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Development of Point-To-Point OCDMA System for Access Network using 2D MDW Code

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ABSTRACT The expanding interest in traffic information has led to an increase of the capacity and functionality of communication systems. For this reason, various multiplexing techniques have been introduced with the purpose of allowing multiple users to share the same optical domain simultaneously. The basis of the system revolution is large bandwidth, the data transmission and security of transmitted information. Optical Code Division Multiple Access (OCDMA) is the most popular multiplexing technique due to its advantages which including the ability to provide as high capacity, flexible bandwidth, and capacity to improve the system security, large cardinality, and scalable asynchronous access. The OCDMA system can be affected by two major challenges which are Multiple Access Interference (MAI) and Phase Induced Intensity Noise (PIIN). Thus, a suitable system by utilizing 2D MDW code with a good cross correlation property is needed to suppress the effect of MAI and mitigate PIIN. Based on this assumption, many 1D codes have been developed in different domain (wavelength, time, and space), but using 1D codes require a very long code length to increase the number of simultaneous users. However, two-dimensional codes have been utilized with the purpose of enhancing the point-to-point OCDMA system performance by increasing the number of simultaneous users with short code length compared to 1D codes. The new point-to-point OCDMA system have been developed to overcome the MAI and PIIN. The study of the new OCDMA system is based on 2D MDW code. The construction of the system is focused on the efficiency of 2-D MDW code to suppress the influence of MAI and PIIN. In designing the system, we used 2D modified double weight (MDW) codes as a signature address since this code can handle more simultaneous active users with a large standard bit error rate (e.g., ≤ 10 -9). Via simulation results, we decided that the new system provides more better performance and improves the ability of the network. This new system can therefore be regarded as a promising optical access network solution for the next decade.

KEYWORDS Point-To-Point OCDMA System, 2D MDW Code, MAI, PIIN.

I. INTRODUCTION

The optical fiber communication system is a recent type of communication system, where the information is transported using an optical wave as a carrier and fiber optics as the transmission medium. Many recompenses can be offered by optical communication systems such as a long transmission distance, saving energy, and transmitting a massive amount of information at one time, where a large number of users can receive the required information at the same time with a fast communication speed [1-3]. As a transmission channel, optical fiber is characterized by a wide bandwidth, small size and weight, low loss, signal security, and electrical isolation. Thus, it is a rich and potentially low-cost resource, where means it can be classified as the best candidate to transport broadband access for a long distance [4-5].

As data transmission increases and the traffic is heavier, the need for a high-rate transmission technology is increasing with the target of high speed and high-capacity transmission. These requirements are achieved using numerous different multiple access schemes, such as Optical Code Division Multiple Access (OCDMA), Time Division Multiple Access (TDMA) and Wavelength Division Multiple Access (WDMA) for multiplexing and de-multiplexing of the information stream [6-7]. In TDMA, all users in the system share the entire bandwidth W, but transmit signals in a chronological sequence, with no interference between any two users, namely orthogonality. However, TDMA requires synchronization to maintain a common timing reference.

Another challenge faced by the TDMA technique is that it is subject to multipath distortion, referred to as nonlinearities, where it is difficult to transmit the wideband signal, which requires equalization to reduce the inter-symbol interference. In WDMA, the available spectrum is divided into physical channels of equal bandwidth. Each physical channel is allocated per subscriber which makes the optical fiber bandwidth better uses. One advantages of WDMA over TDMA is that it uses lower bit rates of optical power in each channel and can achieves higher network capacity. Besides, one of the challenges of WDMA is the limitation of the wavelengths when the number of users becomes large. Moreover, the maximum transmission capacity for TDMA and WDMA depends on the total number of time slots and wavelength channels respectively [8-9]. OCDMA is currently the most well-known multiple access technique [10-11].

Since Optical Code Division Multiple Access (OCDMA) was proposed that has attracted many researchers, due of its ability to enhance the system's performance and information security, and improves the spectral efficiency, and increasing the flexibility of the bandwidth [11-14]. OCDMA is a multiplexing technique that uses an approach different from TDM and WDM where the principal of the OCDMA technique which that allow many subscribers sharing the optical network simultaneously and asynchronously by assigning a distinguish code to each user. At the transmitter, according to a unique assigned code sequence for each of the users, the information bit stream of every user is optically encoded, then it transmitted via the optical fiber system asynchronously. At the receiver, knowing the code sequence of each client, an optical decoder is designed to decode the desired transmitted optical signal and convert it to electronic data to recover the original signal. Various parameters including the data rate, number of simultaneous users, transmission power, receiver power and the type of codes determine the performance of OCDMA networks. However, the types of codes and rate of transmitted data are crucial parameters, as they determine the number of subscribers who can simultaneously access the optical network [15-17].

II. DEVELOPMENT OF POINT-TO-POINT OCDMA SYSTEM FOR ACCESS NETWORK USING 2D MDW CODE

To improve the system performance and overcome the limitations of the existing 1-D OCDMA codes, there is enormous research interest in developing a new point-to-point OCDMA system by using 2-D MDW code. Demand for a system that can support the availability of existing wide is the driving force for the OCDMA research area [17]. Although several existing 1-D OCDMA coding sequences were proposed including encoder / decoder implementations and detection schemes, there were still constraints on the effective use of the available bandwidth to satisfy the large number of subscribers or to meet the cardinal requirements. Several 2-D OCDMA techniques were developed in the design of the point-to-point OCDMA system and code sequences with a focus on specific code properties. The signature code cardinality indicates the maximum allocation capacity on the same channel to accommodate simultaneous customers [18-19]. However, an active 2-D OCDMA model can achieve a smaller cross-correlation than 1-D codes, whereas the code weight of 2-D codes can surpass 1-D codes [20].

