Effect of Beam Divergence on WDM-FSO Transmission System

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ABSTRACT

This work is focused to carry out the investigation of wavelength division multiplexing (WDM) approach on free space optical (FSO) transmission systems. In this work, 8 independent channels having capacity of 1.56 Gbps each are transmitted over FSO link having a span of 15km by considering clear weather conditions. Furthermore, the performance of proposed FSO-WDM system is also evaluated on the effect of varying the beam divergence and results are reported in terms of SNR, BER and eye diagrams.

Keywords

Free space optics (FSO), Divergence, Wavelength division multiplexing (WDM).

1. INTRODUCTION

Free space optics (FSO), also termed as optical wireless, is an optical communication technology that uses line of sight (LOS) communication system and tries to fulfill the need for high bandwidth over short distances. Instead of transmitting the pulses of light through glass fiber, these light pulses are transmitted in a narrow beam through atmosphere [1]. FSO links are low cost, simple and easy to install [2]. Installation is easy because no license is required from FCC for using FSO. Also, there is no time and money wastage in digging the street to lay fiber. But FSO is limited to shorter ranges due to atmospheric turbulences [3]. FSO channel affect the quality of signal due to atmospheric turbulence present, as FSO links are highly dependent on weather conditions. The fog, smoke and rain and scintillations are the form of atmospheric turbulences which degrades the FSO link performance [4]. Many techniques have been proposed to improve the performance of FSO link like aperture averaging, diversity [5] or amplification of signal can be done using optical amplifier [6]. Optical amplification of signal can be achieved by EDFA, Raman or SOA. Most deployed optical amplifier is EDFA because the gain and bandwidth provided by EDFA is very high and due to high bandwidth it can be used for amplification of multiple wavelengths, therefore can be used with WDM network easily. There is always a demand for broader bandwidth communication, which inspired the WDM technique in field of FSO communication. WDM technique started a revolution in optical communication network due to fact that capacity of system can be increased simply by increasing the no. of channels and tightening the channel spacing without using more than one FSO links. So WDM approach can be applied in FSO systems to maximize bandwidth usage but in cheaper way [7-8]. In examining FSO performance, it is important to take several FSO parameters in to consideration. These parameters can be divided in to two parts: internal parameters and external parameters. Internal parameters include optical power, wavelength, bandwidth, Divergence angle and optical loss on transmitter side and BER, receiver sensitivity and receiver field of view (FOV) on receiver side. External parameters are related to environment in which the system must operate. In this paper, we have transmitted the 12.48 Gbps data over FSO link by employing WDM technique. Also, the performance of proposed system is evaluated under the effect of internal design parameter like beam divergence angle. The rest of the paper is organized as follow: section 2 discusses channel model, System description is mentioned in section 3, and Results are discussed in section 4 followed by section 5 which gives the conclusion of this work.

2. FREE SPACE CHANNEL MODE

To observe power at receiver and calculating the link margin, one can determine factors that affect quality of the link. Link margin is ratio of received power P_R and receiver threshold or sensitivity (S) and usually expressed in dB [9-11].

$$\text{Link Margin} = 10\log P_R / S \qquad (1)$$

For signal to be recovered at receiver side, its power must be higher than receiver sensitivity. Sensitivity is usually given by manufacturer and it ranges from -20 to 40 dBm. Power at receiver can be expressed as:

$$P_R = P_T * e^{-\alpha L} * A_{RX} / (\theta L)^2 \qquad (2)$$

Where P_R and P_T are power at the receiver and transmitter respectively, A_{RX} is receiver aperture area, θ divergence angle, α is atmospheric attenuation and L is distance between transmitter and receiver. As shown in equation (2), power at the receiver is directly proportional to the transmit power and receiver aperture area, but inversely proportional to the link range and divergence angle. Exponential part of the equation is related to atmospheric attenuation and it has the strongest influence on the link quality. The received power can be increased by increasing the transmitter power, the receiver area, or by reducing the beam divergence of the transmitter beam. In our simulation work we investigated that as divergence angle is decreased the performance is improved considerably and the reliability of the link increases.

