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Research paper

Quality Factor and SNR Compensation of Free Space Optical Communication Link Using Different Modulators

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Abstract

Free space optical (FSO) systems introduce the best solution for the broadband network requirements with a cost reduction compared to the optical wire communication systems. This paper, studies the signal to noise ratio (SNR) and quality factor (Q-factor) for using two types of modulation formats and compares their performance. The analysis are performed for Mach-Zehnder modulator (MZM) and electro-absorption modulator (EAM) with distance range (1-4) km of FSO by using avalanche photo-diodes (APD) receivers. The simulation results are obtained based on the Optisystem 7.0 with optical high data rate of 10 Gbs for this communication system. The simulation results have shown that MZM gives better performance compared to EAM for different ranges and for the selected beam divergence value.

Keywords: *Electro-absorption modulator;Free space optical systems;Mach-Zehnder modulator*

1. Introduction

Free space optic (FSO) technology requires direct line of sight between the transmitter and the receiver. There are several factors that affects the link quality such as the physical obstruction and weather conditions that limit the range of FSOs. Particularly, in the case of fog, the tiny size drops with high density diffuse the light at the operating frequencies. In addition, the scintillation effect as consequence of atmospheric turbulence, give rise to variations in the optical index of the air in a localized temporary way. In consequences to this phenomenon, the power of the received signal at the detector varies and generate errors to the interpretation of the transmitted signal [1].

Utilizing multiple transmitters, each taking a slightly different route through the atmosphere enhances the transmission and helps smooth out disturbances [2, 3]. The FSO communication system is very low cost compared to other telecommunication systems, however, it is vulnerable to interference and jamming due to its narrow beam transmission [4]. The performance of FSO system is related to the transmission elements such as, modulation formats, type of Laser, transmission window, and atmospheric attenuation that is, signal degradation, signal absorption, scattering and scintillation [5].

In [6], two types of modulators namely Mach-Zehnder modulator (MZM) and electro-absorption modulator (EAM) are compared under clear weather conditions at a rate of 10 Gbps that have been simulated through FSO utilizing OPTISYSTEM. As a result, the EAM have achieved better signal to noise ratio (SNR) and Q-factor compared to the MZM system.

On the other hand, dense wavelength division multiplexing (DWDM) have been utilized to enhance the data rate in optical fiber systems. In [7], system analysis of DWDM system utilizing erbium doped fiber amplifier (EDFA) is investigated at different fiber lengths for the return-to-zero (RZ) and non return-to-zero (NRZ). The results have shown that the BER will increase and the Q-factor decrease as the fiber length increase and vice versa.

Designing FSO systems requires the consideration of these atmospheric attenuation in addition to the link distance and link misalignment. Other factors such as, data rate, sun radiation, selecting the wave-length, and the line-of-sight (LOS) [8]. Unlike radio frequency (RF) systems that requires Fresnel zone clearance, the clearance of the FSO systems between the beam center and any obstructions equals the beam radius. In addition, the alignment of the laser communication systems is crucial compared to the RF systems due to their narrow beam [9].

The power exceeds the receiver sensitivity is called link margin, M_{link} (dB) and can be calculated using [10]

$$M_{link} = P_e - S_r - A_{geo} - A_{atmo} - A_{sc} - A_{sys}. \tag{1}$$

Where, P_e is the total power of the emitter in dBm, S_r is the receiver sensitivity that depends on the bandwidth (Data rate) in dBm, A_{geo} is the link geometrical attenuation measured in dB, A_{atmo} is the atmospheric attenuation due to absorption and scattering and measured in dB, A_{sc} is the attenuation due to atmospheric turbulence measured in dB, A_{sys} represents all other system dependent losses, including misalignment of the beam direction, receiver optical losses, loss due to beam wander, reduction in sensitivity due to ambient light (solar radiation).

