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Understanding the Performance Analysis of Free Space Optical Communication using Red Laser-650nm Wavelength

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Abstract— **Free-space optical communication system (FSO) is an optical communication technology which uses air as a medium to transmit signal from one place to other in the form of light propagating in free space to wirelessly. The word "Free space" means outer space like vacuum, air or something similar. Light sources can be either LEDs or lasers (light amplification by stimulated emission of radiation). FSO is a simple concept that is similar to optical transmission using Fiber-optic cables. FSO meets the need of modern wireless communication by providing safer and high speed connectivity. License free operation, low cost, high security and long range are some of its various features which add to its usefulness. In this research paper FSO link is optimized for operation under 650nm wavelength. Simulation results provide proposed FSO link for a long range communication link more than 1000 meter with increased data rate of up to 3Gbps and more. Also the performance of proposed link can be improved for sustainability of communication channel in normal and critical weather condition, which can be evaluated on the basis of parameters like Q factor, BER , eve diagram and eve height. For θdiv 0.3 mrad and θdiv 0.6 mrad the achieved values of Bit Error Rate (BER) is 10^{-32} and 10^{-30} and Quality Factor (Q) are11.71 and 11.45 respectively.**

Keywords— Q factor, BER, Attenuation, , Divergence angle (θ_{div})

I. INTRODUCTION

Free-space optics, as the name implies, means the transmission of optical signals through free space or air. FSO is an independent protocol that can be fixed to any network topology. The Open System Interconnect (OSI) for FSO is under physical layer. FSO link is mainly depends on geometric and atmospheric attenuation. The geometric attenuation can be controlled by changing the parameters like transmitter diameter, divergence angle and link distance etc. the Atmospheric attenuation depend largely on weather conditions like fog and rain [1]. It can be reduced by proper choice of the parameters like modulation techniques, wavelength and attenuation coefficient. The FSO technology is very useful where the physical connections are impractical due to high costs or some other considerations.

Such propagation of optical capacity through air requires the use of light FSO systems which are generally point-to-point links between buildings on the campus or different buildings of a company can be used to setup wireless communication networks or to supplement radio and optical fiber networks.

Generally medium for short-range links is infrared radiation designed to operate in the windows of 780~850 and 1520~1600 nm using resonant cavity light emitting diodes and laser diodes.

Generally 1550nm lasers are preferred as they provide larger range, high data rate in 20-40 Gbps range and supports high power beam levels. Eye safety and long life are essential features of 1550nm lasers [2]. Also effects of solar noise are less at 1550nm region. 850nm and 1310nm lasers are not preferred as beam has low power, less range and speed of about 2.5 Gbps only [3]. Other two wavelengths used are 750nm (near IR) and 10 µm. The 10 µm lasers are expensive but provide high switching speeds and 750nm lasers are cheaper, consume less power and supports low data rates [2-3]. Transmit telescope collects the light, adjust the line of sight and directs the beam towards receiver.

Visible light communications comprise a technology for transmission of information using light that is visible to the human eye. This research paper proposes a FSO system using red laser 650nm wavelength as communication medium for short range. The possibility is based on tremendous technical advances of available components at low cost and efficient modulation techniques. Pang *et al*.(1999a; 1999b;2002) and Pang (2004) built a system made up of high brightness visible

LEDs which reaches over 20 m outdoors and can provide the function of open space, wireless broadcasting of audio or data signal[4]. High power stable and continuous operation semiconductor LED at 650 nm has been developed for a long time, and is commonly used in optical access and storage system, laser printer or as indicators. A new feature of frequency modulation has been utilized as well due to their low cost and small size. In order to realize this system, study of atmospheric channel concerning red light laser ray is required. It is concluded through numerical analyses that visible laser beam can be used for terrestrial short-range FSO links. Performance parameters of the proposed system were evaluated in detail and experimental system was described finally.

II. ARCHITECTURE

In Figure 1 shows the Block diagram of FSO system [05]. In FSO architecture basically consist source, transmitter, receiver and atmospheric channel. Where the message originates and fed the input signal to modulator and producing data input that is transmitted towards a remote destination is called source.