3. SYSTEM DESCRIPTION

The proposed WDM-FSO system consists of 8 independent channels as shown in Fig.1. The eight channel ranges from 193.1 THz – 194.850 THz with a fixed channel spacing of 250 GHz are combined together by using WDM. Each channel has the capacity of 1.56 Gbps data. In the OptiSystem[TM] software, the FSO link is modeled between an optical transmitter with 5cm antenna and optical receiver with 30cm optical antenna at each end. The FSO link is modeled

between an optical transmitter and optical receiver. The attenuation of free space between two connecting FSO nodes is considered as 0.11 dB/km for clear weather conditions. The transmitter and receiver gains are 0 dB by assuming both the antennas ideal. Also, scintillation and mis-pointing losses are not considered in this simulative work. At transmitting end, on each channel, a 1.56 Gbps data is generated by using a Pseudorandom Bit Generator. This data is fed to NRZ encoder and further modulated by using MZM modulator. A CW laser diode of line-width of 10 MHz with power of 0 dBm is used in our proposed system. The outputs of 8 channels at transmitter side are fed to 8x1 multiplexer. The Optical Amplifiers with gain of 13 dB are used as post and pre amplification technique. At the reception side, 1x8 Demux is used to separate each channels. On each channel, the optical signal is received by Avalanche Photo detector having a dark current of 10 nA. Table 1 shows the parameter and their specification taken in to consideration during the simulation.

Design parameter: Any change to design parameter will also change the performance of circuit. Two most significant design parameters considered are the distance and bit rate.

Performance parameter: The performance parameters observed in this simulation are BER, SNR and output power. BER is widely used to measure the performance of communication system. It is the ratio of no. of bit detected with error to total no. of bit transmitted. SNR is ratio of signal power to noise power. The proposed system is optimized to achieve BER=10^{-9} and SNR= 20 dB.

TECHNICAL SPECIFICATION FOR FSO LINK

Table:1

| Parameter	Value
Bit rate of each channel	1.56 Gbps
Channel Spacing	250 GHZ
Total bit rate	12.48 Gbps
TX aperture diameter	5cm
RX aperture diameter	30cm
Amplifier gain	13dB
CW laser power	0 dBm
Range	15 km
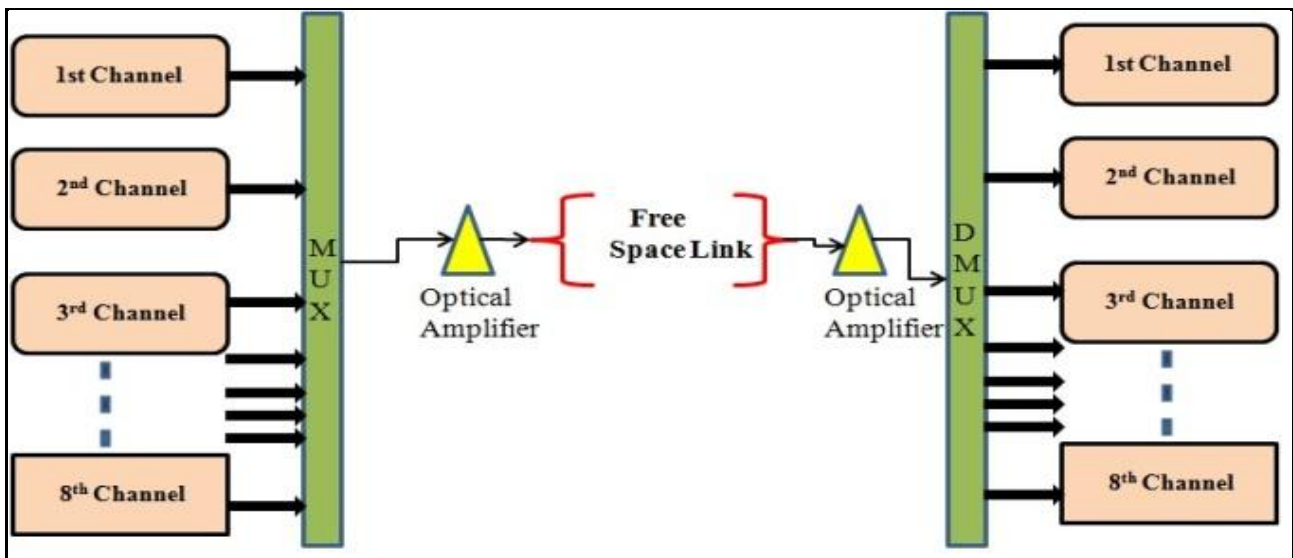
Fig. 1: Proposed -WDM FSO Transmission system

4. RESULT AND DISCUSSION
In this section, the results obtained from our proposed FSO-WDM system are presented. The results are investigated for different beam divergence angle such as 1 mrad, 3 mrad and 5 mrad. It is revealed from Fig.2 that the SNR for channel 1 is degraded on increasing the beam divergence for FSO link from 1 mrad to 5 mrad. A degradation of 25 dB in SNR is reported when the beam divergence is changed from 1 mrad to 5 mrad at FSO link of 15 km.

