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Performance Analysis of WDM-FSO Link under Turbulence Channel

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ABSTRACT

In this paper, the performance analysis of FSO communication link in various atmospheric turbulence has been analysis for different bit rate using NRZ and RZ technique. The effect of turbulence on the link performance has been investigated by varying bit rate, turbulence strength and modulation format. FSO performance carried out for BER, Q. factor, received power under maximum link. Simulation results show that RZ format is best for strong turbulence. Where NRZ technique is used for low and medium turbulence.

***Keywords*:** free space optics; BER; Atmospheric Turbulence; NRZ format; RZ technique

I. INTRODUCTION

Free space optical communication (FSOC) is a technology that uses light propagating in free space optics (FSO) to transmit data between points to another [1]. FSO has similar working with fiber optic communication, the difference being the use of the atmosphere instead of optical fiber as a channel [2]. The transmitted light is a narrow beam through the atmosphere. Comparing with (RF) system, (FSO) features are huge bandwidth, no requirement for spectrum licensing, inherent security, low cost implementations and maintenance, and free from electromagnetic interference [3]. These features offer a crucial solution for the wireless access in the recent presence of (RF) spectrum's scarcity [4]. The major challenge in (FSO) systems is the atmospheric turbulence, which is caused by refractive-index variations of the air along the transmission path [5]. Turbulence is caused by in homogeneities of both temperature and pressure in the atmosphere, and is responsible for the refractive index variation of the air [6]. There are various statistical models to describe the atmospheric turbulence channels, for example, the K-distribution model [7], the log-normal distributed model [8] and the gamma-gamma distributed model [9]. The gamma-gamma distribution channel is most acceptable for the representation of the irradiance of free space optical channel in all weak to strong turbulent conditions. There are a different works studied reported in the literatures on the impact of turbulence on (FSO). Most of the works based on theoretical [10,11], simulation [1,2,12], and experimental [13,14]. In this paper, a simulation analyzes the performance of (FSO) communication system over atmospheric turbulence channel. NRZ-OOK and RZ-OOK are used for modulation techniques. APD photodiode are employed as a detector in the receiver side. We discuss the impact of bit rate, atmospheric turbulence conditions and encoder modulation techniques comprehensively on the system's BER, Q. factor, max. link, SNR and received power.

II. THEORETICAL CONSIDERATIONS

In free space optics, the link equation model is [15]:

$$P_R = P_T \cdot \frac{d_R^2}{\left(d_T + \vartheta . R\right)^2} .10^{-\alpha R/10} \tag{1}$$

where d_R is defines the receiver aperture diameter (m), d_T is the transmitter aperture diameter (m), θ is the beam divergence (mrad), R is the range (km) and α is the atmospheric attenuation.

A gamma-gamma distribution [16] is used to model atmospheric turbulence. In this case the probability density function pdf *P(I)* is given by:

$$P(I) = \frac{(2\alpha\beta)^{(\alpha+\beta)/2}}{\Gamma(\alpha).\Gamma(\beta)} .I^{\left(\frac{\alpha+\beta}{2}\right)-1} .K_{\alpha-\beta}\left(2\sqrt{\alpha\beta I}\right) \tag{2}$$

where Γ(.) is the gamma function, and $K_{\alpha-\beta}$ (.) is the modified Bessel function of the second kind. α and β are the *P(I)* parameters describing the turbulence experienced by waves, they are given by [17] :

$$\alpha = \left\{ \exp\left[\frac{0.49\sigma_R^2}{\left(1+1.11\sigma_R^{12/5}\right)^{7/6}} \right] - 1 \right\}^{-1} \tag{3}$$

$$\beta = \left\{ \exp\left[\frac{0.51\sigma_R^2}{\left(1 + 0.69\sigma_R^{12/5}\right)^{5/6}} \right] - 1 \right\}^{-1} \qquad (4)$$

were, $d = \sqrt{kD^2/4L}$, $k = 2\pi/\lambda$ is the wave number, L is the link span and D is the receiver's aperture diameter. The parameter σ_R^2 is the rytov variance, it is given by:

$$\sigma_R^2 = 1.23 C_n^2 k^{7/6} . L^{11/6} \qquad (5$$

where C_n^2 is the altitude-dependent on the index of the refractive structure parameter that determining the turbulence strength.

III. SIMULATION DESIGN

Free space optical communication (FSOC) under turbulence channel design has modeled and simulated for performance characterization by using opt system [7]. The main components of the optical link are shown in Fig. 1. This figure shows the basic devices that have been in this study. A pseudo-random bit sequence (PRBS) is generates. These Signals are then split into two equal parts, which are encode by two modulation technique (NRZ and RZ). CW laser is the main source, and a mach-zehnder modulator (MZM) is used to modulated data, multiplexing (WDM), and demultiplexing (DeMUX) systems can be optimized to achieve a maximum link range. The transmitter optical signal is the transmitted over FSO link which has different turbulence characteristics. An Optical amplifier (EDFA) is used to amplification signals.

