Impact of Polarization Interleaving (PI) on WDM-FSO system

Neha Gupta, Dr. Amandeep Singh Sappal

***Abstract*— This work is focused to carry out investigation of WDM Free Space Optical transmission when even and odd channels are orthogonally polarized. In this work 8 independent channels each having capacity of 1.56Gbps are transmitted over free space optical link of 15 kilometer at different beam divergence angles. Systems with and without polarization interleaving are compared here in this paper. Then after WDM-FSO polarization interleaving systems with 16 channels are realized. The bit rate of each channel is increased to 8Gbps and it has been found that WDM-FSO system with polarization interleaving having 16 channels and 128Gbps bitrates of whole system is optimized to work properly up to 25 kilometer range after its comparison with WDM-FSO polarization interleaving system having 8 channels and capacity 12.48 Gbps of whole system. Performance is measured in the terms of Quality Factor and Eye Diagrams.**

***Index Terms*- - Free Space Optics (FSO), Wavelength Division Multiplexing (WDM), Polarization Interleaving (PI)**

I. INTRODUCTION

FSO is a viable solution to exchange data between skyscrapers. FSO system came to existence in response to growing need for high speed and tap proof communication. It full fills the need for high bandwidth and does not require licensed band which mitigates scarcity of spectrum hence provides cost effective solution [1]. Direct Line of Sight offers many advantages as compared to conventional wired and RF wireless communication.

Full duplex communication mode is characteristic feature in FSO systems by mounting on the top of building or even within the building. Besides many advantages of FSO some factors limit the performance of FSO systems like atmospheric turbulence, haze, fog, scintillations and strict alignment requirements [2]. WDM technique with FSO systems, the number channels can be increased hence helps in increasing the capacity of system .WDM technique can also be used to minimize the bandwidth usage [3],[4]. When using WDM with quite a number of channels there may arise a problem of interference between adjacent channels. In examining the performance of FSO system several parameters are to be considered. like optical power, wavelength, beam divergence, receiver sensitivity etc [5].In this paper 12.48 Gbps data is transmitted over FSO link by applying WDM technique and compared with WDM-FSO system with Polarization Interleaving by varying the beam divergence angle from 1 mrad to 5 mrad. Next two FSO-WDM polarization interleaving systems, one with 8 channels and 1.56Gbps bit rate of each channel second with 16 channels and 8Gbps bit rate of each channel are compared. The rest of the paper is organized as follows section II deals with free space channel model, system description is mentioned in section III, design parameters in section IV ,results are shown in section V followed by section VI which is conclusion.

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II. FREE SPACE CHANNEL MODEL

For calculating the link margin and power at receiver one can determine the factors that affect the quality of link, link margin is ratio of received power P_R and sensitivity S and is expressed in Db [6],[7].

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

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

Where P_R and P_T are power at the receiver and transmitter respectively. A_{RX} is aperture area of receiver, θ is beam divergence angle ,L is distance between transmitter and receiver, α is atmospheric attenuation.

III. SYSTEM DESCRIPTION

In FSO by incorporating WDM-PI technique 8 independent channels, each of 1.56 Gbps non return to zero(NRZ) is modulated over light sources of 0 dBm input power operating at 1545 nm through Mach Zehnder Modulator(MZM) .The eight channels are divided into even and odd channels and are applied to two multiplexers separately. The output of two multiplexers is then fed to polarization controller whose function is to set the input signal in arbitrary polarization state. The azimuth and elliptical angle parameters define the polarization state of output signal. In this case output signal is independent of polarization state of input signal.

Considering E_{inx} and E_{iny} as the polarization components of the input signal, the output signal is:

$$E_{out}(t) = \begin{pmatrix} \sqrt{1-k}.\exp(j.\delta_x(t)) \\ \sqrt{k}.\exp(j.\delta_x(t)) \end{pmatrix} . \sqrt{|E_{inx}|^2} + \sqrt{|E_{iny}|}^2 \quad (3)$$

Where k is the power splitting ratio parameter and is the phase difference between the x and y components.

The splitting ratio is:

$$K = (1-\cos(2.\eta).\cos(2.\epsilon))/2 \quad (4)$$

And the phase difference is:

$$\delta_{yx} = arc\ sin \left(\frac{\sin(2.\epsilon)}{2.\sqrt{k.(1-k)}} \right) \quad (5)$$

The x and y phase components are derived from

$$Sf = \frac{\delta_x - \delta_{inx}}{\delta_y - \delta_{iny}} \quad (6)$$

Where Sf is the symmetry factor.