The modulator is a part where input signal modulate in the form of optical pulses using different – different types of technique like: AM, FM, OOK, PM, IM etc. for achieving high data rate we need to vary phase, amplitude and frequency. FSO system has been operated in the near IR wavelength range between 750 and 1600nm. These wavelengths are chosen according to the requirement of the system. At 780 nm, inexpensive CD lasers are available, but the average lifespan of those lasers is an issue. Around 850nm, reliable, inexpensive, high performance transmitter and detector components are there like Silicon avalanche Photo Diode (APD) is which VCSEL technique can be used and whose disadvantage is that the demodulation of beam is not possible with this technique [6]. These wavelengths are good for FSO, because of high quality transmitter and detector components. WDM is used in this because of which we can be able to get more data due to multiplexing but interference increases in this technique. Ultimately 50-65 times as much power can be transmitted at this frequency that can be transmitted at 780-850nm for the same eye safety [7]. Generally the equipment works at one of the wavelength 850nm or 1600nm. Lasers operating at 850nm are much less expensive so are used for applications over moderate distances. Controlled Pump laser use as a optical source. Laser pumping is the act of energy transfer from an external source into the gain medium of a laser. The energy is absorbed in the medium, producing excited states in its atoms. When the number of particles in one excited state exceeds the number of particles in the ground state or a less-excited state, population inversion is achieved. In this condition, the mechanism of stimulated emission can take place and the medium can act as a laser or an optical amplifier. The pump power must be higher than the lasing threshold of the laser. [8].

While signal transmission the data signal is modulated with a carrier signals so that it can be transmitted over a channel. During a transmission of signal over a channel, then it experiences fluctuations in amplitude and phase, known as scintillation which may be due to change of refractive index in different weather conditions. It effects the FSO communication and reduces the performance. To improve the BER performance of a link due to scintillations different modulation approaches used, selection of appropriate modulation schemes is an important factor which determines the overall system performance. The On-Off shift keying is the simple and widely adopted modulation scheme. In this a transmitted 1 is on and transmitted 0 is off. From the view point of the receiver, RZ has been reported to offer better performance over NRZ in FSO links [9]. Due to higher peak power, a higher S/N ratio, a lower bit error rate than NRZ encoding, the RZ coding mostly used[7].RZ pulses always create distinct transitions between encoded bits (ones being „on" and zeros being „off") and thus create a much cleaner optical signal for the receiver to read [7]. It has simple receiver design, bandwidth efficiency and cost effectiveness. The improved modulation techniques are DPSK, DQPSK etc. but due to simplicity OOK technique is best known.

In Adaptive modulation technique the channel conditions are estimated at the receiver side and feed this signal to the transmitter using an RF feedback channel, so that the transmitter can be adapted relative to the channel conditions. For error free and long distance transmission Adaptive modulation is a term is very useful. In this technique there is an RF backup channel which is used to provide communication under severe atmospheric conditions if some signal loss is there [10]. In this way the performance of a channel is improved using the RF feedback.

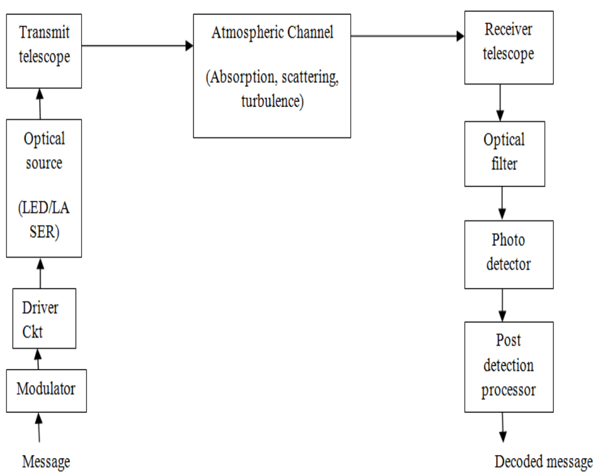

Fig.1 Block Diagram of FSO [5]

The transmitter is the combination of Driver circuit, Optical source and Transmit Optics shown in fig 1. LEDs and Laser diodes are basic semiconductor devices that are mostly used as a optical transmitters. LED is produced incoherent light. Therefore, due to their simple design, LEDs are very useful for low-cost applications. Semiconductor laser produce coherent light. The major difference between LEDs and Laser is that LEDs produce incoherent light, while laser diodes produce coherent light.Transmit telescope collects the light, adjust the line of sight and directs the beam towards receiver.

A free space link between transmitter and receiver is called Atmospheric channel. It is open channel so that there are number of factors that affect the signal like its data rate, long range connectivity and error rate also. The main factors that affect the signal are absorption, turbulence, scattering and beam divergence etc. It also contains a telescope fitted with a lens that collects maximum light to provide maximum power to photo detector and also a optical filter is used to reject some unwanted noise or signal that added during reception of the signal. The misalignment between transmitter and receiver telescope occurs due to the deviation of link from line of sight path. This can cause pointing error of several micro radians resulting in a huge power loss [11].

At the receiver end there are basically two types of optical receivers that can use: non-coherent receivers and coherent receivers. The non-coherent receiver is that directly detect the instantaneous power that receive at the end of receiver, A coherent receiver is optically mixes a locally generated light wave field with the received field, and the combined wave is photo detected. These receivers are used when information is modulated onto the optical carrier using PM, FM or AM. At the receiver side Avalanche Photo Diodes (APD) or P- I -N diodes. APDs used as a photo detector.

