

Impact Analysis Of MZM ER In Free Space Optical Link Under Hazy Conditions

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Abstract

This paper presents the design of a free-space optical link operating under hazy atmospheric conditions. The performance evaluation is conducted using Bit Error Rate, Q-factor, Optical Signal to Noise Ratio and Eye Diagram analysis. The optical link supports a data rate of 10 Gbps over a transmission distance of 2.5 km. The effect of variation of MZM Extinction Ratio on the link is studied and it is revealed that increasing the Extinction Ratio results into improved quality transmission.

Keywords: FSO, MZM, Extinction Ratio, BER, Q Factor

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I. Introduction

Free Space Optics (FSO) is a wireless technology that uses light to transmit data through free space between two points. By operating without physical fiber and relying on line-of-sight laser or LED links, FSO offers high data rates, license-free operation, and rapid deployment for backhaul and last-mile connectivity. A typical FSO system includes an optical transmitter, an atmospheric propagation channel, and an optical receiver. The transmitter employs a near-infrared laser source (e.g., 850 nm, 1310 nm, or 1550 nm) to convert electrical data into a modulated optical signal, which is collimated and transmitted using telescopic optics. At the receiver, the incident optical beam is collected, detected by a PIN or avalanche photodiode, and converted into an electrical signal for further signal processing.

FSO systems support multi-gigabit data rates comparable to fiber-optic links. The use of optical frequency band makes the system inherently immune to electromagnetic interference and do not require spectrum licensing. The ease of deployment, particularly in scenarios where fiber installation is challenging, along with the high directionality of optical beams, makes FSO a cost-effective and secure communication solution [1-2]. FSO communication systems are strongly affected by atmospheric impairments. Absorption and scattering caused by fog, haze, precipitation, and aerosols lead to severe attenuation, with fog and haze posing the greatest challenge due to particle sizes comparable to optical wavelengths. Additionally, atmospheric turbulence results in beam wander, scintillation, and irradiance fluctuations [3]. The highly directional nature of FSO links also necessitates accurate transmitter–receiver alignment, as small pointing errors can cause link outages [4].

The performance of an FSO communication system is generally analyzed using key metrics including Bit Error Rate (BER), Q factor, Optical Signal-to-Noise Ratio (OSNR), and eye-diagram analysis. BER indicates the reliability of data transmission, while the Q factor provides a quantitative measure of signal quality. OSNR assesses the relative strength of the optical signal in the presence of noise, and eye diagrams visually illustrate signal integrity and timing behavior. Collectively, these parameters are used to evaluate the feasibility and robustness of FSO links under varying atmospheric conditions. FSO is commonly used for high-speed, short-to-medium-range communication in applications such as last-mile access, building-to-building links, disaster recovery, military communications, and satellite-to-ground systems [4-6]. It is also deployed as a backup link to enhance fiber network reliability.

In this paper, the extinction ratio (ER) of a Mach-Zehnder Modulator (MZM) has been varied to analyze its impact on performance of FSO link under hazy conditions. The ER is a measure of the difference in optical power between the on and off states of MZM. A higher ER means a clearer distinction between these states, which improves signal integrity and reduces the likelihood of bit errors. A lower ER, on the other hand, makes the signal harder to distinguish, leading to higher BER and poorer overall system performance. Typical ER values in optical communication systems range from 10 to 25 dB, with higher ratios preferred for high-speed or long-haul links.

II. Simulation Setup

The optical link is designed to transmit the data at bit rate of 10 Gbps in free space for 2.5 km distance.

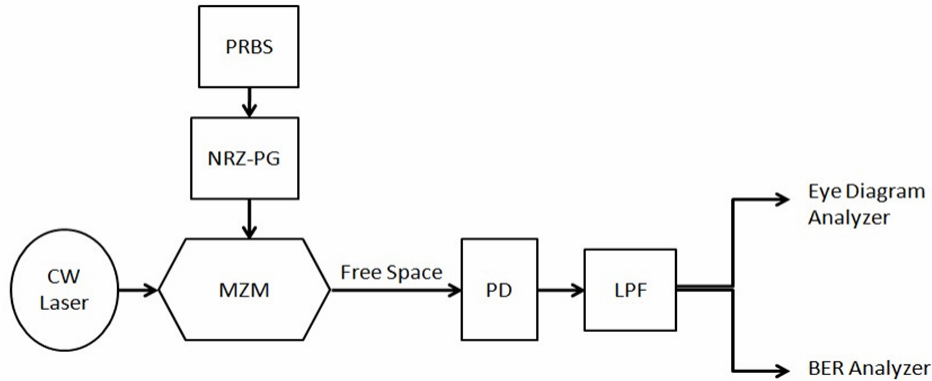


Fig.1 Block diagram of FSO link; CW: Continuous Wave; PRBS: Pseudo random bit sequence generator; NRZ-PG: Non return to zero-pulse generator; MZM: Mach Zehnder modulator; PD: Photodetector; LPF: Lowpass filter