This amplifier specially suited in a long-haul system. The optical signal is then received by the receiver, which is an APD photodiode and is followed by low pass Bessel filter, with cut-off frequency 0.75 bit rate. The final stage is using regenerate electrical signal of the original bit sequence and the modulated electrical signal as in the optical transmitter to be used for BER tester. Some of measurements tools such as, BER analyzer, electrical power meter, and optical spectrum analyzer are used as well. The system design parameters in the representative characteristic are illustrated in Table (1).

IV. SIMULATION RESULTS

This part presents simulated results for analyzing the performance of (FSO) communication under turbulence channel. A comparative study has been carried out for (FSO) communication at various modulation format, data rate and strength turbulence. The signal optimization is achieved successfully to handle the condition on turbulence weather, with certain parameters change. Table (2) shows the parameter's optimization, this system is running at maximum link.

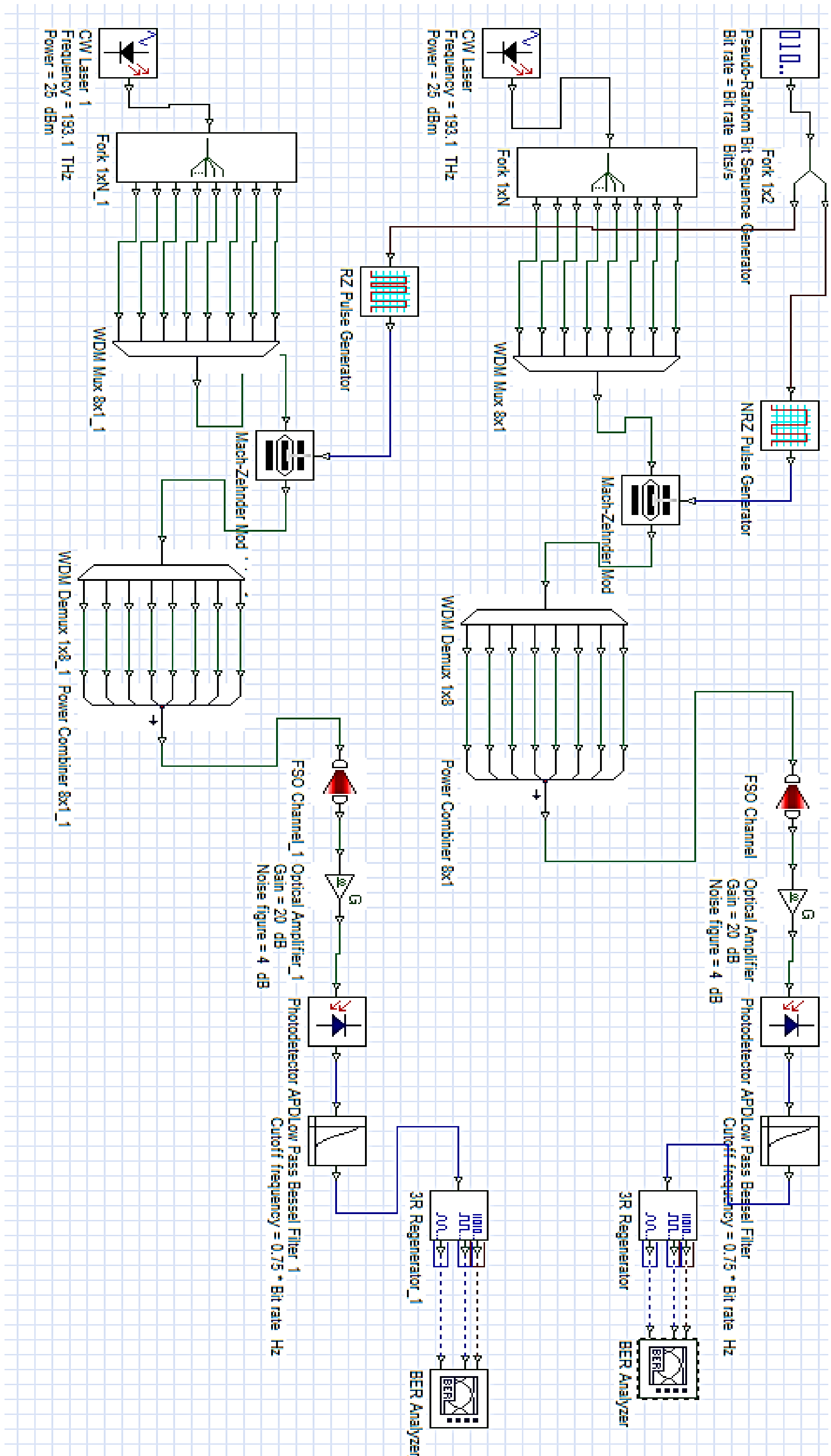


Figure 1. Optical link design

It can be seen from Table (2) that under optimized conditions of data rate, turbulence strength, and modulation technique, the increasing in turbulence, data transmission rate causing the decrease in the maximum transmission link. It can be notice that when the strength turbulence is applied ($5*10^{-13}$) $m^{-2/3}$. An improvement increase occurs when (RZ) was used as a modulation format, where the distance of data transmission increases and reaches to 92 km and 63 km for 5Gbps and 10Gbps, respectively.