For sampled signals Equation 3, Equation 4, and Equation 5 describe the output signal. The following Stokes representation describes parameterized and noise bins signals:

$$S_{out} = \left(|E_{inx}|^2 + |E_{iny}|^2\right) \begin{bmatrix} 1 \\ \cos(2.\varepsilon) \, . \cos(2.\eta) \\ \cos(2.\varepsilon) \, . \sin(2.\eta) \\ \sin(2.\varepsilon) \end{bmatrix} \quad (7)$$

The polarized channels are again multiplexed and sent over FSO link to receiving section which comprises of 8 avalanche photodiodes(APDs) that detect the demultiplexed signal followed by Bessel low pass filter with cut off frequency of 9.36 Gbps. Then after 16 channels each of 8 Gbps after polarization interleaving are sent over FSO link . Table 1 shows the parameters and their specifications taken into account during simulation.

Table I: Simulation Parameters

PARAMETER	VALUE
Bit rate of each channel	1.56 Gbps
Channel Spacing	250 GHz
Total bit rate	12.48 Gbps
Tx aperture diameter	5 cm
Rx aperture diameter	30 cm
Amplifier gain	13 dB
CW laser power	0 dBm
Range	15 Km

I. DESIGN PARAMETERS

Performance of circuit is changed if any design parameter is changed. Most significant design parameters are bit rate, distance and number of channels.

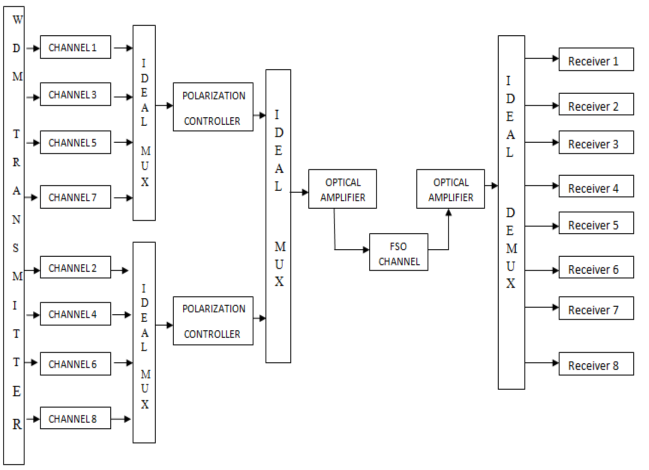


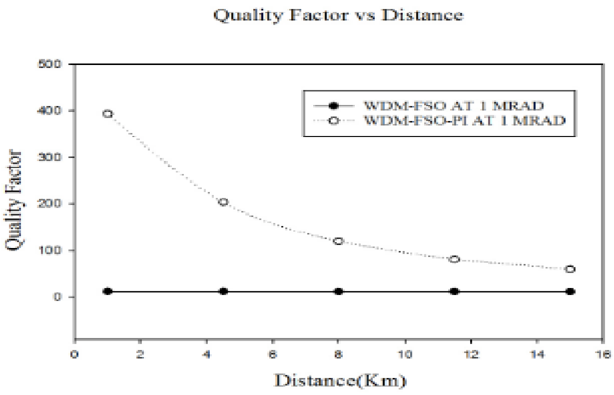
Fig 1. Block Diagram of proposed WDM-FSO-PI System.

IV. RESULTS AND DISCUSSION

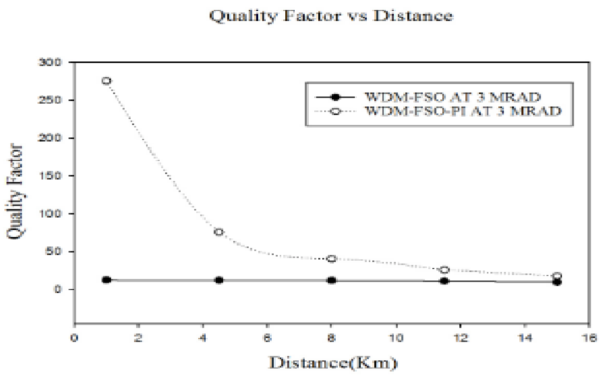
In this section the results obtained from comparison of proposed WDM-FSO-PI system and WDM-FSO system are presented. The results are investigated for different beam divergence angles such as 1mrad, 3mrad, 5mrad.