The successful installation of the FSO to achieve optimum transmission requires accurate estimation to the weather conditions, surrounding obstacles, path type, and transceiver alignment [11]. The accurate alignment is a crucial issue in the design of the FSO due to

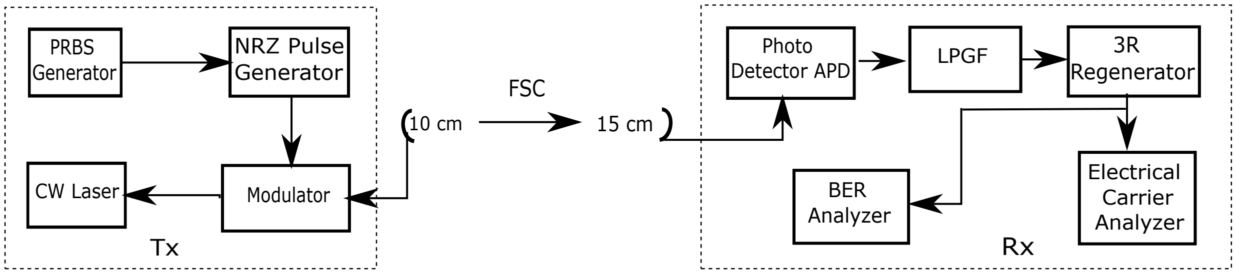

Figure 1: FSO system Transceiver

the very narrow beam widths which might result in a sever reduction in the signal [12]. In addition, weather conditions such as, wind and temperature change should be taken into consideration in the design of the mounts to maintain stable connection [13].

Geometrical losses for the FSO transmission systems can be written as [14]

$$G_L(dB) = 10 \times \log \left\{ \frac{D_{RX}}{A_{TX} + [R \times Div]} \right\}. \tag{2}$$

Where, $G_L(dB)$ is the geometric loss for the FSO systems measured in dB, D_{RX} is the diameter of the receiver measured in meter (m), A_{TX} is the aperture of the transmitter measured in m, R is the range measured in kilo meter (km), and Div is the divergence angle measured in mrad.

In this paper, we focus on two modulators, MZM and EAM at 1550 nm wavelength and one avalanche photo-diode (APD) for FSO systems. Simulation results have shown higher Q-factor for the system with MZM compared to the system with EAM for the same wavelength.

The rest of this paper is organized as follows. The methodology is presented in Section 2, results and discussion is presented in Section 3, and conclusions are drawn in Section 4.

2. Methodology

The results of this paper is obtained utilizing Optisystem 7.0 to implement the proposed FSO system as shown in Fig.1, where the modulator represents either MZM or EAM type. Based on Fig.1, the FSO link have shown to have three sections that are the transmitter, channel, and the receiver. The random binary sequence is generated first using the pseudo random binary sequence (PRBS) generator, followed by the non-return to zero (NRZ) pulse generator to convert the 0, 1 sequence into a coded signal. The modulator stage represents the MZM or the EAM respectively, where the coded data is modulated each time using one of these modulators. Following the modulator, the continuous-wave (CW) laser block, which specifies several parameters such as the side mode, chirp, relative intensity noise, suppression and the line width.

The transmitted signal propagates to the receiver through the free space channel that affects the propagated signal with the beam divergence, transmitter loss, attenuation geometric loss, link distance, receiver loss and other additional losses.

The last section of the FSO system is the receiver which intercept the propagated signal with APD that multiply the electrons in the intrinsic zone to boost the signal power by producing more photo-electrons that achieve the required SNR. Following the APD, the received signal is filtered with the low-pass Gaussian filter (LPGF) before the transmitted signal regenerated utilizing the 3R re-generator block and fed to the bit-error-rate (BER) analyzer.

Table 1: Simulation Parameters

Parameters	Description/ value
transmitting wavelength	1550 nm
transmitting optical power	10 dBm
transmitter and receiver aperture	10, 15 cm
transmission rate	10 Gbs
link distance	1-4 km
attenuation	0.4 dB/km
beam divergence	1 m.rad

3. Results and Discussion

The simulations obtained in this paper based on the FSO link with two modulators, MZM and EAM, and for different free space channel range utilizing optisystem 7.0. The selected modulators are compared including the Q-factor for different ranges and at 1550 nm wavelength.