BER performance is shown in Figs. (2) and (3) for various turbulence strength. It can seen BER value for the weak turbulence is approximately same as that of strong turbulence but the NRZ format is better RZ format at maximum link. On the other side, RZ format exceed maximum link from (NRZ) format under strong turbulence.

Also it can notice that in Figs.(4) and (5) that (NRZ) Optical spectrum has a strong component for weak and medium turbulence compared to (RZ) spectrum. For strong turbulence, (RZ) spectrum has a strong component compared with (NRZ). This is the cause that (RZ) format is preferred over (NRZ) format for strong turbulence.

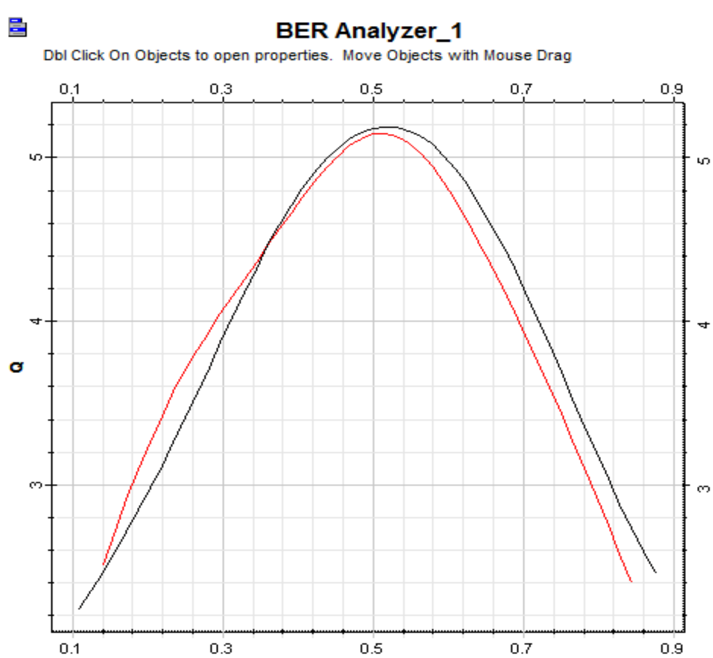
Table 1. Data parameters.

Parameter	Value
Bit rate	(5, 10) Gbps
power	25 dBm
frequency	193.1THz
Transmitter aperture diameter	10 cm
Receive aperture diameter	20 cm
Beam divergence	1 mrad
Turbulence strength C_n^2	$(0.01,0.1,5)*10^{-13}$ $m^{-2/3}$
Amplifier gain	20 dB
Noise figure	4 dB
Photodiode gain	3
Responsivity	1 A/W
Dark current	10 nm

Table 2. Performance analysis of FSO with various turbulence.

Modulation technique	NRZ				RZ			
Bit Rate	5 Gbps		10 Gbps		5 Gbps		10 Gbps	
$C_n^2(10^{-13})$ $m^{-2/3}$	BER	Q. factor	BER	Q. factor	BER	Q. factor	BER	Q. factor
0.01	90.37e-9	5.1864	96.39e-9	5.1736	92.79e-9	5.1467	53.24e-9	5.3040
0.1	60.94e-27	10.4318	2.05e-18	8.6347	83.45e-9	5.1664	58.09e-9	5.2881
5	93.8e-9	5.1795	68.29e-9	5.237	81.1e-9	5.172	73.49e-9	5.245
Modulation technique	NRZ				RZ			
Bit Rate	5 Gbps		10 Gbps		5 Gbps		10 Gbps	
$C_n^2(10^{-13})$ $m^{-2/3}$	Max. link	Pr	Max. link	Pr	Max. link	Pr	Max. link	Pr
0.01	92.3	-48.174	84	-47.666	40	-52.149	28	-51.118
0.1	40.8	-35.052	40.5	-35.777	38	-52.132	26	-51.136
5	38.9	-48.189	35	-47.499	92	-52.127	63	-51.183

a



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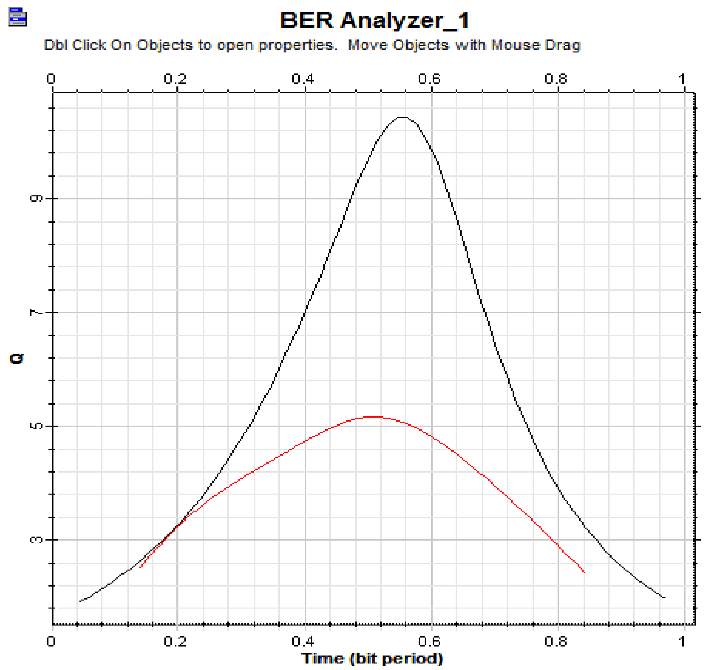

