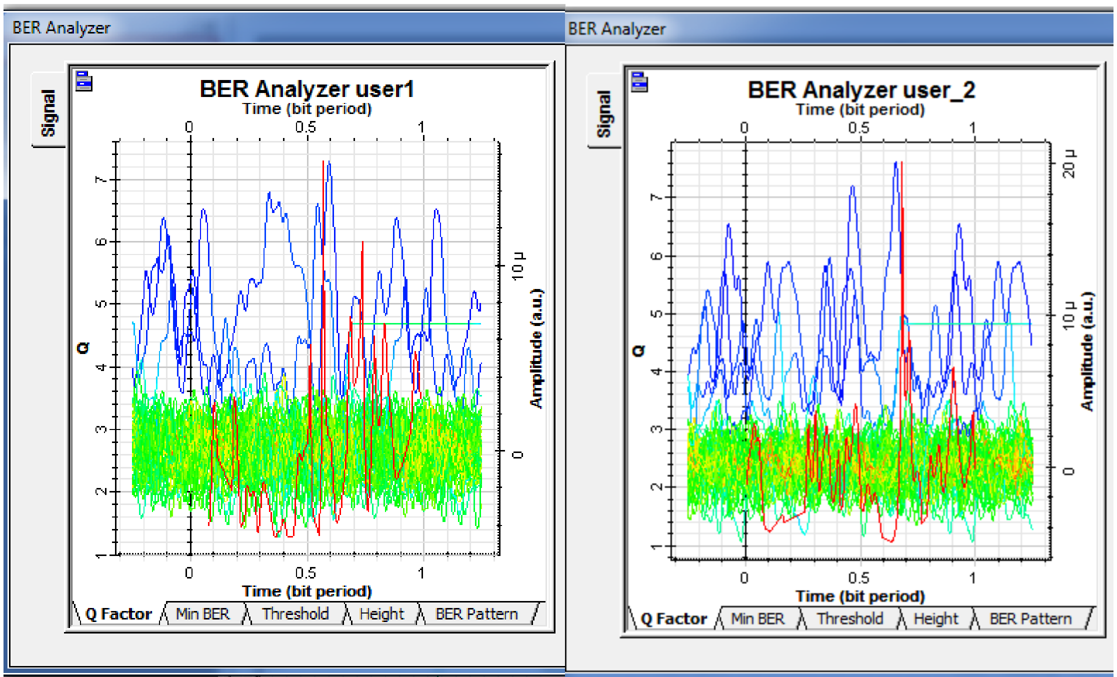

Figure 4. 14: Bit error Rate and Quality Factor of Cyclic Shift OCDMA for users1 and user2