(a)

(a)

(b)
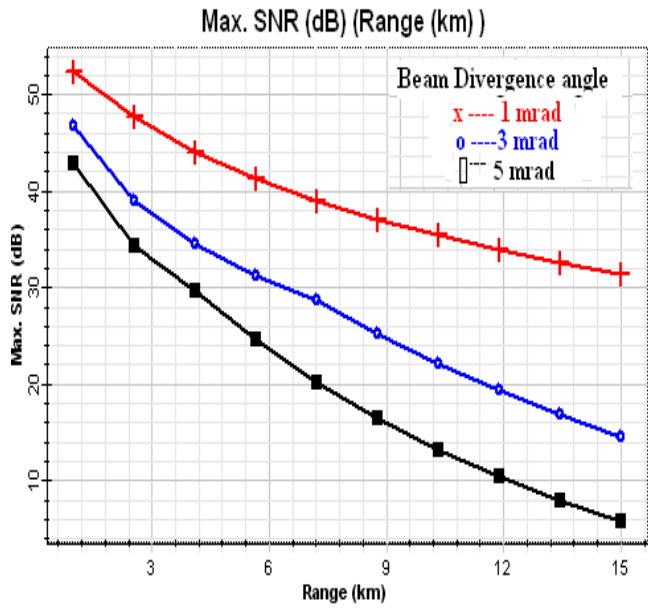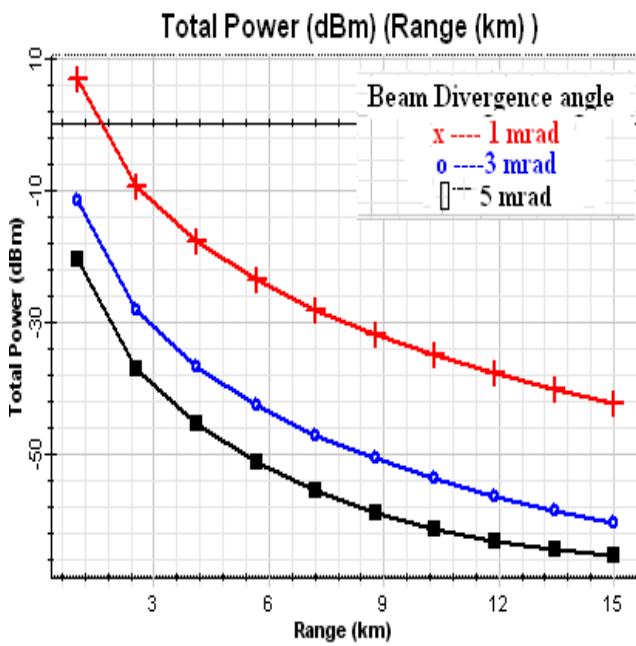
(b)