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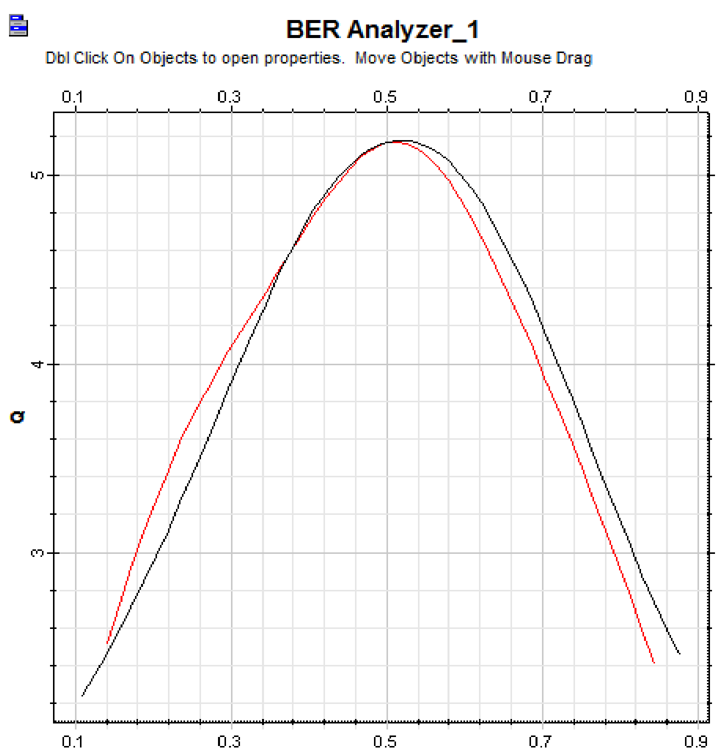
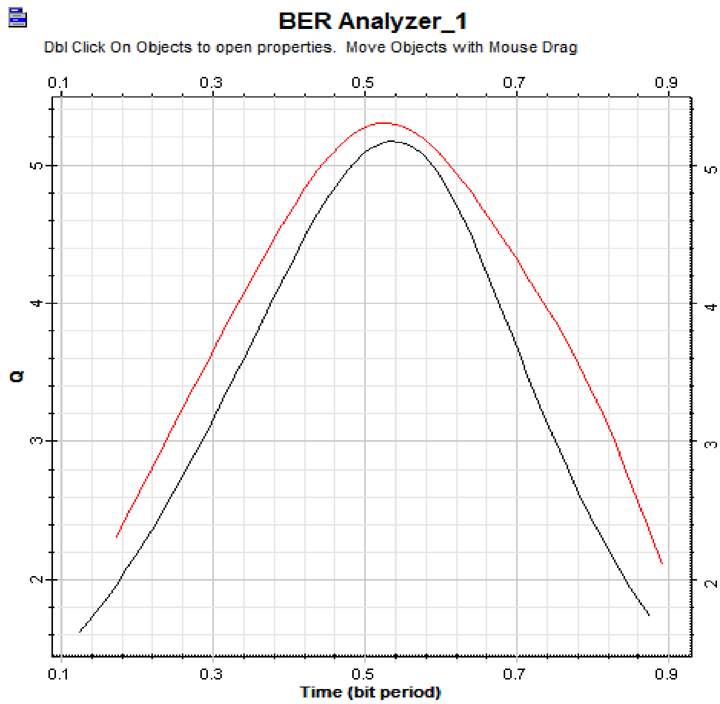
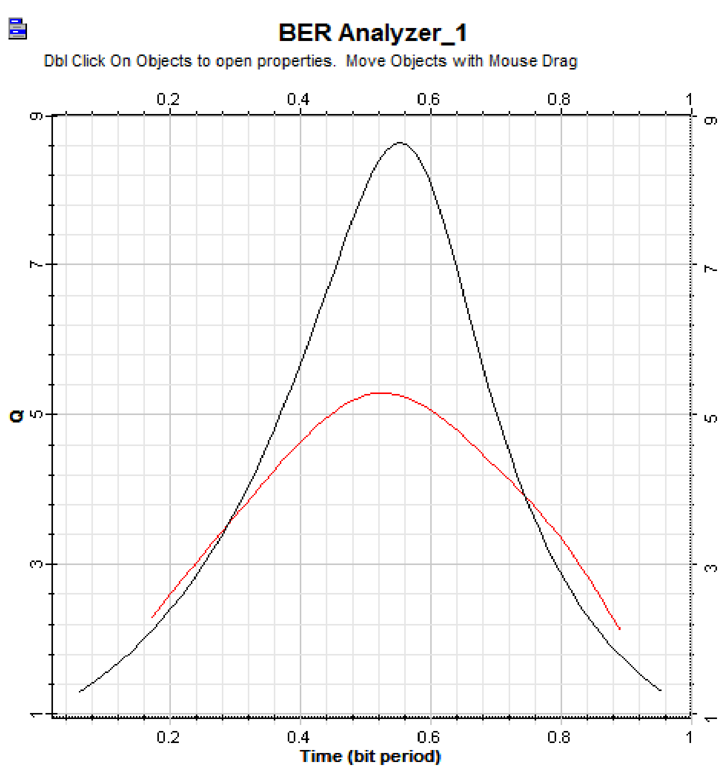