The photo detector converts the received optical field to an electronic signal, which is demodulated. The demodulator output signal is de interleaved and decoded. The decoded bits are fed into an information sink. In an optical communication system through the turbulent atmosphere, the intensity $P(u, t)$ of the received optical signal can be written as[12]

$$P(u,t) = A(u,t)P_s(t)$$

where $A(u, t)$ is a stationary random process for the signal scintillation caused by the atmospheric turbulence, u is an event in the sample space, and $Ps(t)$ is the received optical intensity in the absence of turbulence.

Normally 1550nm lasers are preferred as they provide larger range, high data rate in 20-40 Gbps range and supports high power beam levels. Eye safety and long life are essential features of 1550nm lasers [12]. Also effects of solar noise are less at 1550nm region. 850nm and 1310nm lasers are not preferred as beam has low power, less range and speed of about 2.5 Gbps only [13]. Additional two wavelengths used are 750nm (near IR) and 10 µm. 10 µm lasers are expensive but provides high switching speeds and 750nm lasers are cheaper, consumes less power and supports low data rates. Author HU GUO [4] and Gaurav Soni had used visible light for communication of short distances like 650nm [14]. The wavelength window 1300nm – 1400nm or higher are affected by absorption due to water, carbon dioxide, oxygen and other gases also. But 650nm region is only sensitive to oxygen and carbon dioxide, thereby giving advantage over others. It provides high switching speeds, cheaper, consumes less power and supports low data rates. A simulation model has been proposed in this paper to use 650nm for slightly longer range.

III. COMMUNICATION LINK ANALYSIS

a) Link Margin:

For calculating the link margin and Observing power at the receiver, one can determine factors that affect quality of the link. Link Margin is a ratio of the received power P_R and receiver threshold(*s*) it's usually expressed in decibels.

$$LM = 10 \, Log \, P_R / S \quad (1)$$

Receiver threshold is usually given by manufacturer and it ranges from -20 to -40 dBm. Power at the receiver [15] ,[16] can be expressed as:

$$P_R = P_T * ARX \, / \, (\theta L)^2 * e^{\alpha L} \quad (2)$$

where: P_R and P_T are power at the receiver and transmitter respectively, A_{RX} is receiver aperture area, θ divergence angle, α atmospheric attenuation and L distance between transmitter and receiver. As shown in the equation (2),[16] equation (2) is defined as 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. Another factor that adds to attenuation of the signal is beam divergence.

The link margin of an FSO link will decrease with increasing rain rate, which is measured in mm/hr of rain, attenuation due to fog,haze.

b) Link Power:

Free Space Optics (FSO) system performance can be characterized by four main parameters
•Total transmitted power
•Transmitting beam width
•Receiving optics collecting area
• Receiver sensitivity

The relation between transmitted power and received power is given by the equation1 below [4]:

$$P_{Reciever} = P_{Transmitter} \quad (D^2/L^2\theta^2 div) \quad 10\text{-}\gamma L/10 \quad \tau transmitter \; \tau receiver \quad (1)$$

Where $P_{Reciever}$ is the Power received (dBm) at the receiver , $P_{Transmitter}$ is the Power transmitted (dBm), D is diameter of receiver, θdiv is divergence angle; is atmospheric attenuation factor (dB/km), τtransmitter and τreceiver are respective optical efficiencies. Each FSO terminal has a loss of 1.8 dB at transmitter and receiver. According to Beers-Lambert Law [17]

$$L = E\text{-}\sigma l \quad (2)$$

Where l (km) is the range of the laser transmittance and σ is the typical attenuation coefficients (0.1 for clear air).Power budged model for FSO link is given by in relation 3 [1]:

$$P_{Reciever} = P_{Transmitter} - \alpha sys - \alpha atm \quad (3)$$

Where α atm is the total atmospheric attenuation, α sys is]the system attenuation. The transmission and dispersion loss also depends on distance if the distance increases, the transmission and dispersion loss also increases and the power goes to decreases.

IV. PERFORMANCE EVALUATION

In this section we shall consider the situation of optical propagation in detail between two points in terrestrial applications for proposed FSO link. The simulator used is optisystem. A low power red light laser diode, optical amplifier and a Si photodiode were employed with parameters given in Table 1 together with other parameters supposed in this simulation.