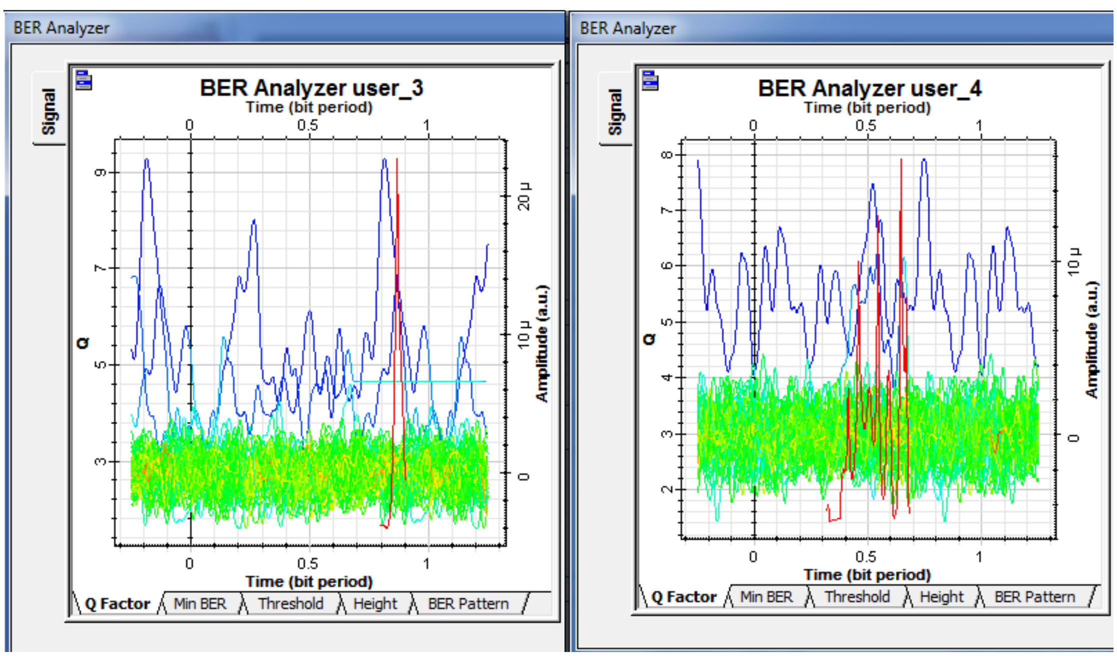

Figure 4. 15: Bit error Rate and Quality Factor of Cyclic Shift OCDMA for users3 and user4

4.5 RESULTS AND DISCUSSIONS

The results Cyclic Shift code is presented in this section. The signals transmitted and received in electrical and optical domain are shown. The performance is evaluated in terms of the Bit Error Rate, Quality factor. The results obtained for both the codes are compared.

In the second part of the project the above proposed code is implemented in two dimentional domain. We will compare the cyclic shift code for 4 users in one dimentional and two dimentional domain. In one dimentional domain only spectral encodin is done, whereas in two dimentional domain spectral and polariation are used for encoding.

The transmitter and receiver signal for 1st, 2nd, 3rd, and 4th user shown by oscilloscope is shown in figure 4.16, figure 4.17, figure 4.18 and figure 4.19.

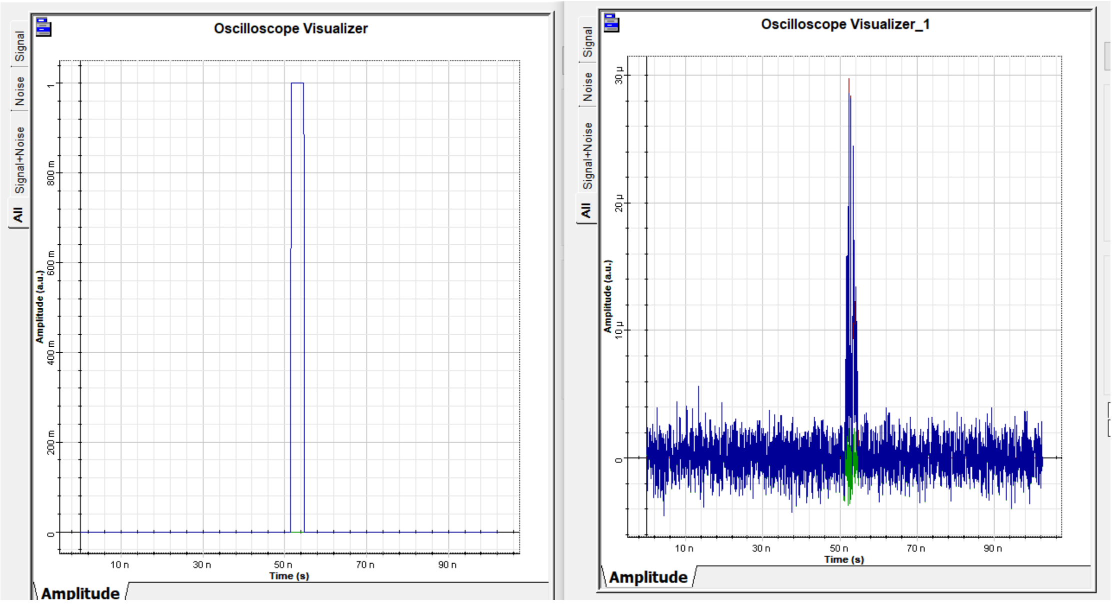

Figure 4. 16: Elecrical signal transmitted and received for user1.