**Fig 2: Measurement for Beam divergence (a) SNR (b) Total Power**

Consequently the total power received at photo detector is reported in Fig. 2(b) which shows that a degradation of -21 dBm is calculated when beam divergence is changed from 1 mrad to 5 mrad. Similarly eye diagrams are evaluated for channel 1 and channel 8 under the effect of beam divergence are shown in fig.3. The eye diagrams are more précised when beam divergence is set to 1 mrad. As soon as the beam divergence increased, the eye pattern is going to be distorted. Table 2 shows the BER for 8 channels at different value of divergence angle.
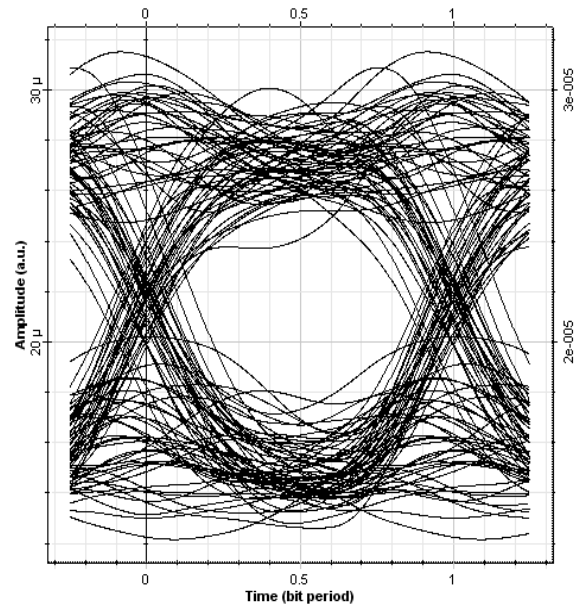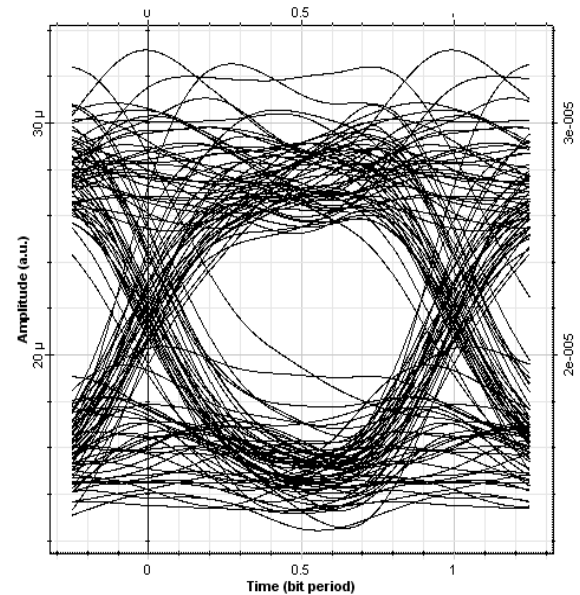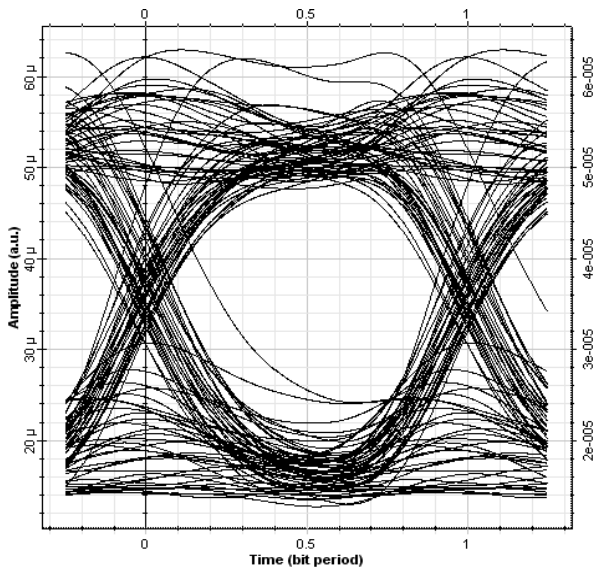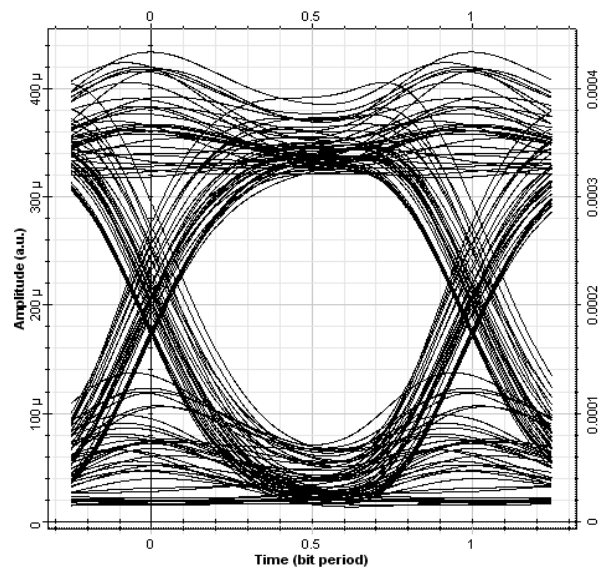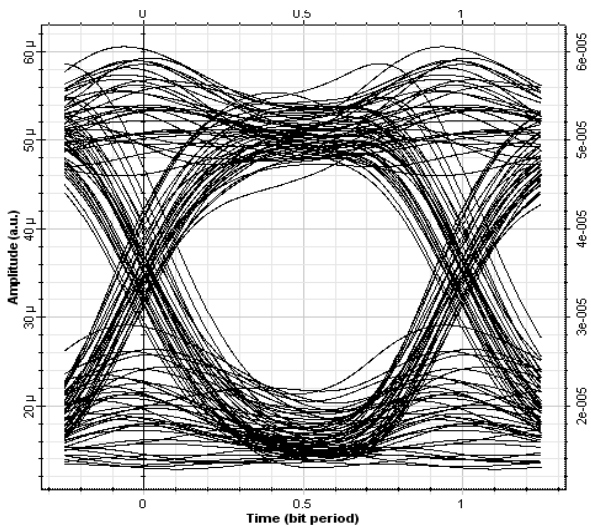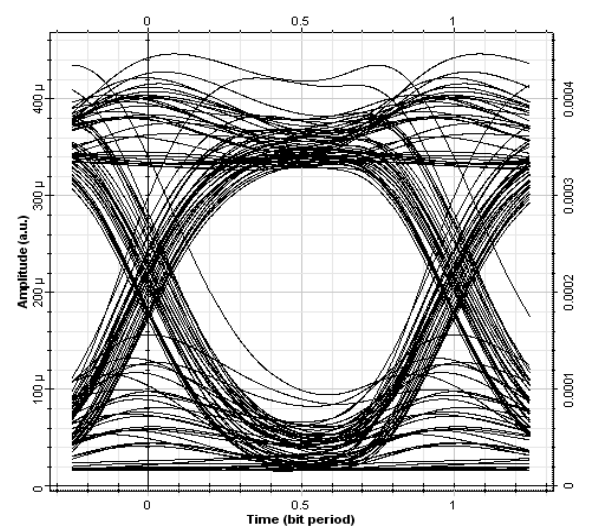
(c)