Figure 1 represents the simplified block diagram of the free space optical (FSO) link. Pseudo Random Bit Sequence (PRBS) generator produces digital information and pulse generator encodes it in Non-Return Zero (NRZ) format. The continuous wave laser generates optical signal and encoded information is superimposed on the latter. The MZM modulates optical carrier utilizing baseband signal i.e encoded NRZ information. The output signal generated by MZM is transmitted through FSO. This transmitted signal is received by Avalanche photodiode (APD) in receiver section. The optical signal detected by APD is converted into an electrical signal. This signal is further processed by the low pass Bessel filter where the low frequency components are retained and high frequency components are rejected. The filtered output signal is analyzed in terms of Q factor, BER, OSNR and eye diagrams. The simulation setup shown in figure 2 has been simulated in Optisystem software. The table 1 presents key simulation parameters and their values.

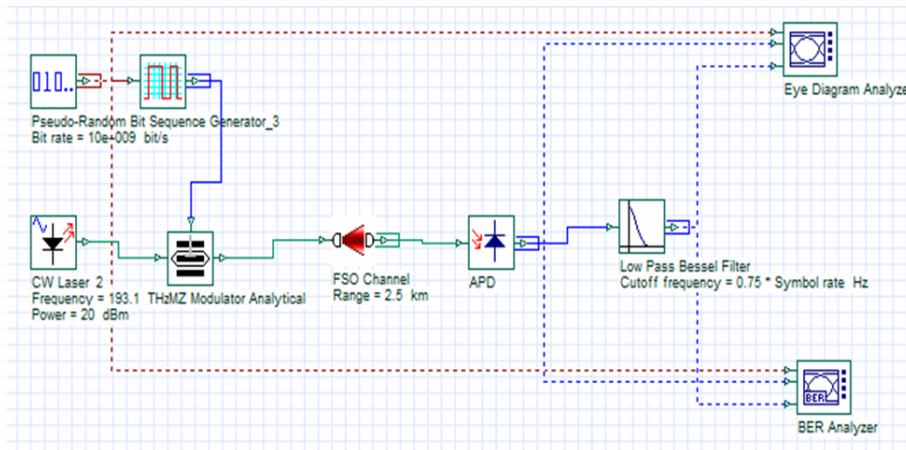


Fig 2: Simulative Diagram for the designed FSO Network

Table1. Simulation Parameters involved in system design

Parameter	Value
Wavelength	193.1 THz
Laser Power	20 dBm
Bit Rate	10 Gbps
FSO distance	2.5 km
Extinction Ratio	10 dB to 50 dB
Attenuation	5dB/km (Hazy Weather)

III. Results And Discussion

The model depicted in figure 2 has been simulated and the observations have been recorded in terms of various performance parameters. The figures 3, 4 and 5 reveal how the performance parameters BER, Q factor and OSNR vary with the variation in MZM ER. The figure 3 displays impact of ER variation on BER. The BER performance improves with increase in ER. The BER goes from 10^{-13} to 10^{-22} as MZM ER is varied from 10 to 50 dB. The figure 4 shows that value of Q factor improves from 7.5 to 9.2 as ER is increased from 10 to 20 dB. The further increase in ER to 50 dB leads to only marginal increase in Q factor from 9.2 to 9.5. The figure 5 depicts similar pattern for OSNR. The increase in ER from 10 to 20 dB leads to improved OSNR from 16.5 to 21 dB. The variation of ER from 20 to 50 dB results into marginal increase in OSNR from 21 to 22 dB. The figure 6 presents eye diagrams at ER 10 and 30 dB. It can be seen clearly that increment in ER from 10 to 30 dB results into increased eye opening indicating better performance.