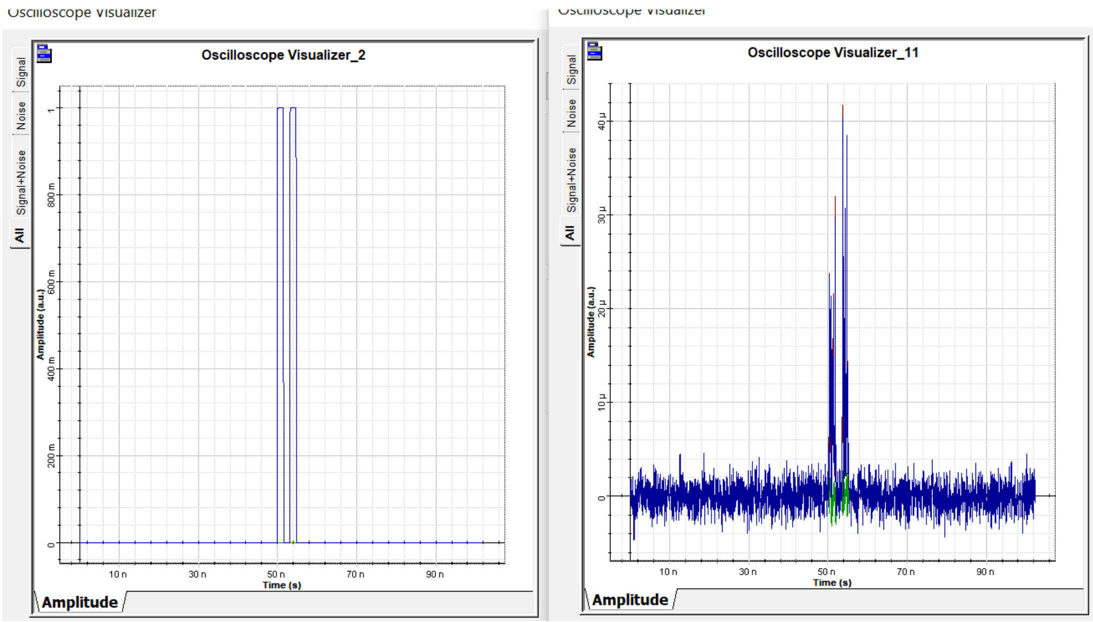

Figure 4. 17 Transmitted and received signal of user 2.

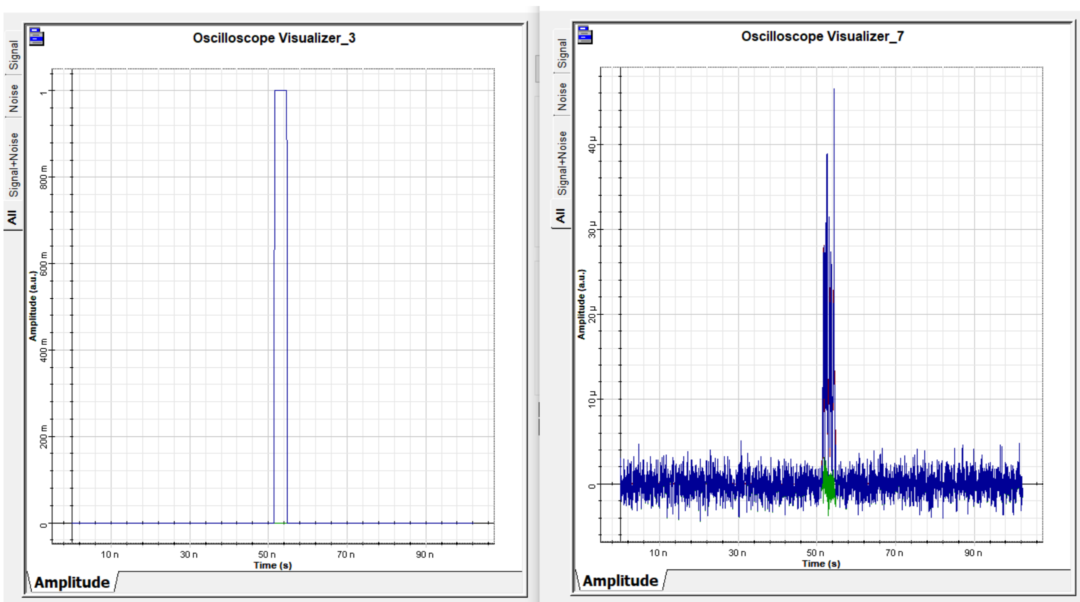

Figure 4. 18 Transmitted and received signal of user 3.