A. Point-to-Point OCDMA System Design Methodology

This section focuses on the method of designing the point-to-point OCDMA system for access networks by using a 2-D MDW coding scheme. The application of OCDMA can be realized depending on the incoherent optical system. The method used will be performed in three major phases in this study. A fundamental study of the method of designing a point-to-point system in the OCDMA represents the first phase. The construction of the system is focused on the efficiency of 2-D MDW code to suppress the influence of MAI and PIIN, which are the main issues involved. The main aims are developing a new OCDMA system based on the proposed code in terms of SNR and BER under the consideration of all receiver noises. Therefore, an ideal optical code sequence should have a property of ideal cross-correlation to mitigate the interference of different users and have SNR which is as high as possible and BER that is as low as possible. For this reason, the design methodology is an issue to be considered to obtain a point-to-point OCDMA system with satisfactory performance. A code sequence with high cardinality is resulted in a high auto-correlation peak, with ideal cross-correlation properties, high SNR and low BER. The formulation of SNR and BER are modeled and developed in the second phase based on the theoretical study to determine the performance improvement. Using 2-D MDW code as a possible solution can overcome the limitation of 1-D wavelength-time OCDMA codes that improved a high number of users and improved the BER result. Figure 1 is the diagram for the OCDMA point-to-point model. In the third phase of the simulation analysis, the system will be validated, and the implemented code improved using simulation software (Optisys software), where all the parameters used by the simulation interpretation reflect the current world.

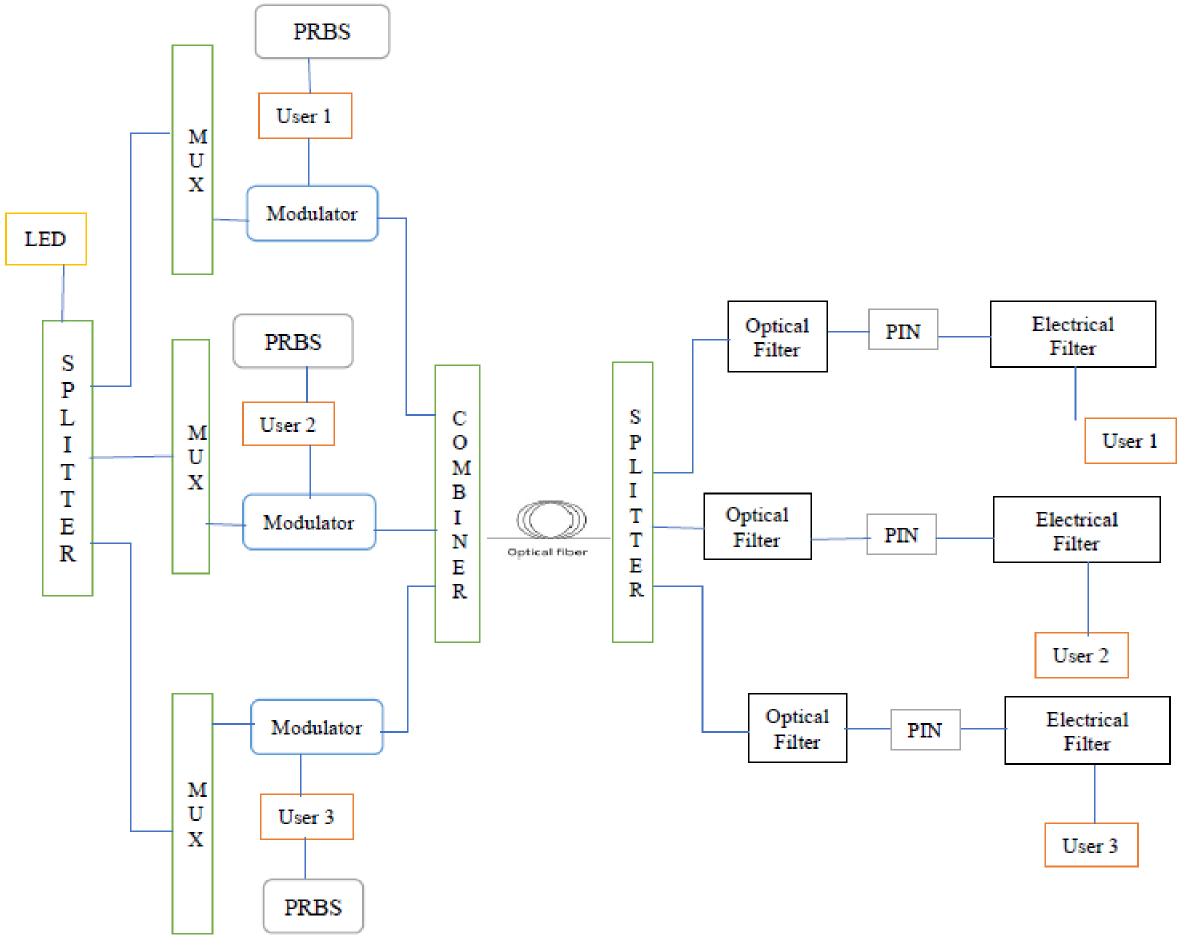


Figure 1: Schematic Design of Point-to-Point OCDMA System

B. 2-D Modified Double Weight (MDW) code

The form of the MM x NN matrix also serves to indicate 2-D MDW codes. The 2-D MDW codes are automatic correlation and cross-correlation values with M as Multiple wavelengths, N as the width of transient coding, W as a weight, respectively πa as well as πc. It is indicated by (M x N, W, πa, πc). That 2-D codes of the j_{th} user $C^{j}_{M,N}$, in equation (1), are a matrix of vectors in the M row $d^{j}_{k,N}$ related to temporary spread; $d^{j}_{1,N} = c^{j}_{k,1}, c^{j}_{k,2}, \dots, c^{j}_{k,N-1}, c^{j}_{k,N}$ where $c^{j}_{k,i}$ {0,1} then k is wavelength, k ϵ{1,...,M}[5, 7, 9].