Parameter	Value
Laser	Controlled Pump Laser
Wavelength	650 nm
Data Rate	3 Gbps
Threshold Current	20 ma
Link Range	2020 meter
Modulation	NRZ
Divergence angle (θ_{div})	0.3 mrad
Slope efficiency	0.5 W/A
Transmitter Aperture diameter	7cm
Receiver Aperture diameter	13cm
Transmitter Loss	-1dB
Receiver Loss	-2dB
Additional Attenuation	-23dB/Km
Geometric Loss $\alpha_{geometric}$	-7.26 dB
Maximum Current	300 ma

Table 1: Simulation Parameters

In Transmitter section contain pseudo random bit sequence generator, NRZ pulse generator block and Controlled Pump Laser. The function pseudo random pulse generator is generates the random bits as per required bit rate. The NRZ modulator generates electrical pulses in non return to zero formats. In NRZ method, transitions from logic 0 to logic 1, and vice versa, directly across the zero voltage level. The Controlled Pump Laser is use to modulate the optical signal and transmit through FSO channel. We have set the wavelength to 650nm that produces visible red laser beam. The FSO channel in which provision is provided by simulator to change parameters of free space like link range, attenuation etc. For analyze the optical power, between transmitter and receiver simulator provides power meter and spectrum analyzer tools that are connected at transmitted and receiver side to evaluate performance of the link. Further for improving the signal strength and manage Q and BER we add optical amplifier between FSO channel and Photo detector The simulator proves to be powerful and much comparable to practical conditions as it provide provision for adjusting parameters like power transmitted, bit rate, noise bandwidth, range, geometric and additional losses, propagation delay and types of diodes along with their responsively. Some efficient feature are available in Red laser like cheaper, consume less power, high switching speed and also supports low data rates due to that red laser beam is used here [4].By simulation of free space optical link has been done to study the performance of the system Different parameters of link are varied and adjusted according to the existing conditions. The simulation parameters of proposed FSO link are shown in Table 1. The results are obtained for different values of parameters like divergence angle θ_{div}, Receiver aperture diameter, Attenuation etc. We achieved maximum range up to 2020 meters with 650nm red laser and data rate of 3Gbps. The value of θdiv selected is 0.3 mrad. The link has been optimized under attenuation values of -23 dB/km. We shall also include transmitter and receiver loss 1dB and 2 dB respectively. The link can tolerate geometric attenuation $\alpha_{geometric}$ of – 7.26 dB. The reference value of Q is 9.46 with an acceptable BER of 10^{-23}. The total attenuation that the proposed link can tolerate is -30.26dB [14].

V. SIMULATION RESULT AND DESCRIPTIONS

An experimental performance analysis using simulation of the proposed FSO link using Optical amplifier, NRZ modulation Scheme is carried out and optimized results are discussed.

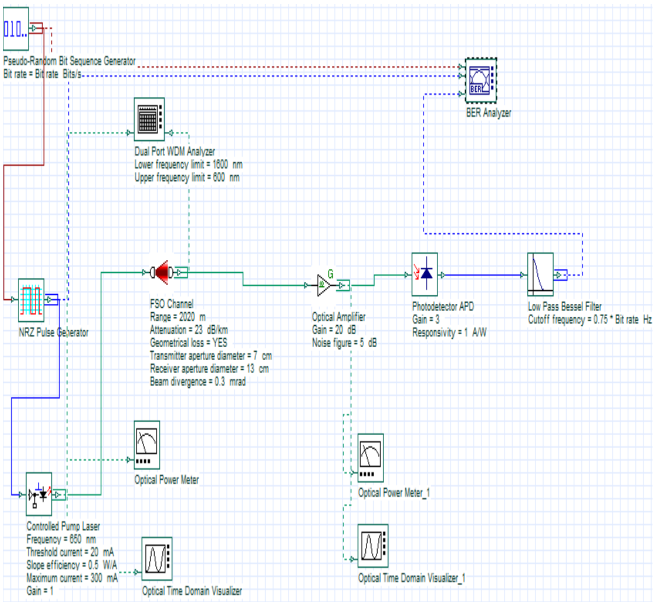

Figure 2: Proposed FSO Link

In figure 2 shows the proposed FSO link. The transmitter laser source was a 5 mW at wavelength 650 nm operating at temperature of 25 °C. The FSO channel include optical amplifier with 20dB gain and Noise Figure 5dB respectively. The main purpose of amplifier to amplify the signal and increase strength of signal at receiver end. The receiver electronic structure includes photo-PIN-diode, amplifier and Data-interface. The transmission experiment was performed outdoors be with divergence angle θdiv is 0.3mrad and 0.6mrad respectively, attenuation of 23dB/km and receiver aperture 13cm, In reference paper [14] BER & Q factor was 1.41*$10^{-23}$and 9.46 respectively with link range up to 1000 meters with divergence angle θdiv is 0.3mrad and data rate 1.25Gbps.