Figure 2. BER analyzer for data rate 5Gpbs at turbulence, a) $0.01{*}10^{-13}$ $m^{-2/3}$, b) $0.1{*}10^{-13}$ $m^{-2/3}$, c) $5{*}10^{-13}$ $m^{-2/3}$. Red line: RZ format, Black line NRZ format

a


BER Analyzer_1
Dbl Click On Objects to open properties. Move Objects with Mouse Drag
0.1
0.3
0.5
0.7
0.9
Q
5
4
3
2
Time (bit period)

b


BER Analyzer_1
Dbl Click On Objects to open properties. Move Objects with Mouse Drag
0.2
0.4
0.6
0.8
1
Q
9
7
5
3
1
Time (bit period)

c

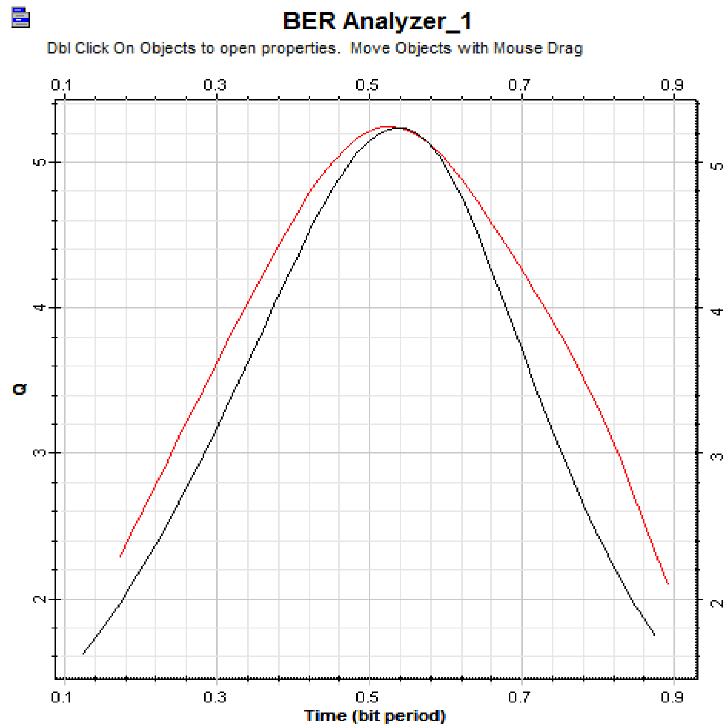
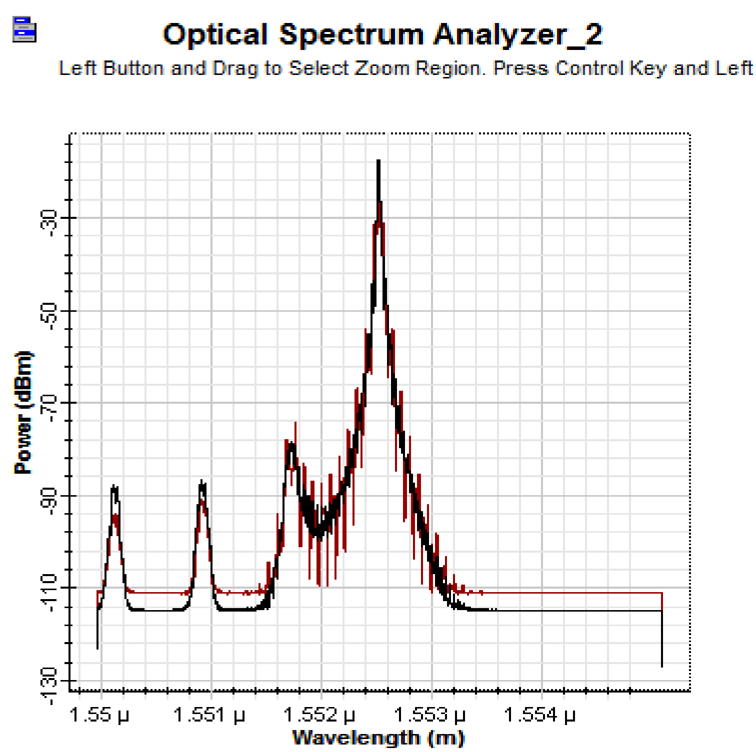