Fig. 2 shows the eye diagram of MZM and EAM using APD system to detect the optical signal at 1550 nm wavelength. The eye diagram shows that the Q-factor for MZM system has better performance compared to the system with EAM block.

Fig. 3 shows a comparison between the two selected modulators with respect to the Q-factor Vs the range in km. The range has been selected from (1-4) km, while the transmitted power was set to 10 dB. It have been observed that the system with MZM has better Q-factor than the EAM systems. The improvement in the Q-factor was the highest at the range 2 km with 37.77, while the lowest improvement was at 1 km with 28.85. In addition, for both systems, the Q-factor decreases as the range increase.

By comparing our results to [15], it have been observed that the Q-factor was 63.85 when the beam divergence and the receiver aperture was 1 mrad and 10 cm, respectively. However, our results have shown that the Q-factor was 291.2 when the beam divergence and the receiver aperture becomes 2 mrad and 15 cm, respectively.

Fig. 4 demonstrates a comparison between the two modulators taking into consideration the signal to noise ratio (SNR) Vs the range. It have been shown that for both systems, as the range increase, the SNR decreases considerably. By combining the results of Fig. 3 and Fig. 4, the relationship between the SNR and the Q-factor is presented in Fig. 5.

Fig. 5 shows that the Q-factor has been increased for both modulators with respect to the SNR. However, the Q-factor was higher in the MZM system compared to EAM for the selected range.

By considering the results above, MZM systems have shown to have better performance compared to the EAM systems with higher Q-factors and for different ranges.

4. Conclusion

In conclusion, FSO operates on very high bit rate, up to 10 Gbps, and is highly immune to interference and interception, which nominate this system to different applications in the telecommunication systems. This work presents the impact of MZM and EAM modulators, which shows considerable decline in Q-factor at different ranges both modulators, respectively. On the other hand, the SNR was higher higher using MZM system compared to the EAM at different ranges. It is concluded from the above discussion that MZM systems have shown to have better performance compared to the EAM systems with higher Q-factors and for different ranges.

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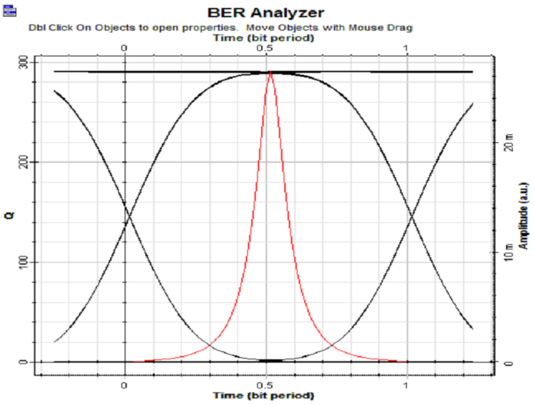
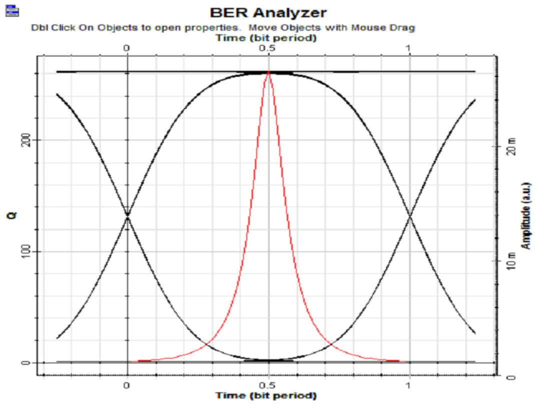
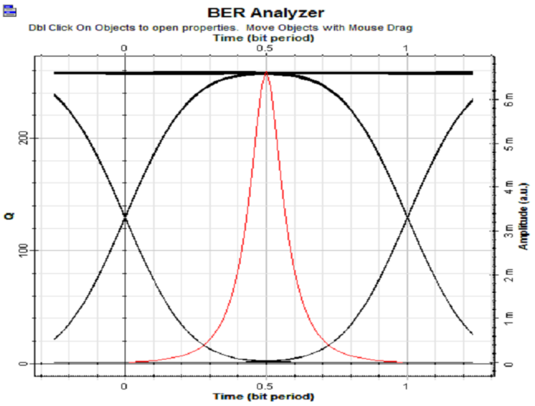