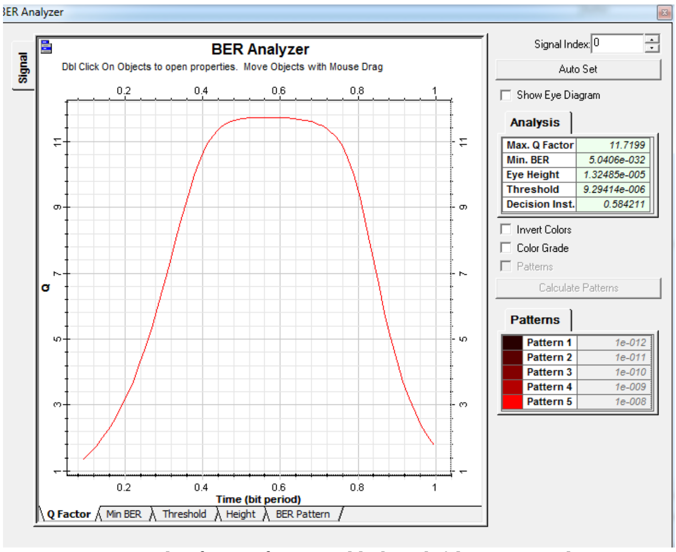

Figure 3: BER and Q factor of proposed link with θdiv =0.3mrad up to 2020 meters using CPL.

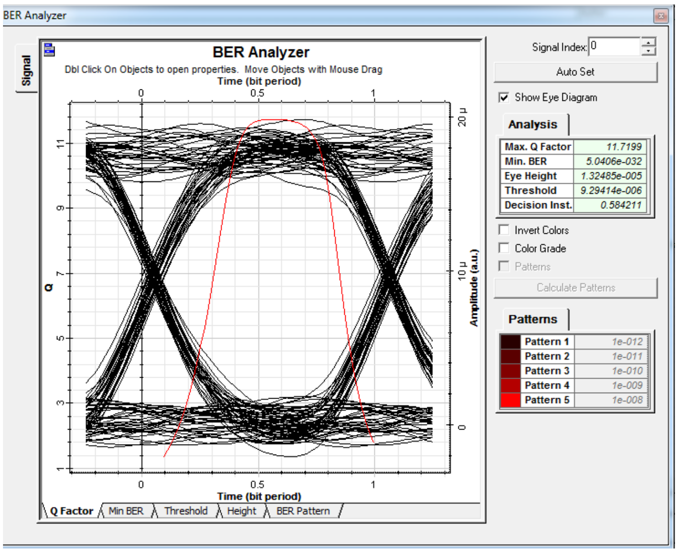

Figure 4: EYE Diagram of Proposed FSO link with θdiv =0.3mrad up to 2020 meters using CPL.

In Figure 3 and Figure 5 shows the BER and Q factor of proposed link with θ_{div} 0.3 mrad and θ_{div} 0.6 mrad respectively For θdiv 0.3 mrad on optimized FSO link the BER attained is 5.04*10^{-32} and value of Q is 11.71 with link range 2020 meters at data rate of 3Gbps. For θdiv 0.6 mrad BER attained is 1.09*10^{-30} and Q is 11.45 for with link range 1820 meters at data rate of 3Gbps. In Figure 4 and Figure 6 shows the eye Diagram for θdiv 0.3 mrad and θdiv 0.6 mrad respectively. The black lines shows the eye diagram and red line indicates BER curve and shows BER curve of the specified link of attenuation 23dB/km having range 2020 meters and 1820 meters respectively.

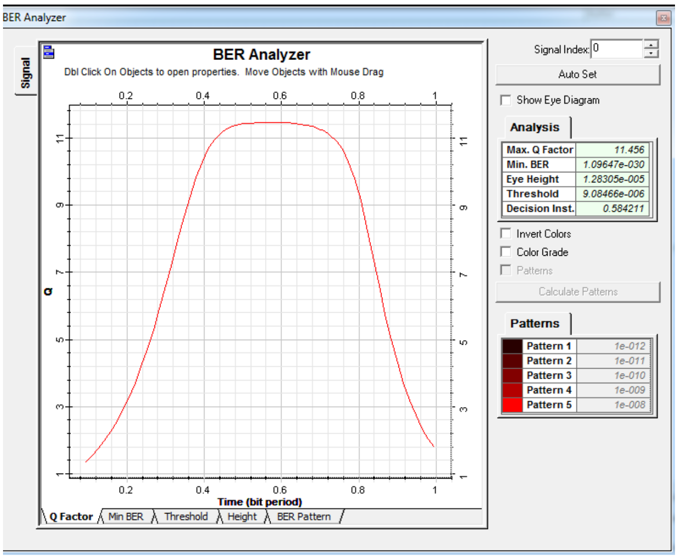

Figure 5: BER and Q factor of proposed link with θdiv =0.6mrad up to 1820 meters using CPL.