$$C^{j}_{M.N} = \begin{bmatrix} d^{j}_{1.N} \\ d^{j}_{2.N} \\ . \\ . \\ . \\ d^{j}_{M-1.N} \\ d^{j}_{M.N} \end{bmatrix} \qquad (1)$$

That signals $r_{k,N}(t)$ are one of the transient distributed data transmitted by the Fu client over the k wavelengths then defined as $r_{k,N}(t) = \Sigma^{Fu}_{j-1} b^{j}_{i}(t) d^{j}_{k,N}$, where $b^{j}_{i}(t)$ is i_{th} user data bit of j_{th} and Fu was the user number. M signals $r^{j}_{k,N}(t)$ are packetized as well as the complete pulse $R_{M,N}(t)$ is represented on the optical fiber as M x N[5, 7, 9].

$$R_{M.N}(t) = \begin{bmatrix} r_{1,N(t)} \\ r_{2,N(t)} \\ \cdot \\ \cdot \\ \cdot \\ r_{M-1,N(t)} \\ r_{M,N(t)} \end{bmatrix} \qquad (2)$$

2-D OCDMA MDW network consists of M (transmitter) and N (receiver). $A_{g,h}$ is that code is used in which g ϵ (1,2,3, …, M-1) and h ϵ (1,2,3, …, N-1) are used. X_g and Y_k are respectively encoding of spectrum and space. Table 1 illustrates projections of 2-D code of the MDW [5, 7, 9].

TABLE I

2-D MDW CODE PROJECTIONS $k_1 = 4$ AND $k_2 = 2$

$\boldsymbol{X_{g,h}/Y_g}$	*[000011011]*	*[011000110]*	*[110110000]*
$\begin{bmatrix} \mathbf{0} \\ \mathbf{1} \\ \mathbf{1} \end{bmatrix}$	$\begin{bmatrix} 000000000 \\ 000011011 \\ 000011011 \end{bmatrix}$	$\begin{bmatrix} 000000000 \\ 011000110 \\ 011000110 \end{bmatrix}$	$\begin{bmatrix} 000000000 \\ 110110000 \\ 110110000 \end{bmatrix}$
$\begin{bmatrix} \mathbf{1} \\ \mathbf{1} \\ \mathbf{0} \end{bmatrix}$	$\begin{bmatrix} 000011011 \\ 000011011 \\ 000000000 \end{bmatrix}$	$\begin{bmatrix} 011000110 \\ 011000110 \\ 000000000 \end{bmatrix}$	$\begin{bmatrix} 110110000 \\ 110110000 \\ 000000000 \end{bmatrix}$

$X = [x_0, x_1, x_2, \dots, x_{M-1}]$ and $Y = [y_0, y_1, y_2, \dots, y_{N-1}]$ are the 1-D MDW coding sequence. The cross-correlation of it could be a 2-D MDW extracted from four of these matrices $A^{(d)}$ characteristics, in which d is identified by $d \,\epsilon\, (0,1,2,3)$:

$$A^0 = Y^T X \qquad (3)$$

$$A^1 = Y^T \bar{X} \qquad (4)$$

$$A^2 = \bar{Y}^T X \qquad (5)$$

$$A^3 = \bar{Y}^T \bar{X} \qquad (6)$$

The cross-correlation between $A^{(d)}$ and $A_{g,h}$ can be defined as:

$$R^{(d)}(g,h) = \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} a_{ij}^{(d)} a_{(i+g)(j+h)} \qquad (7)$$

In which a $a_{ij}^{(d)}$ would be $(i,j)_{th}$ of $A^{(d)}$ and perhaps a $a_{(i+g)(j+h)}$ is $(i,j)_{th}$ of $A_{g,h}$; $g \,\epsilon\, (1,2,3, \dots, M-1)$ and $h \,\epsilon\, (1, 2, 3, \dots, N-1)$, respectively.

Table 2 shows the cross-correlation of the $R^{(d)}$ (g, h) generated 2-D MDW code. From the table, the value of $R^{(3)}$ (g, h) is non-zero if the value of g ≠ 0 ∩ h ≠ 0. Alternatively, the values of $R^{(0)}$ (g, h), $R^{(1)}$ (g, h), $R^{(2)}$ (g, h) and $R^{(3)}$ (g, h) indicate the unique relationships in g, h) and h, respectively. The cross-correlation feature is described through using $R^{(3)}$ (g, h) to remove A (g, h) from $R^{(0)}$ (g, h), $R^{(1)}$ (g, h) and $R^{(2)}$ (g, h) when g ≠ 0 ∩ h ≠ 0. The current 2-D MDW-derived cross-correlation structure will be shown as;

TABLE II

CROSS-CORRELATION OF 2-D MDW [16]

$X_{g,h}$	$R^{(0)}(g,h)$	$R^{(1)}(g,h)$	$R^{(2)}(g,h)$	$R^{(3)}(g,h)$
$g = 0$ $h = 0$	$k_1 k_2$	0	0	0
$g = 0$ $h \neq 0$	k_1	k_1	0	0

$g \neq 0$ $h = 0$	k_2	0	$k_2(k_1 - 1)$	0
$g \neq 0$ $h \neq 0$	1	1	$k_1 - 1$	$k_1 - 1$

$$R^{(o)}(g,h) - R^{(1)}(g) - \frac{R^{(2)}(g,h)}{(k_1-1)} + \frac{R^{(3)}(g,h)}{(k_1-1)} = \begin{Bmatrix} k_1 k_{2,}\, for\ g = 0\ and\ h = 1 \\ 0, \qquad otherwise \end{Bmatrix} \tag{8}$$