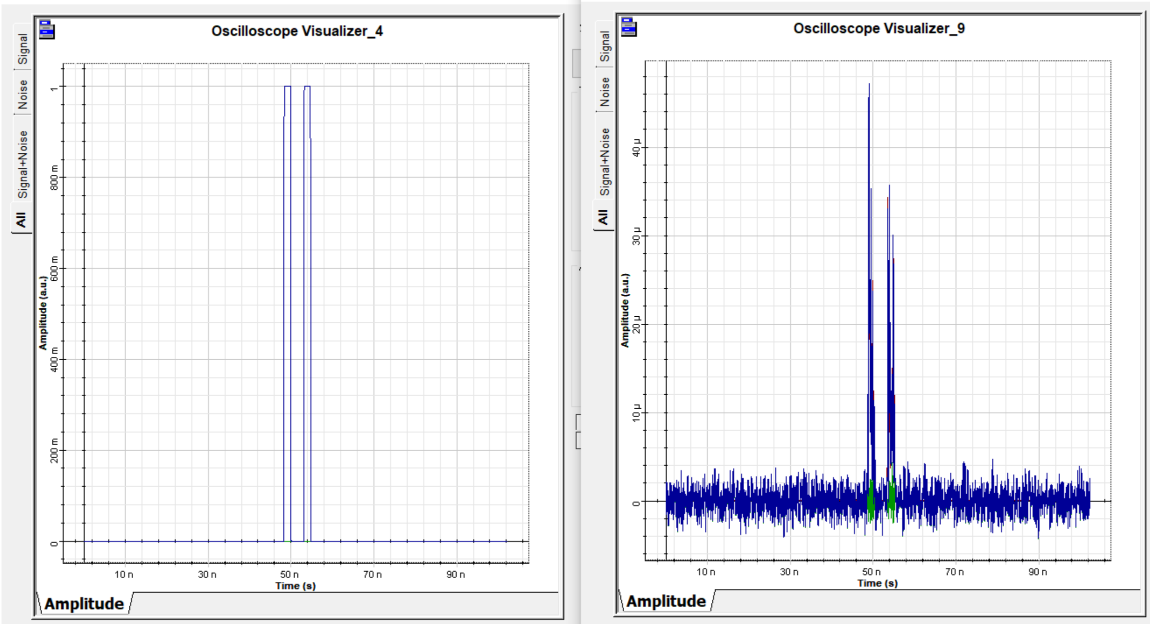

Figure 4. 19 Transmitted and received signal of user 4

As the number of users is increased, the Quality factor and Bit Error Rate (BER) starts degrading. When a single user is transmitted in the system the received signal has high Q-Factor and BER. As the number of users is increased the performance deteriorates. However the minimum values required for the system is maintained. The performance for received signal for 3rd user with the increasing users is shown in figure 4.20.

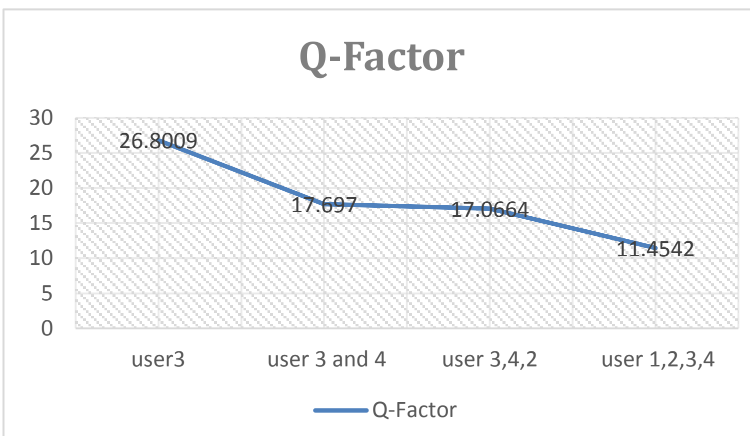

Figure 4. 20: Performance with the increase in number of users.