Figure 3. BER analyzer for data rate 10Gpbs at turbulence, a) $0.01*10^{-13}$ $m^{-2/3}$, b) $0.1*10^{-13}$ $m^{-2/3}$, c) $5*10^{-13}$ $m^{-2/3}$. Red line: RZ format, Black line NRZ format

a



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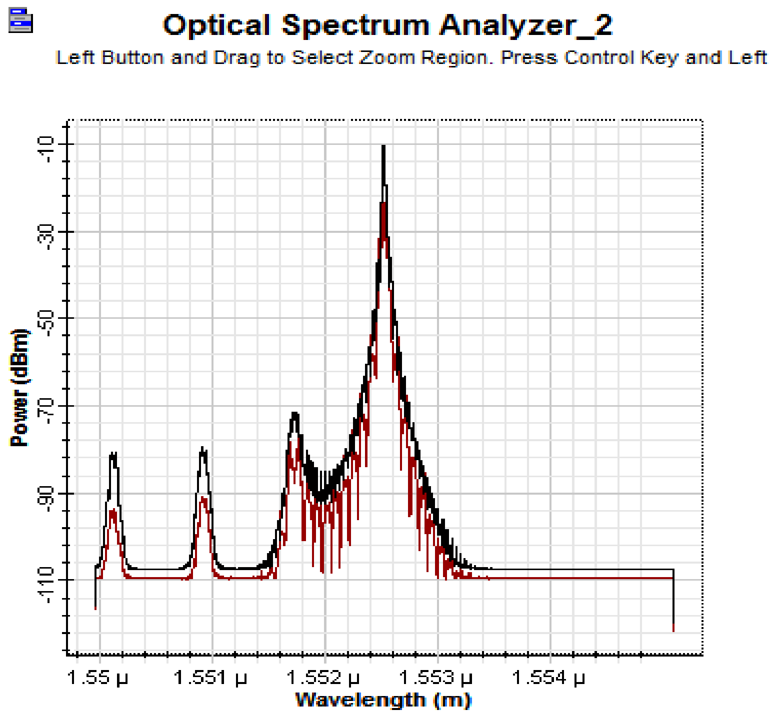

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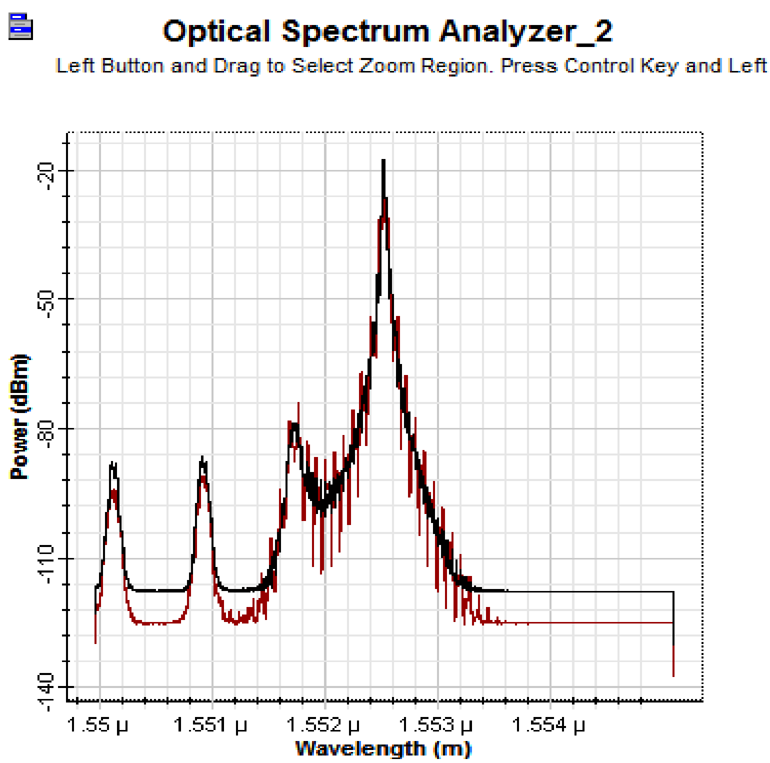
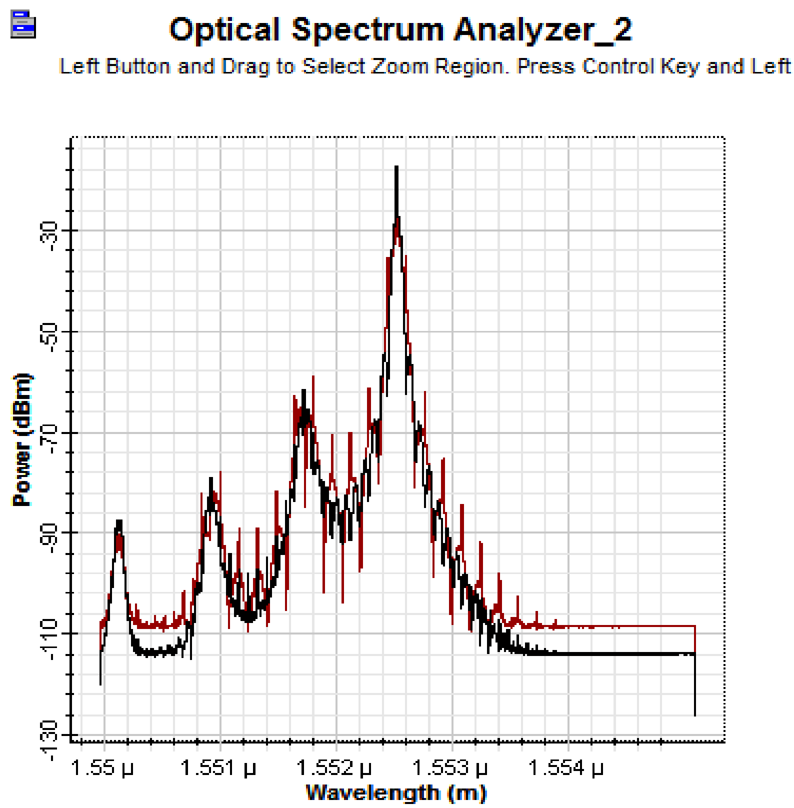
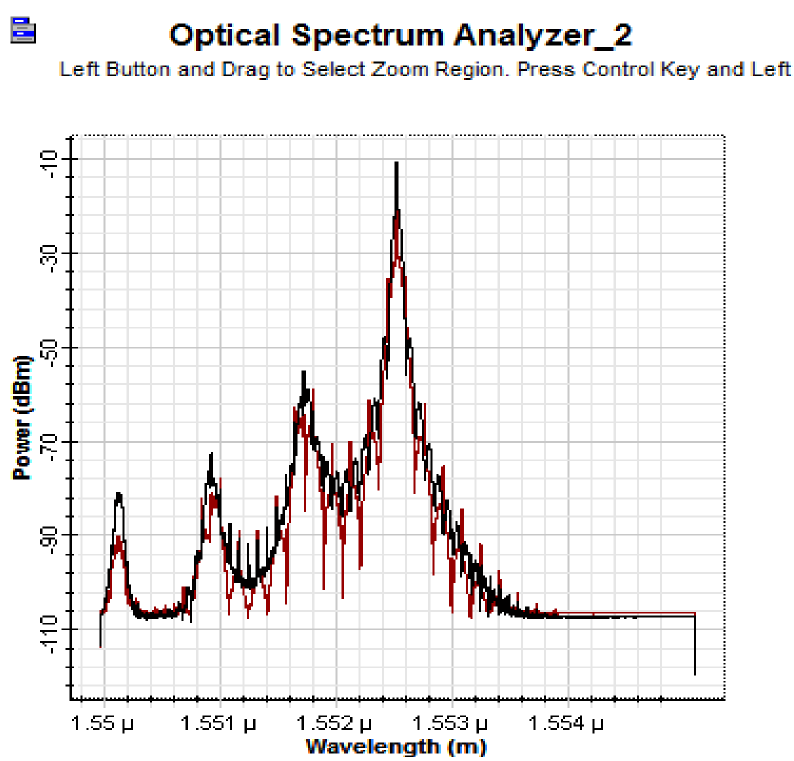