C. 2-D Wavelength/Time (W/T) Signal-to-Noise Analysis

There are three types of distortion which are Phase-induced intensity noise (PIIN), shot noise, and thermal noise that results analysis must be taken into consideration. To classify the acquired thermal lights, the photodiode is being shown as described [9]:

$$< i^2 > 2eIB + I^2 B\tau_c + \frac{4K_b T_b B}{R_L} \tag{9}$$

I_{PIIN}^2 noise power could be represented below:

$$< I_{PIIN}^2 > \frac{B_r R^2 P^2 sr}{M\Delta f k_2^2 (MN-1)^2} [k_1 k_2 (MN-1)^2 + [k_2(W-1)(M-1)]^2] \tag{10}$$

A status of short noise could be described as follows:

$$< I_{short}^2 >= 2eB_r \left\{ \frac{R^2 P_{sr}^2}{Mk_2(MN-1)} [k_1 k_2 (MN-1) + 2k_1(W-1)(N-1) + 2k_2(W-1)(M-1) + 4(W-1)(M-1)(N-1)] \right\} \tag{11}$$

A power of a thermal noise would be:

$$< I_{thermal}^2 >= \frac{4K_b T_n B_r}{R_L} \tag{12}$$

Maximum photocurrent receiver efficiency I_r:

$$< I_r^2 >= \left[\frac{RP_{sr} k_1}{M}\right]^2 \tag{13}$$

A signal-to-noise (SNR) receiver coefficient was specifically defined:

$$SNR = \frac{I_r^2}{\langle I_{PIIN}^2 \rangle \langle I_{short}^2 \rangle \langle I_{thermal}^2 \rangle} \tag{14}$$

Therefore, the Bit Error Rate (BER) could be a signal-to-noise ratio (SNR) [9]:

$$BER(M) = \frac{1}{2} erfc\left(\sqrt{\frac{SNR}{8}}\right) \tag{15}$$

In which $erfc$ was:

$$erfc(x) = \frac{2}{\sqrt{x}} \int_{x}^{\infty} e^{(-z^2)} dz \qquad (16)$$

III. PERFORMANCE OF POINT-TO-POINT OCDMA SYSTEM

The bit rate has a direct impact on the OCDMA network's efficiency. The bit-error-rate (BER) of MDW code is calculated for each optical wavelength. The BER between the optical wavelengths of MDW code was compared. The hybrid system's BER efficiency was assessed over the entire length of the fibres (50km). The error-free transmission (BER<10-9) is obtained by the proposed system. The simulation results were obtained through a detailed simulation that takes into consideration all factors that affect system efficiency, such as dispersion and nonlinear effect. The parameters that were used are shown in table 3.

TABLE III
THE PARAMETERS USED IN THE SIMULATION

Parameter	Value
Number of users	3
MDW code length	M =9, N =3
MDW code weight	$k1 = 4$; $k2 = 2$, for spectral and temporal chip respectively
WDM filters bandwidth	0.8 nm
Data format generator	NRZ
Mach-Zehnder Modulator extinction ratio	30 Db
Transmission multimedia	ITU-T G.652 standard single mode optical fiber
Transmission distance length	50km, 60km
Attenuation	0.25 dB/km
Dispersion	16.75 Ps/nm/km
Data rate	155Mbps, 622Mbps, 2.5Gbps, 10Gbps
Decoder	Rectangular Optical filters, PIN Photodiode
Dark current for the PIN	10nA
Detection techniques	Direct detection techniques

The values of the system parameters are adopted in this simulation based on the typical values in a real environment. The MDW code were applied as the signature code for three users of OCDMA system. The simulation of MDW code is carried out the data of 155Mbps, 622 Mbps, 2.5 Gbps and 10 Gbps for a transmission distance of 50 km and 60km in some techniques along ITU-T G.652 standard single mode optical fiber. DC generator generates the electrical pulses which are the input of the LED, the bandwidth of the WDM is 0.2nm to slices the code length in spectral domain to its weight.

A Pseudo Bit Sequence is a binary sequence that, while generated with a deterministic algorithm, and NRZ signal data format is used to generate the information signals. A signal was modulated with Mach-Zehnder Modulator with 30 dB extinction ratio. The combiner has been used to spread the process and collect the signals for the three users to transmit them along with the single mode fiber optical with attenuation of 0.8 dB/km and the dispersion 16.75 PS/nm/km for 1550 nm wavelength.

For the receiver side as shown in Figure 2and 3, where a spectral decoding process is achieved, the optical receive signal from the single fiber is sliced by the splitter for three receivers in each branch. The output of the upper branch of the letters is input to the rectangular filter with a bandwidth of 0.8 nm to decode the spectral domain. The lower branch splitter signal input to the rectangular with 0.8 nm bandwidth, this signal is the interference signal that would be suppressed from the upper branch by the directed after converted to electrical signal by photodetector PIN. The output signal of the converted to electrical signal. The noises generated at the receivers are random and much uncorrelated, the value of dark current 10nA and the coefficient of thermal noise is 1×10^{-22} W/Hz for each photodetector. Finally, the electrical signal is filtered by Low Pass Bessel Filter and the cut-off frequency is 0.75*Bit rate. The network performance is evaluated in terms of:

- BER: The number of received bits of a data stream over a communication channel that have been altered due to noise, interference, distortion, or bit synchronization errors is referred to as the number of bit errors in digital transmission. The number of bit errors per unit time is known as the bit error rate (BER). The bit error ratio (also known as BER) is calculated by dividing the number of bit errors by the total number of transferred bits over a given time interval. The BER is a non-unit efficiency metric that is often expressed as a percentage.
- Eye Diagram; The eye graph will show if the signs are too long, too short, ineffectively synchronized with the framework clock, too high, too low, overly uproarious, or too mild, making it difficult to adjust, or if there is a lot of undershoot or overshoot. The open eye style is related to minor sign bending. The eye structure concludes with the bending of the sign waveform as a result of picture obstruction and commotion.