Following figure 4.21 and figure 4.22 shows the performance prameters of four users for the proposed 2-D Cyclic Shift SAC-OCDMA with polarization.

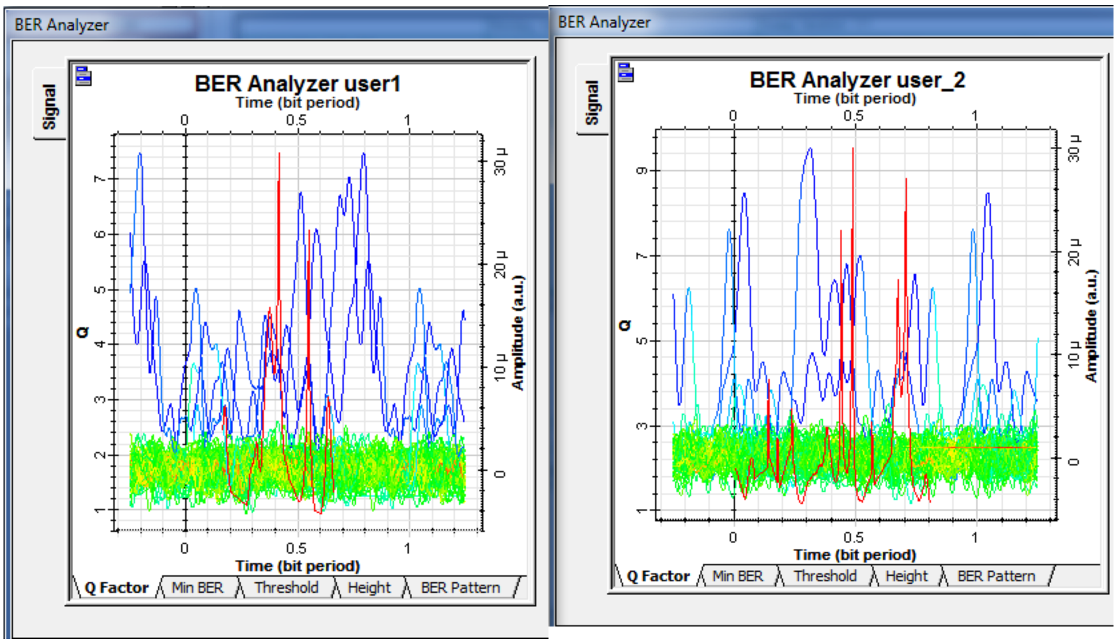

Figure 4. 21:Proposed 2-D SAC-OCDMA with cyclic shift code for user 1 and user 2

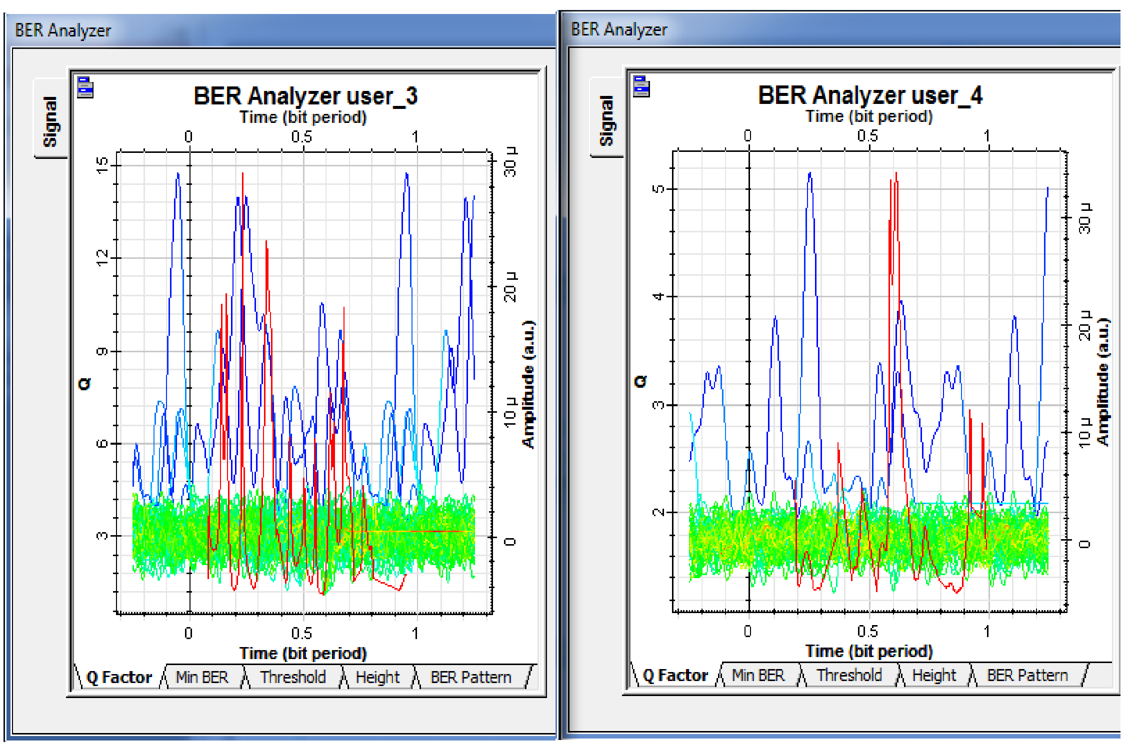

Figure 4. 22: Proposed 2-D SAC-OCDMA with cyclic shift code for user 3 and user 4.

Table 4. 2: Comparision of Cyclic Shift SAC-OCDMA with proposed 2-D Cyclic Shift SAC-OCDMA.

	2-D Cyclic Shift SAC-OCDMA with polarization for 4 users (Range 30Km)		Cyclic Shift SAC-OCDMA for 4 users (Range10Km)	
	Min. BER	Max. Q Factor	Min. BER	Max. Q Factor
USER 1	3.607e-014	7.48218	1.57479e-013	7.28782
USER 2	9.53057e-022	6.33365	1.286e-014	7.61481