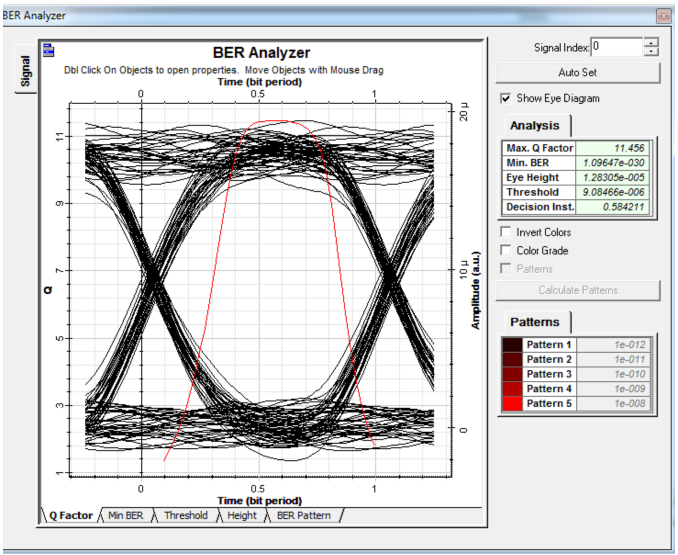

Figure 6: EYE Diagram of Proposed FSO link with θdiv =0.6mrad up to 1820 meters using CPL.

The permissible BER & Q factor was 1.41*$10^{-23}$and 9.46 respectively in reference paper for θdiv is 0.3mrad with link range 1000 meter and data rate 1.25Gbps [14]. Therefore for θdiv 0.3mrad and 0.6mrad we attained BER 5.04*10^{-32} and 1.09*10^{-30}, Q is 11.71 and 11.45, with link range 2020 meters and 1820 meters respectively at data rate of 3Gbps which are in permissible limits.

Therefore Use of low-cost red light laser diode for short distances makes this link interesting for private users. By using Red light 650nm laser Good reliability and availability can be achieved by using this system for short distances. This shows that the link is stable and can be used for given data rates and even higher. The eye diagram in Figure 4 and Figure 5 shows that the signal has been received with less or no error. It has an eye opening of 1.32*10^{-005} and 1.28 10^{-005} for θdiv 0.3mrad and 0.6 mrad respectively.

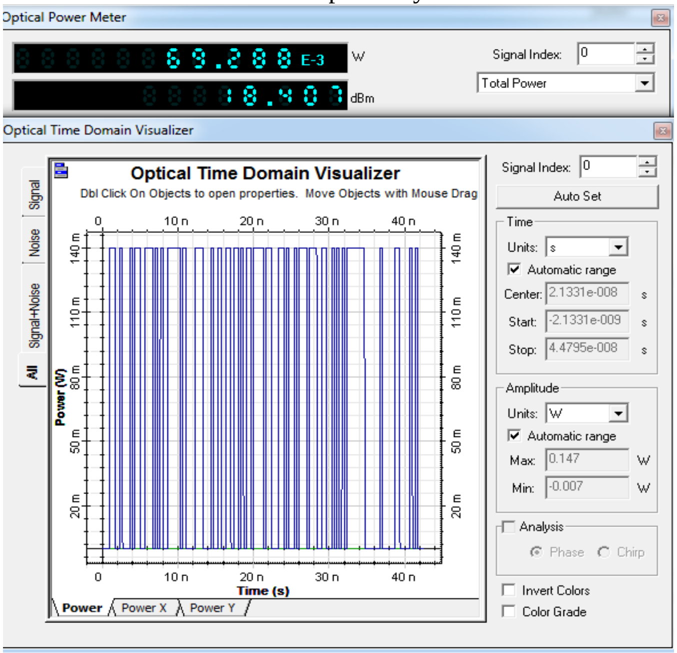

Figure 7: Transmitted Optical Power for Link Range 2020 meters and 1820 meters at θdiv= 0.3mrad and θdiv = 0.6mrad using CPL.

Figure 7 shows transmitted optical power spectrum of the optimized link for length 2020 meters. The spectrum of the transmitted power also shows the peak wavelength at 650nm. Optical power transmitted is 69.20*10^{-3} Watts calculated by the power meter. For analyzed the loss of optical power at receiver end can be calculated by using the spectrum analyzer at receiver end.

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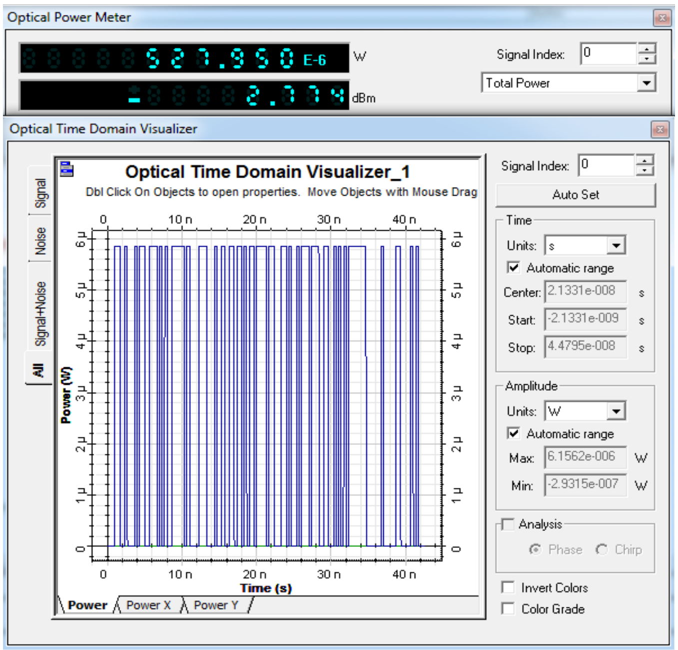