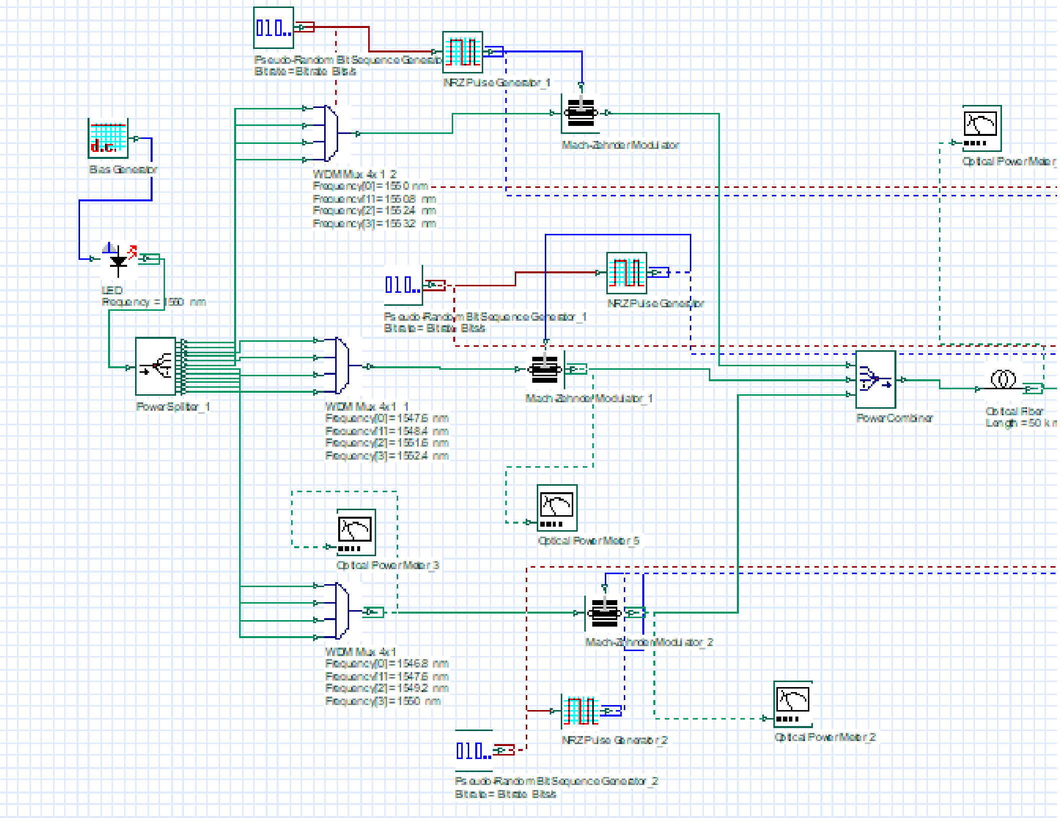


Figure 2: The Design Circuit of the Transmitter Side

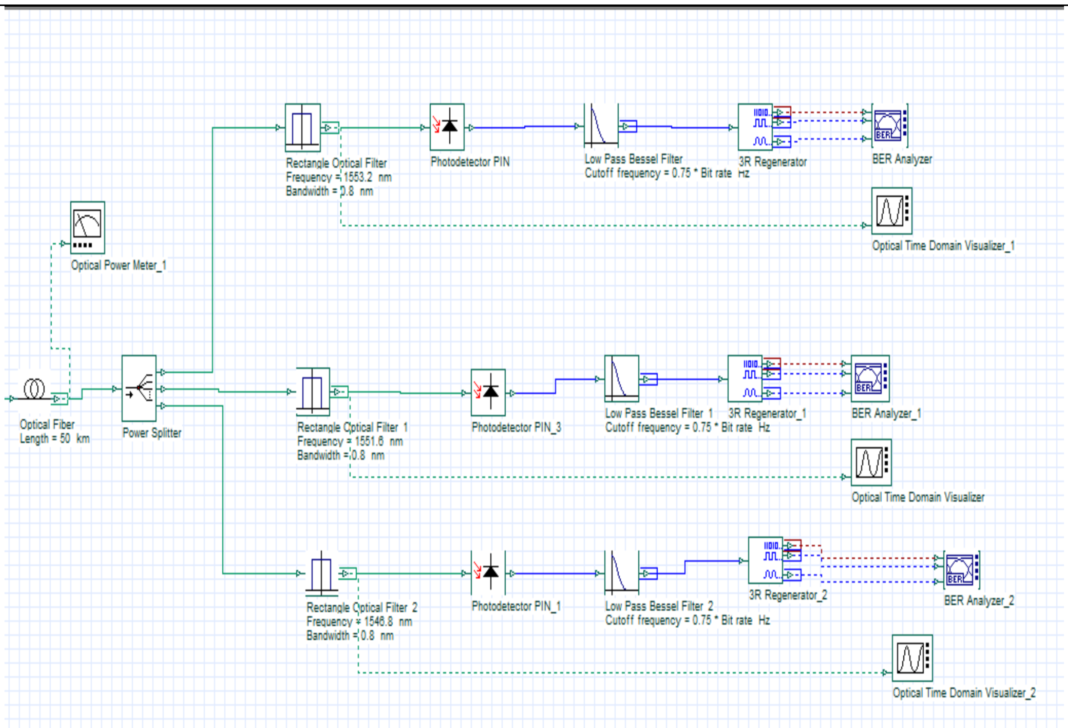
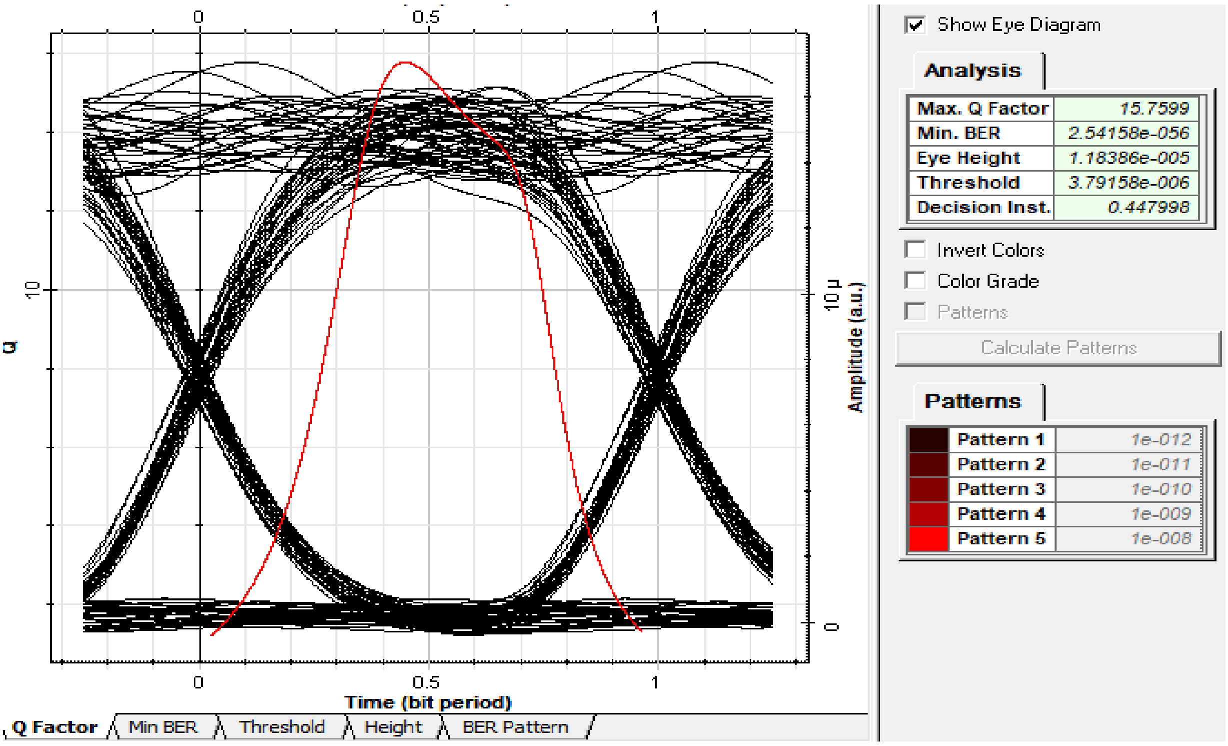


Figure 3: The Design Circuit of the Receiver Side