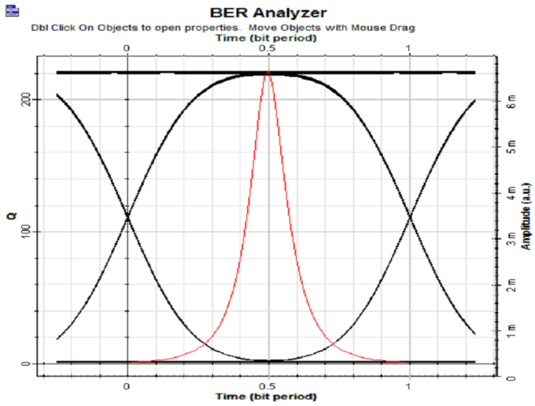
(a) MZM-1 km system.



(b) EAM-1 km system.



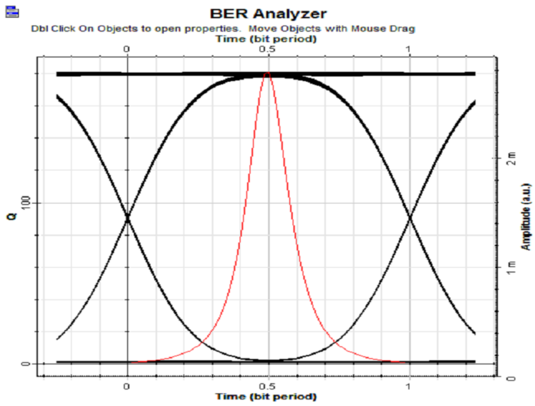
(c) MZM-2 km system.



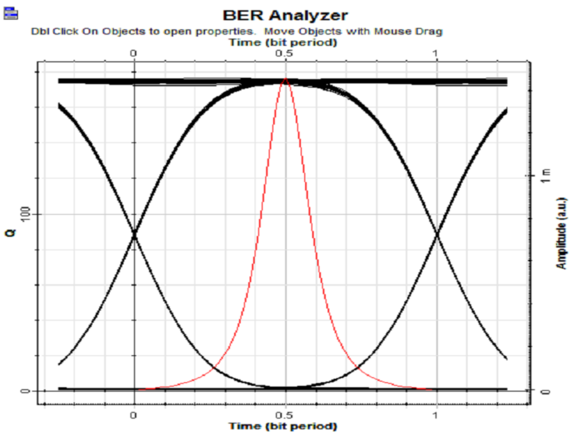
(d) EAM-2 km system.

MZM_3km.png

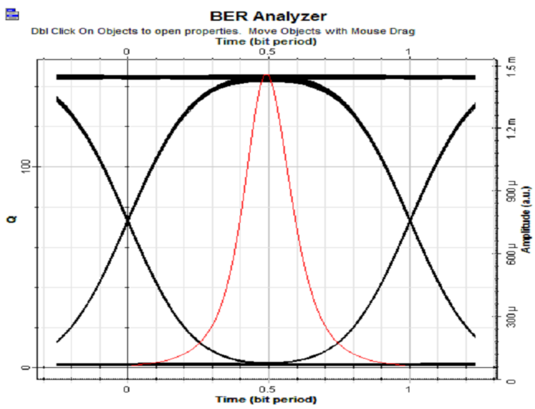
(e) MZM-3 km system.



(f) EAM-3 km system.



(g) MZM-4 km system.



(h) EAM-4 km system.

Figure 2: Eye diagram of MZM & EAM with APD systems at 1550 nm wavelength.