(e)

(d)

(f)

Fig 3: Evaluation of Eye Diagrams at different beam divergence angles (a) Channel 1 at 5 mrad (b) Channel 8 at 5 mrad (c) Channel 1 at 3 mrad (d) Channel 8 at 3 mrad (e) Channel 1 at 1 mrad (f) Channel 8 at 1 mrad

Table 2: BER for 8 channels at different beam divergence angle

Number of channels	BER at Beam divergence angle		
	5mrad	**3mrad**	**1mrad**
Channel 1	6.7×10^{-7}	2.7×10^{-13}	2.7×10^{-18}
Channel 2	1×10^{-7}	1×10^{-13}	3×10^{-18}
Channel 3	1×10^{-9}	6×10^{-16}	5.4×10^{-19}
Channel 4	9×10^{-8}	2.83×10^{-14}	1.2×10^{-18}
Channel 5	1.7×10^{-9}	1.9×10^{-17}	2.46×10^{-23}
Channel 6	1.7×10^{-8}	4.4×10^{-17}	1.83×10^{-23}
Channel 7	1.9×10^{-7}	5.26×10^{-15}	2.1×10^{-22}
Channel 8	5×10^{-9}	6.7×10^{-17}	4.0×10^{-22}

5. CONCLUSIONS

In this work, we have transmitted 12.48 Gbps by using 8 independent channels having capacity of 1.54 Gbps each channel through FSO link up to 15 km under clear weather conditions. The results are reported under the effect of beam divergence which plays an important role in designing FSO links as atmospheric turbulences. The FSO link for the proposed WDM-FSO system will prolong to 15 km with acceptable SNR and total power when the beam divergence is set to 1 mrad. When the beam divergence changes from 1 mrad to 3 mrad, the FSO link will prolongs to 11 km. Furthermore when the beam divergence increases up to 5 mrad, the FSO link will reduces to 6 km only with acceptable SNR and total power. The simulative results have been shown that divergence 1 mrad offers significantly performance improvement for FSO link compared to 5mrad.

ACKNOWLEDGEMENT

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