Figure 8: Received Optical Power for Link Range 2020 meters at θdiv= 0.3mrad using CPL.

Figure 8 shows received optical power spectrum of the optimized link for length 2020 meters at θdiv= 0.3mrad. Optical power received is 527.95*10^{-6} Watts calculated by the power meter.

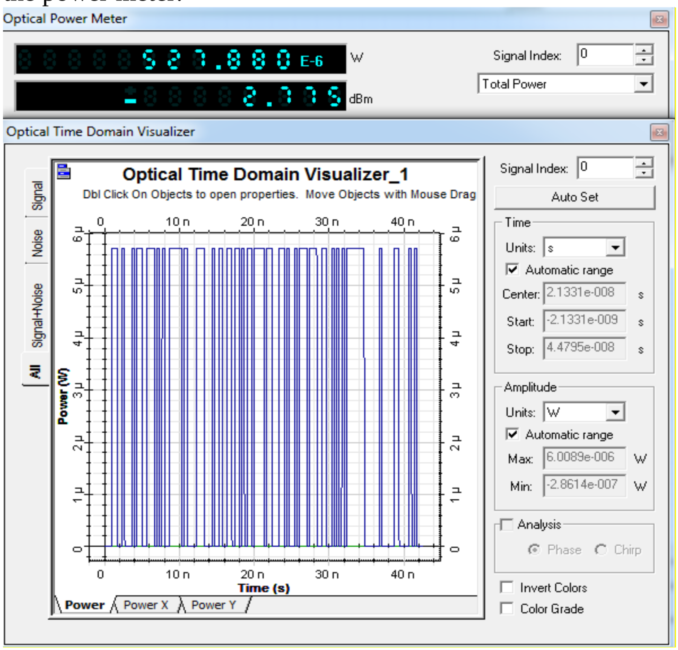

Figure 9: Received Optical Power for Link Range 1820 meters at θdiv= 0.6mrad using CPL

In Figure 9 shows received optical power spectrum of the optimized link for length 1820 meters at θdiv= 0.6mrad. Optical power received is 527.88*10^{-6} Watts calculated by the power meter.

The spectrum of the Received power also shows in Figure 8 at θdiv is 0.3 mrad and Figure 9 at θdiv is 0.6 mrad respectively by using Optical Time Domain Visualizer also shows the peak wavelength at 650nm. The result shows the reducing of optical power to a great extent after travelling a distance of 2020 meters and 1820 meters for θdiv is 0.3mrad and 0.6mrad respectively.

VI. COMPARISON OF LASER SOURCES (DIRECTLY MODULATOR LASER AND CONTROLLED PUMP LASER) FOR THE PROPOSED FSO LINK

In this section, the comparison of link performance for directly modulator Laser and Controlled pump laser is studied. In Figure 3,4,7,8 show the BER, Q ,Eye diagram, Transmitter Power and received Power result by using Controlled pump laser at θdiv is 0.3mrad and Figure 5,6,7,9 show the BER, Q ,Eye diagram, Transmitter Power and received Power result by using Controlled pump laser at θdiv is 0.6mrad with NRZ modulation.

In figure 10,11,12,13 show the BER, Q ,Eye diagram, Transmitter Power and received Power result by using directly modulated laser at θdiv is 0.3mrad and Figure 14,15,12,16 show the BER, Q ,Eye diagram, Transmitter Power and received Power result by using directly modulated laser at θdiv is 0.6mrad with NRZ modulation.

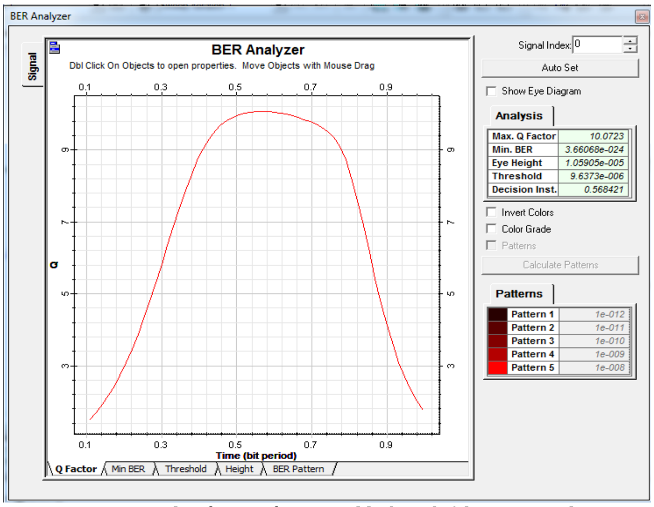

Figure 10: BER and Q factor of proposed link with θdiv =0.3mrad up to 1500 meters using DML.