Table II. Values of Q factor vs Distance at different beam divergence angles.

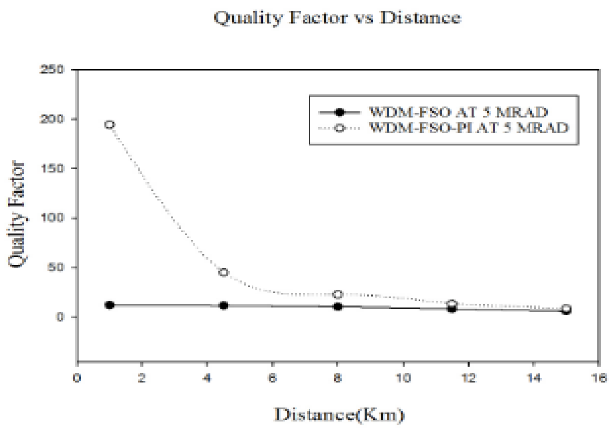
DISTANCE (KM)	QUALITY FACTOR					
	WDM-FSO at 1 MRAD	WDM-FSO-PI at 1 MRAD	WDM-FSO at 3 MRAD	WDM-FSO-PI at 3 MRAD	WDM-FSO at 5 MRAD	WDM-FSO-PI at 5 MRAD
1	12.4025	393.455	12.3852	275.41	12.3594	194.51
4.5	12.3636	203.83	12.1643	75.6986	11.8284	45.0757
8	12.294	119.956	11.7043	40.4227	10.584	22.8796
11.5	12.191	81.2436	10.9112	25.8829	8.50641	13.5089
15	12.0453	59.5112	9.703	17.6649	6.15261	8.62748



(a)



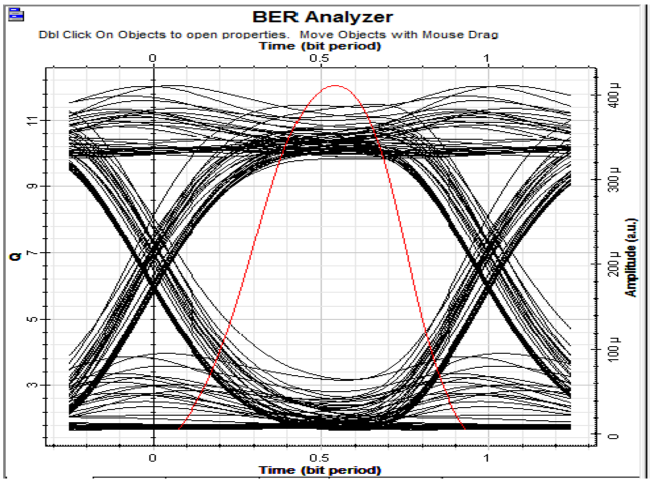
(b)



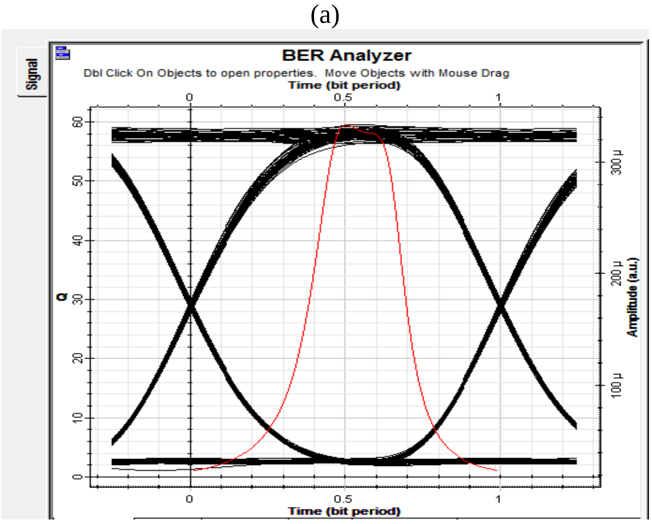
(c)

Fig (a), (b), (c): comparison between WDM-FSO and WDM-FSO-PI systems at 1 mrad, 3 mrad and 5 mrad respectively.

On comparison of WDM-FSO-PI system with WDM-FSO system without polarization interleaving ,it is found that although the quality factor degrades as beam divergence angle increases but it improves approximately 32 times in case of WDM-FSO-PI as compared to WDM-FSO up to a distance of 15 Km.