Figure 4. Optical spectrum analyzer for data rate 5Gpbs at turbulence, a) $0.01*10^{-13}$ $m^{-2/3}$, b) $0.1*10^{-13}$ $m^{-2/3}$, c) $5*10^{-13}$ $m^{-2/3}$. Red line: RZ format, Black line NRZ format.

a


Optical Spectrum Analyzer_2
Left Button and Drag to Select Zoom Region. Press Control Key and Left
Power (dBm)
-30
-50
-70
-90
-110
-130
1.55 μ
1.551 μ
1.552 μ
1.553 μ
1.554 μ
Wavelength (m)

b


Optical Spectrum Analyzer_2
Left Button and Drag to Select Zoom Region. Press Control Key and Left
Power (dBm)
-10
-30
-50
-70
-90
-110
1.55 μ
1.551 μ
1.552 μ
1.553 μ
1.554 μ
Wavelength (m)

c

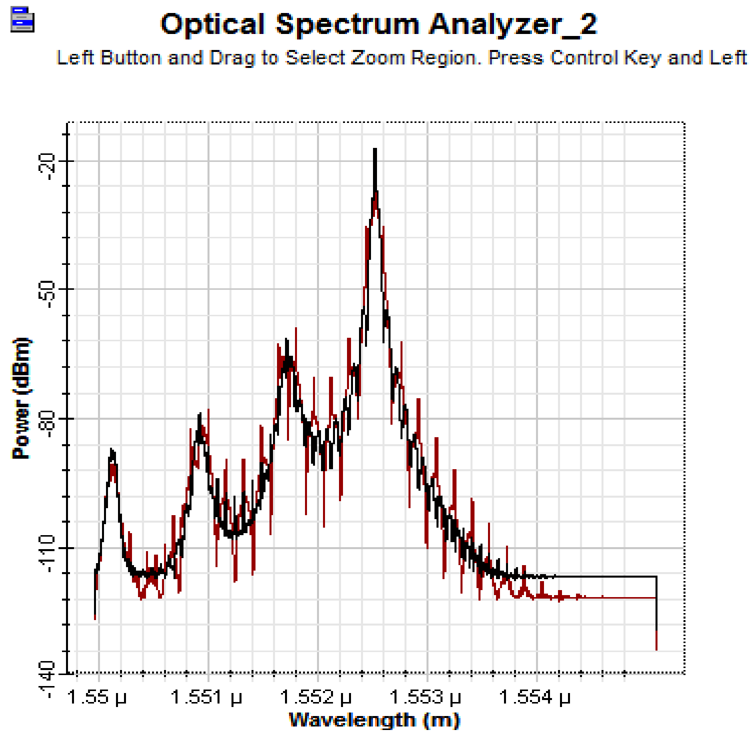
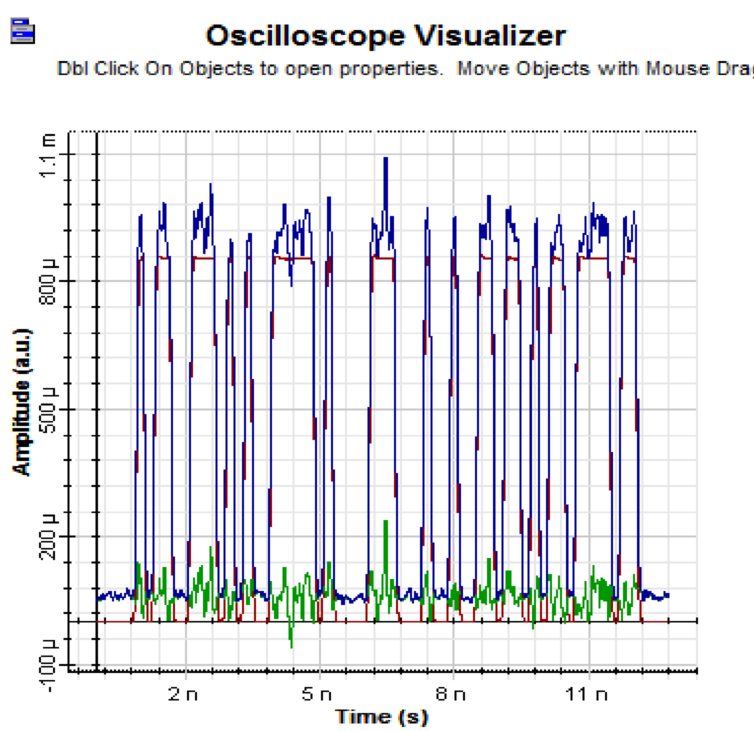


Figure 5. Optical spectrum analyzer for data rate 10Gpbs at turbulence, a) $0.01*10^{-13}$ $m^{-2/3}$, b) $0.1*10^{-13}$ $m^{-2/3}$, c) $5*10^{-13}$ $m^{-2/3}$. Red line: RZ format, Black line NRZ format

It is noticed in Fig. (6) the amplitude of the received signal which record in oscilloscope. The amplitude of the detect signal for NRZ reach to 800 (a. u), while for RZ the amplitude record about to 20 (a. u).

a



b

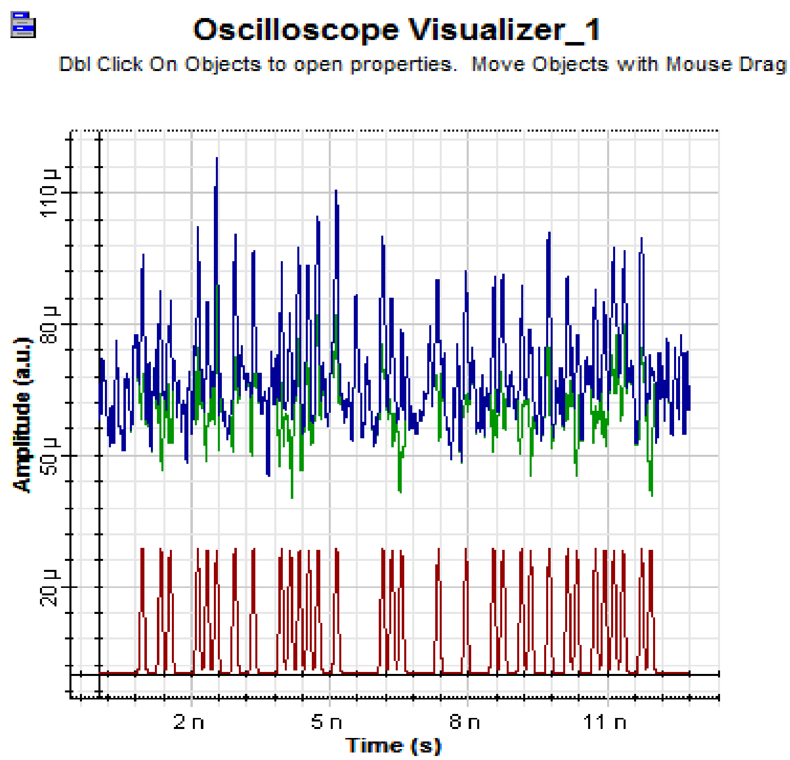


Figure 6. Output signal record, a) NRZ, b) RZ. Red Line: Detect Signal, Green Line: Noise Signal, Blue Line: (Detect + Noise) Signal.

V. CONCLUSIONS

Free space optical link performance is analyzed by taking BER as a performance metric. In this simulation a WDM has been employed successfully. The designed parameters are varied and simulated to analyze the impact of distance, bit rate and turbulence on the BER performance. It has been observed that RZ modulation gave us better performance in comparison to NRZ modulation under strong turbulence because RZ format has a strong carrier component compared to NRZ format. When the atmospheric turbulence is increased and reached to strong turbulence, then the maximum link is reduced with acceptable BER.

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