USER 3	1.98555e-049	14.7168	8.0196e-021	9.28393
USER 4	2.7830-008	5.146	1.13548e-015	7.92549

The average bit error rate for the proposed system of 2-D Cyclic Shift SAC-OCDMA with polarization for 4 users for a distance of up to 30km for each user is found to be less than 2.783e-008 meets the standards of telecommunication. For Cyclic Shift SAC-OCDMA the bit error for 4 users for a distance of 10Km is shown in table 10.

4.6 COMPARSION OF 2D OCDMA HADAMARD AND CYCLIC SHIFT CODE

The proposed 2D OCDMA using Hadamard and Cyclic Shift code is compared in terms of the Quality factor as shown in figure 4.23.

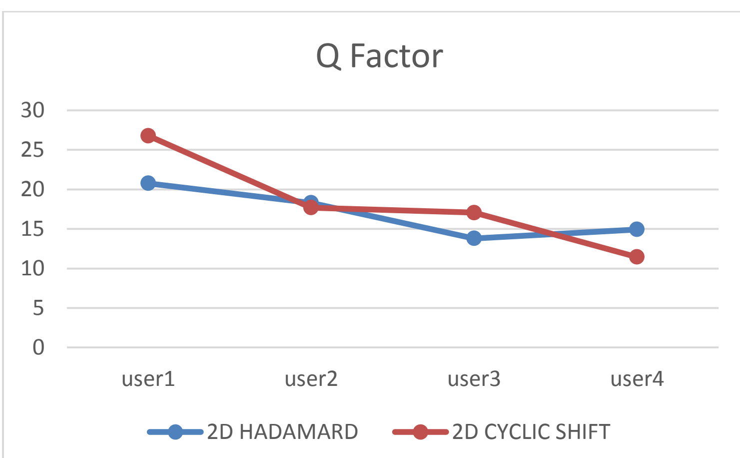

Figure 4. 23: Comparison of Q Factor of Hadamard and Cyclic Shift code for increase in number of users.