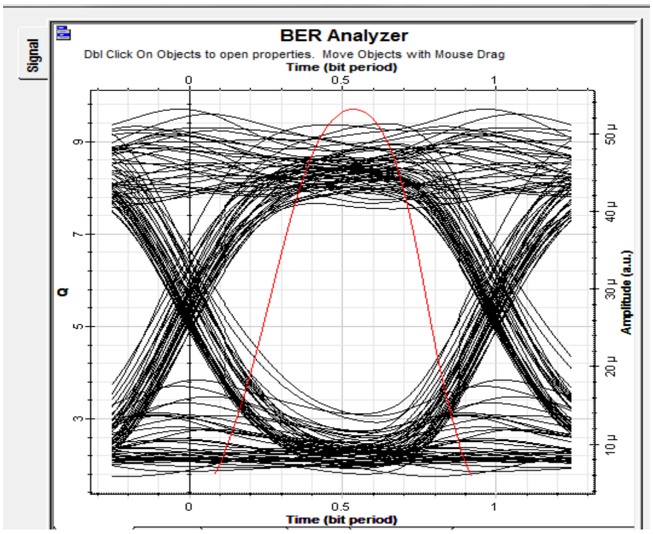


(a)



(b)

Fig (a), (b) Eye diagrams showing comparison of WDM-FSO system and WDM-FSO-PI system at 1 mrad respectively.



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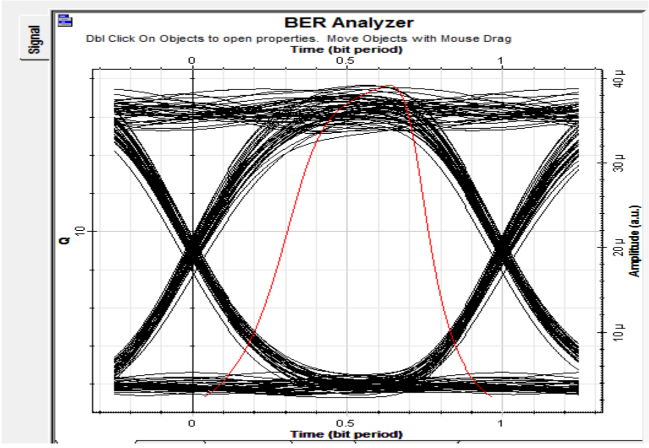
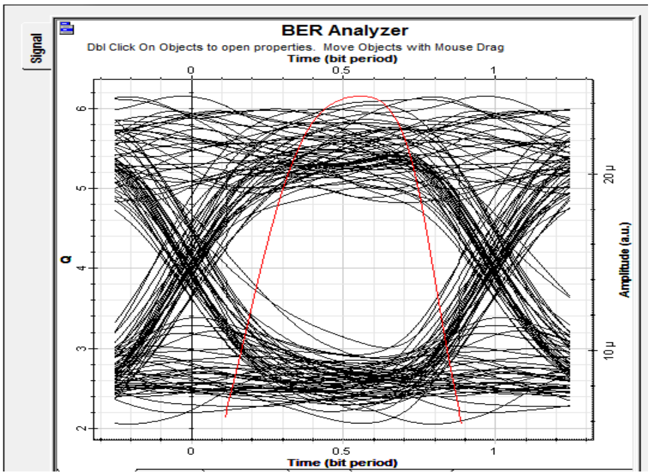
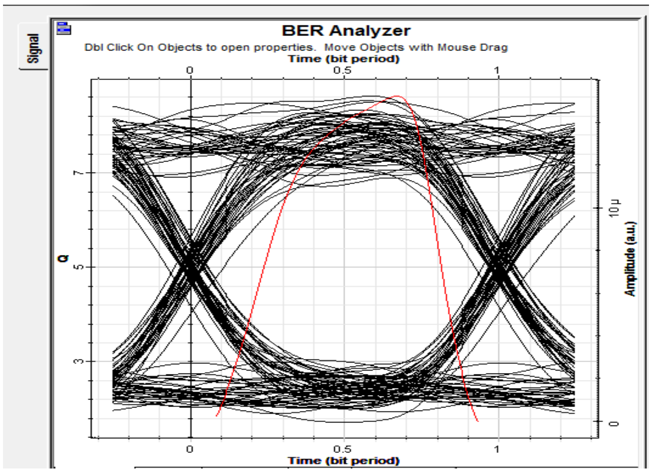


(d)

Fig (c), (d) Eye diagrams showing comparison of WDM-FSO system and WDM-FSO-PI system at 3 mrad respectively.