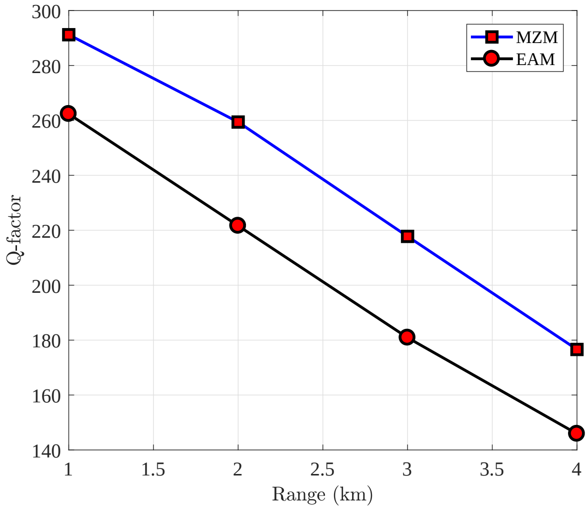
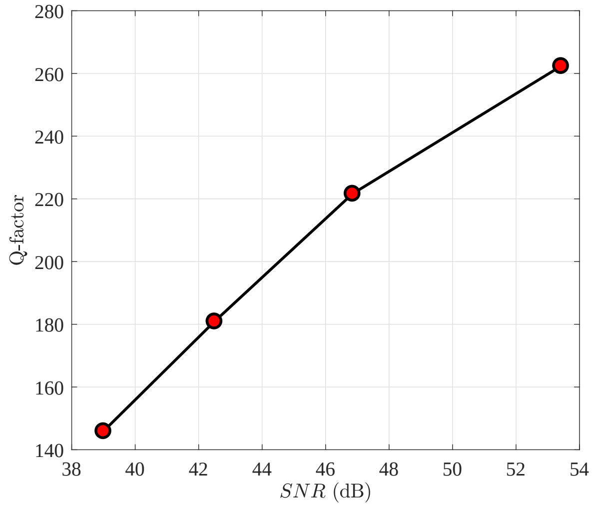
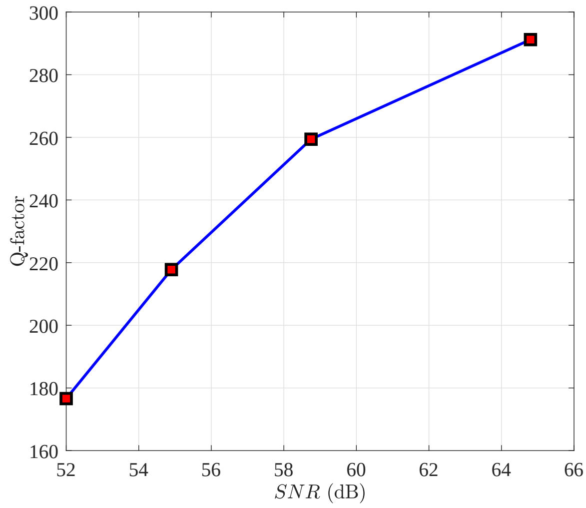


Figure 3: Q-factor vs range for MZM and EAM systems.



(a) MZM systems.



(b) EAM systems.

Figure 5: Q-factor Vs SNR for MZM and EAM systems.

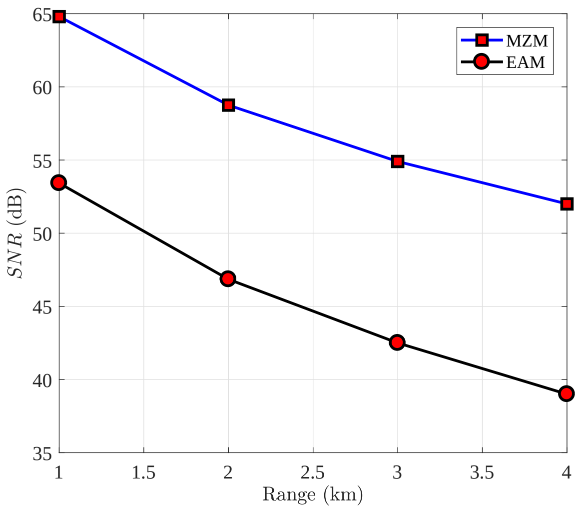


Figure 4: SNR vs range for MZM and EAM systems.