☑ Show Eye Diagram

Analysis

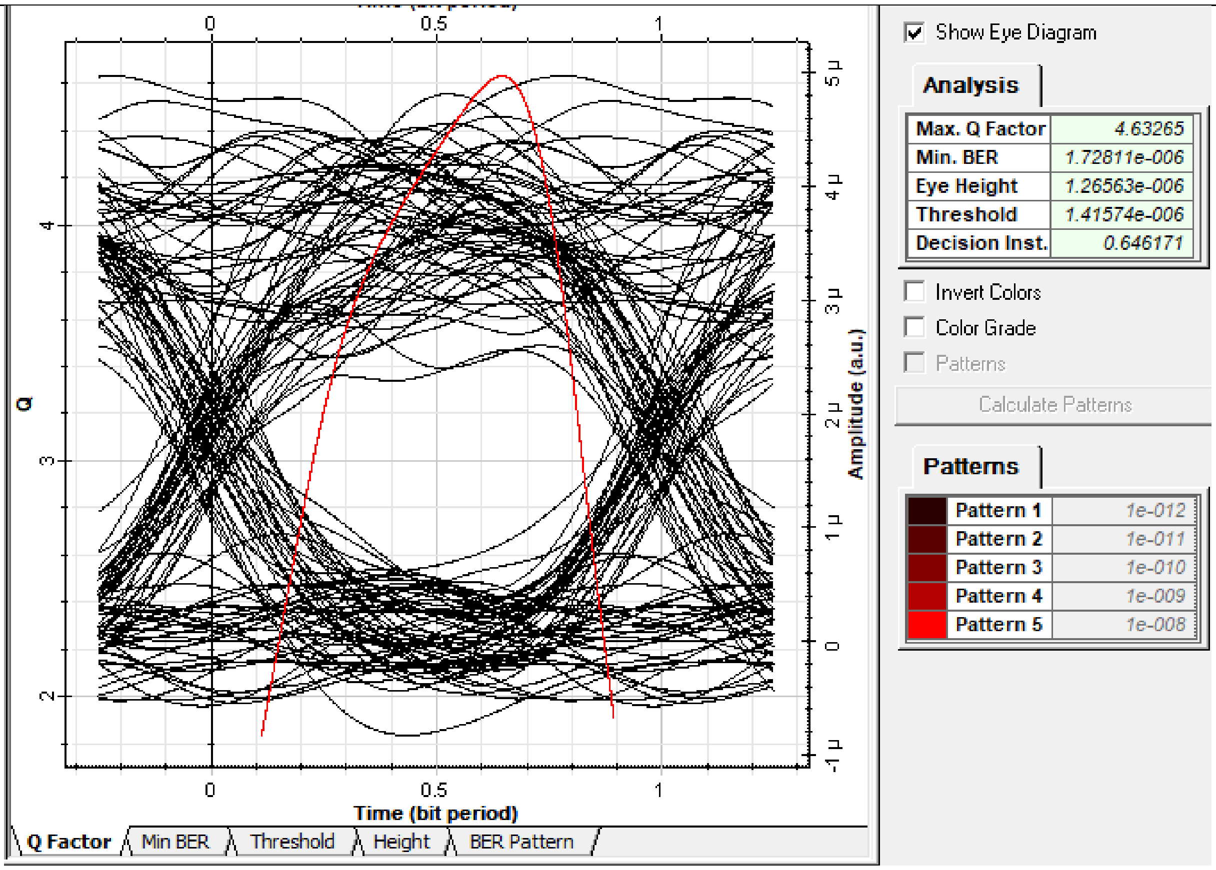
Max. Q Factor	15.7599
Min. BER	2.54158e-056
Eye Height	1.18386e-005
Threshold	3.79158e-006
Decision Inst.	0.447998