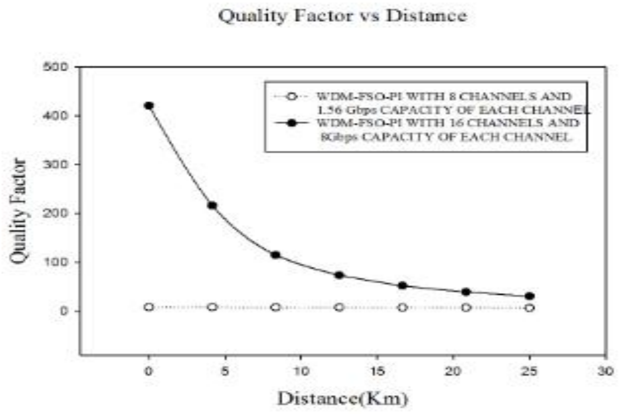
(e)



(f)

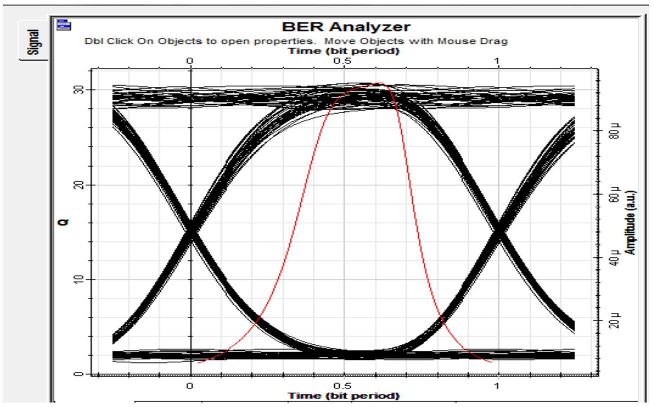
Fig (e), (f) Eye diagrams showing comparison of WDM-FSO system and WDM-FSO-PI system at 5 mrad respectively.

Then on increasing the bit rate of each channel to 8Gbps and also the no. of channels to 16 in WDM-FSO-PI system, it is observed that in comparison to WDM-FSO-PI system with 8 channels each of capacity 1.56Gbps no matter the quality factor degrades but the system prolongs to 25 Km range with acceptable quality factor.

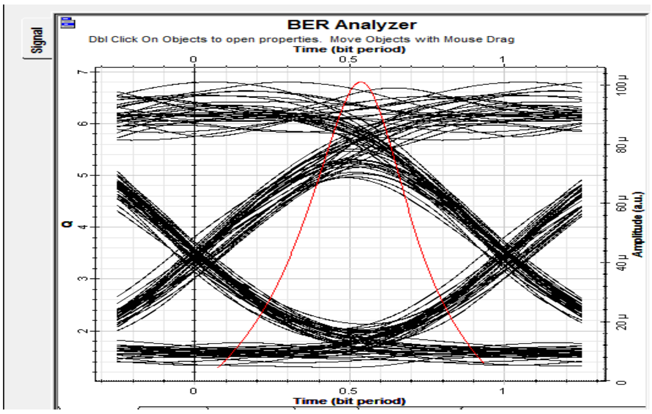


(a)

Fig (a) Comparison of WDM-FSO-PI system with 8 channels, system capacity 12.48Gbps and WDM-FSO-PI with 16 channels, system capacity 128 Gbps.



(a)



(b)

Fig 2 Eye Diagram of WDM-FSO-PI system a) 8 channels each of capacity 1.56 Gbps at 25 km b) 16 channels each capacity of 8 Gbps at 25 Km

V. CONCLUSION

In this paper, a high speed hybrid WDM-FSO-PI system is designed which shows a great improvement in quality factor in comparison to WDM-FSO system due to mitigation of interference of contiguous channels. Simulative result show that 1mrad beam divergence angle offers significant performance improvement for WDM-FSO-PI link compared to 5 mrad. There is a tradeoff between system capacity and quality factor as well as range up to which the FSO link works satisfactorily .WDM-FSO-PI with 16 channels and 128Gbps system capacity attains the quality factor of 6.80072 at 25Km link length and WDM-FSO-PI system with 8 channels and 12.48Gbps system capacity attains the quality factor of 30.7482 at 25Km range . Hence the system is optimized and prolongs to 25Km when 128 Gbps system capacity and 16 channels are used.

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