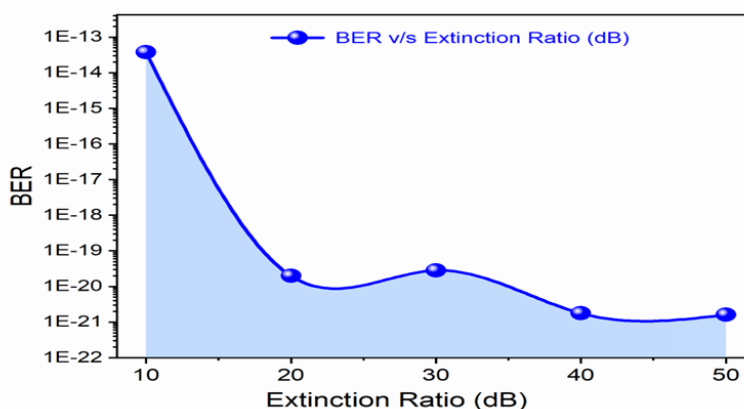


Fig 3: BER vs Extinction Ratio

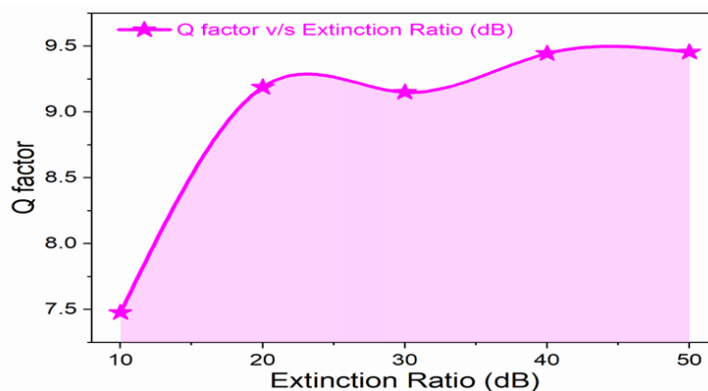


Fig 4: Q Factor Vs Extinction Ratio

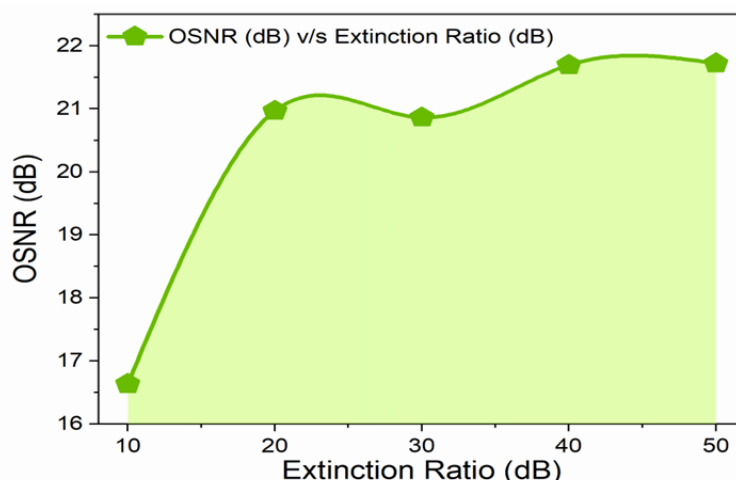


Fig 5: The OSNR performance with variation in Extinction Ratio

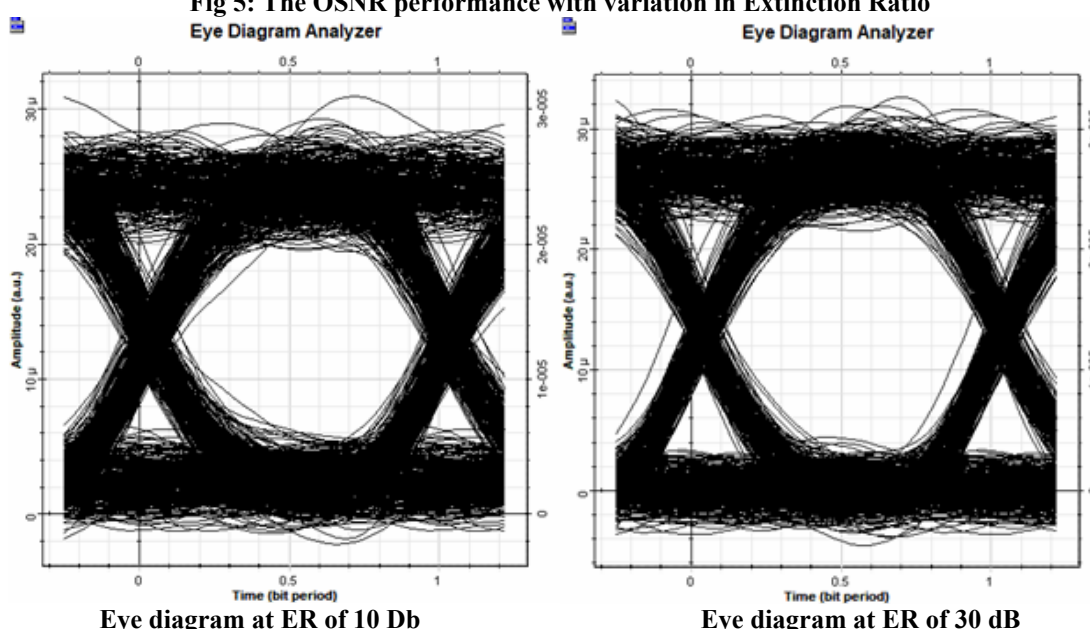


Fig 6: Eye Diagrams at MZM ER 10 and 30 dB

IV. Conclusion

The performance of an FSO link has been analyzed under hazy conditions. The analysis has been carried out using parameters namely BER, Q factor, OSNR and eye diagram. It was observed that there is significant improvement in all the above said parameters as the MZM ER is increased from 10 dB to 20 dB. The further increase in ER leads to marginal improvement in performance. The FSO link has been established for data transmission at the bit rate of 10Gbps for 2.5 km distance. It is concluded that MZM ER should be optimized for improved performance.

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