☐ Invert Colors
☐ Color Grade
☐ Patterns

Patterns

■	Pattern 1	1e-012
■	Pattern 2	1e-011
■	Pattern 3	1e-010
■	Pattern 4	1e-009
🟥	Pattern 5	1e-008

Figure 4: Eye Diagram of 155Mbps for 50km



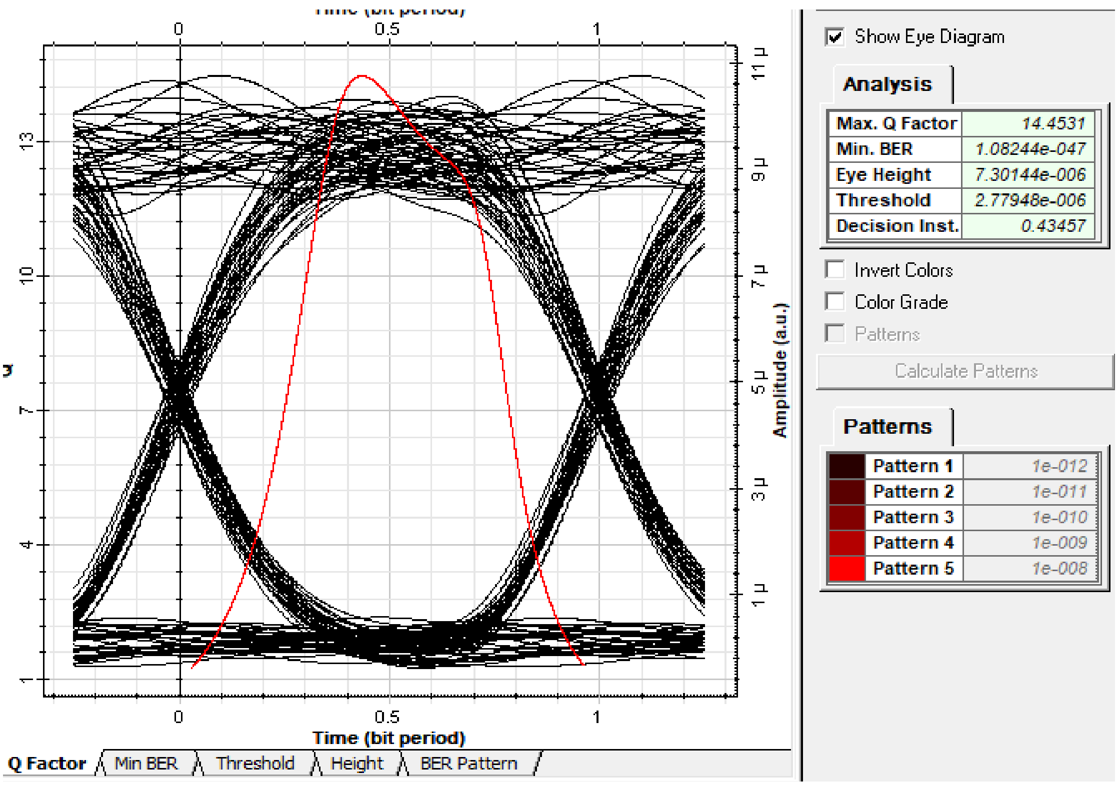
☑ Show Eye Diagram

Max. Q Factor	4.63265
Min. BER	1.72811e-006
Eye Height	1.26563e-006
Threshold	1.41574e-006
Decision Inst.	0.646171

☐ Invert Colors
☐ Color Grade
☐ Patterns

Pattern 1	1e-012
Pattern 2	1e-011
Pattern 3	1e-010
Pattern 4	1e-009
Pattern 5	1e-008