As the number of users are incresed the performance of both the code is very similar. However the cyclic shift code's the performance is slightly better than Hadamard code. The Quality factor ranges between 26 and 11 for cyclic shift but using Hadamard code it ranges between 20 and 14.

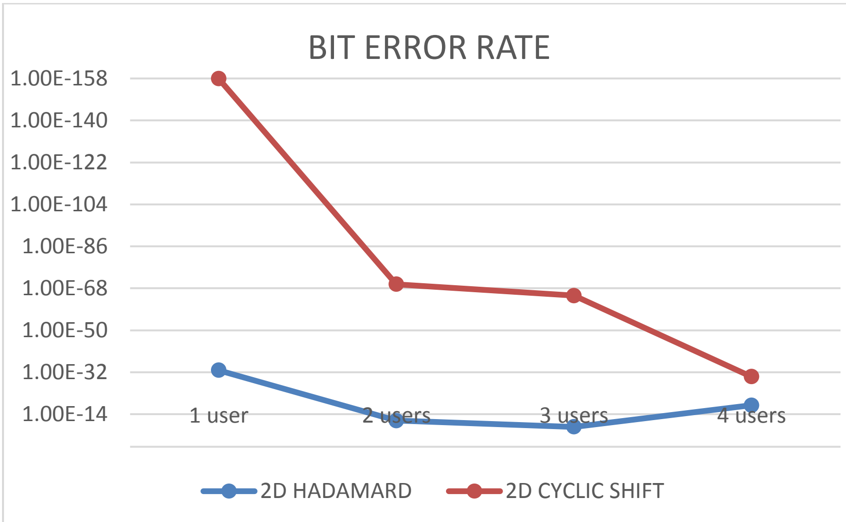

Figure 4. 24: Comparison of BER of Hadamard and Cyclic Shift code for increase in number of users.

The Bit Error Rate for the 2D OCDMA system designed using Hadamard code and Cyclic Shift code as the number of users is increased is shown in figure 4.24. The graph clearly shows the better performance of 2D OCDMA Cyclic Shift code than the Hadamard Code.

CHAPTER 5

CONCLUSION AND FUTUREWORK

In this dissertation a 2D OCDMA is designed with wavelength and phase as the two dimensions using Hadamard and Cyclic Shift coding techniques is designed in OptiSystem Software. The 2D OCDMA using Hadamard is designed with data rate of 200Mbps for a range of 10Km, 20Km and 30Km for six users. The performance in terms Q-Factor analyzed of by increasing the number of users supported by the system and also at different distances. The 2D OCDMA using Cyclic Shift is designed with a data rate of 622 Mbps for a distance of 20Km. The performance of 2D OCDMA is compared with 1D OCDMA using Cyclic Shift code. The performance of 2D OCDMA is found to be better than 1D OCDMA for 4 users. The system designed in OptiSystem shows accepted results for both the codes. The codes are characterized with simple encoding and decoding process that requires minimal number of components for designing the system. The proposed system also reduces the number of wavelengths required for encoding process hence reduces the bandwidth requirement.

2D coding increases the system capacity, enhances the security of the system and provides higher spectral density. The higher spectral density reduces the components required for designing the system, hence reduces the cost of designed system. The combination of codes with less code length and low cross-correlation and adds dimensionality to the system as the number of users that can be accommodated can be increased without degrading the quality of signals. The use of codes with simple construction and which can eliminate multiple access interference (MAI) and Phase Induced Intensity Noise (PIIN) plays a crucial role in the designed system. Generally spectral/time and spectral/ spatial domains are used in OCDMA, use of spectral/phase can be explored for a cost effective and simpler OCDMA system.

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LIST OF PUBLICATIONS

I. Navya Siringi, Gurjit Kaur, Performance evaluation of two-dimensional cyclic shift coding technique for Optical Code Division Multiple Access System. In 4th International conference on Recent Trends in Communication & Electronics (Accepted)

II. Navya Siringi, Gurjit Kaur, Performance of Wavelength/Phase OCDMA using Hadamard Code. In 9th International Conference on Photonics, Optics and Lasers Technology.(communicated)