Figure 5: Eye Diagram of 622Mbps for 50km



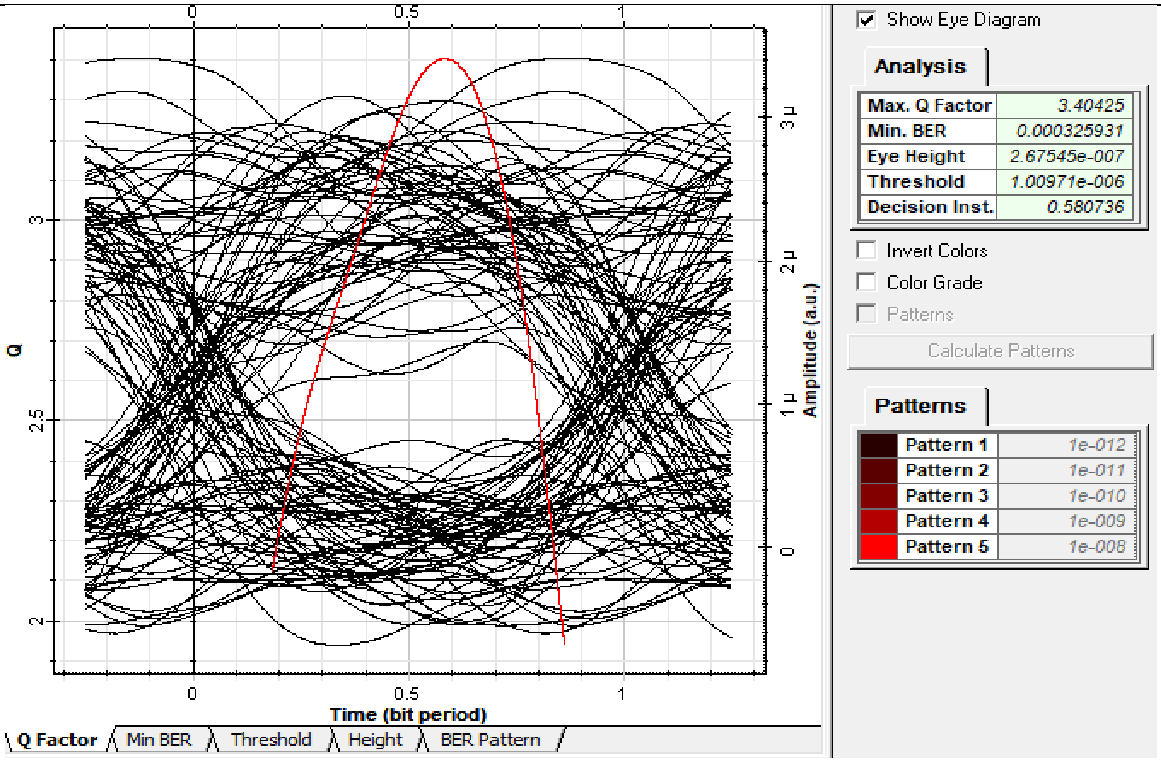
☑ Show Eye Diagram

Max. Q Factor	14.4531
Min. BER	1.08244e-047
Eye Height	7.30144e-006
Threshold	2.77948e-006
Decision Inst.	0.43457

☐ Invert Colors
☐ Color Grade
☐ Patterns

Pattern 1	1e-012
Pattern 2	1e-011
Pattern 3	1e-010
Pattern 4	1e-009
Pattern 5	1e-008

Figure 6: Eye Diagram of 155Mbps for 60km



☑ Show Eye Diagram

Analysis

Max. Q Factor	3.40425
Min. BER	0.000325931
Eye Height	2.67545e-007
Threshold	1.00971e-006
Decision Inst.	0.580736

☐ Invert Colors
☐ Color Grade
☐ Patterns

Patterns

■	Pattern 1	1e-012
■	Pattern 2	1e-011
■	Pattern 3	1e-010
■	Pattern 4	1e-009
🟥	Pattern 5	1e-008

Figure 7: Eye Diagram of 622Mbps for 60km

From the Figure 4, Figure 5, Figure 6, and Figure 7, the eye diagrams can detect the intended signal accurately because of data bit rate was smaller, which is 155Mbps and 622Mbps. However, the higher the bit rate, higher the value of BER which make the signal difficult to detect at 2.5Gbps and 10Gbps. The simulation results shown that 155Mbps and 622Mbps data rate is suitable to use in a long range of free space optical communication system because of the visual range in a conventional technique can achieve up until 60km in acceptable of bit error rate 10^{-9}. From the Table 4 and Table 5, eye diagrams can have a clear eye opening and can detect the intended signal accurately because of the smaller data rate. However, smaller input power decreases the quality of the signal which is getting poor by the higher of the noise level.

TABLE IV
RESULT INPUT POWER VERSUS BER FOR 50KM

Data Rate	*Total Power (dBm)*	*BER*
155Mbps	-5.235	2.54158E-56
622Mbps	-11.263	1.72811E-06

TABLE V
RESULT INPUT POWER VERSUS BER FOR 60KM

Data Rate	*Total Power(dBm)*	*BER*
155Mbps	-7.235	1.08244E-47
622Mbps	-13.263	0.000325931

IV. CONCLUSION

The main goals of this research is to study and analyze the performance of the point-to-point OCDMA system that manages and has high spectral efficiency for a large number of users by distance. The simulation demonstrates that 2-D MDW code performance can be realized with good performance with direct detection technique. The eye diagram is shows the effect of the various bit rate on the system performance that implemented with direct detection on this new OCDMA system. When the data bit rate increases, the system performance was degradation as shown in figures. Still, the system has a high BER for small value of bit data rate. The simulation results shows that 155Mbps data rate is suitable to use in a long range of free space optical communication system because of the visual range in a conventional technique can achieve 60km in acceptable of bit error rate 10-9. The data rate of 155Mbps also more sensitive to detect the signal transmit in the system compared to the other data rate. Since for this evaluated the performance of the system is improved with 2-D MDW code because as the bit rate is increasing still BER is low and the effective receive power is low as well. The simulation results shows that higher input power is strong signal to be used compared to others, it gives the smaller BER. A low input power (SNR) will have an increased BER. Put simply a strong signal is better than a weak one and has less chance of errors. The reason error increases with SNR is because of noise and it can achieve 60km in acceptable of bit error rate 10-9.

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