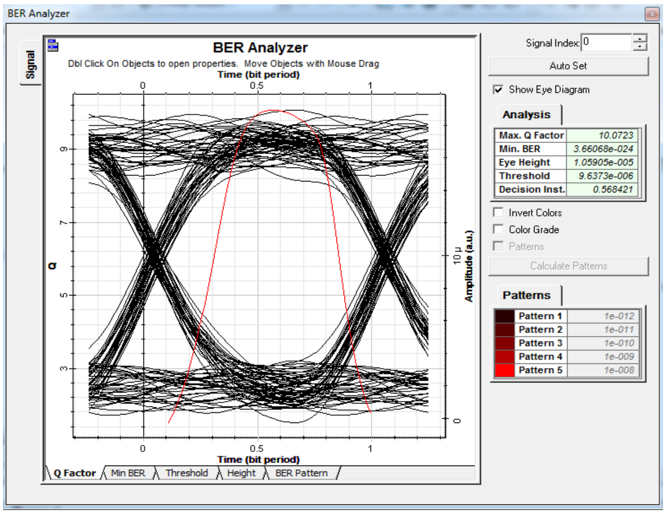

Figure 11: EYE Diagram of Proposed FSO link with θdiv =0.3mrad up to 1500 meters using DML.

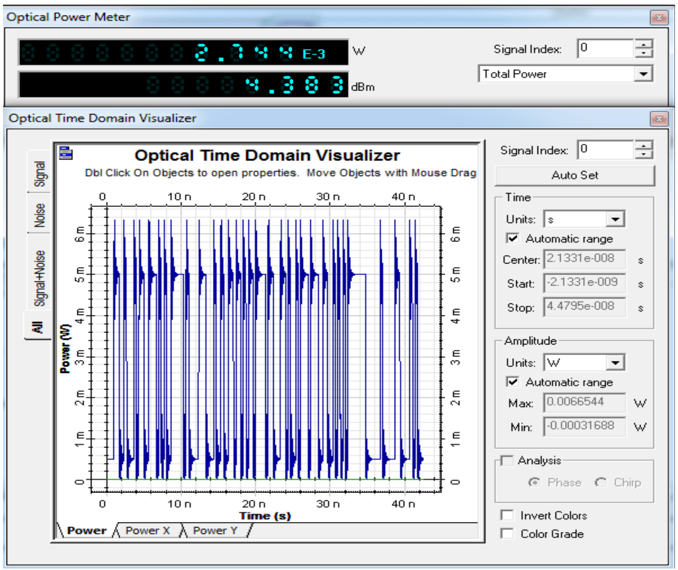

Figure 12: Transmitted Optical Power for Link Range 1500 meters and 1300 meters at θdiv= 0.3mrad and θdiv = 0.6mrad using DML.

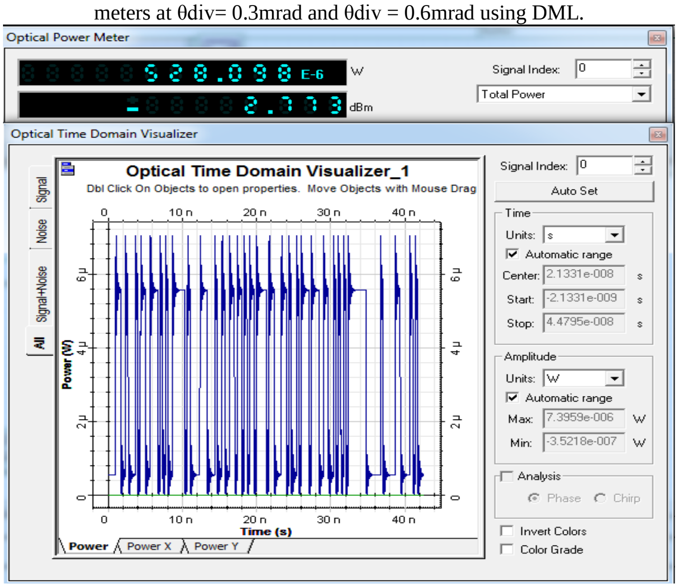

Figure 13: Received Optical Power for Link Range 1500 meters at θdiv= 0.3mrad using DML.

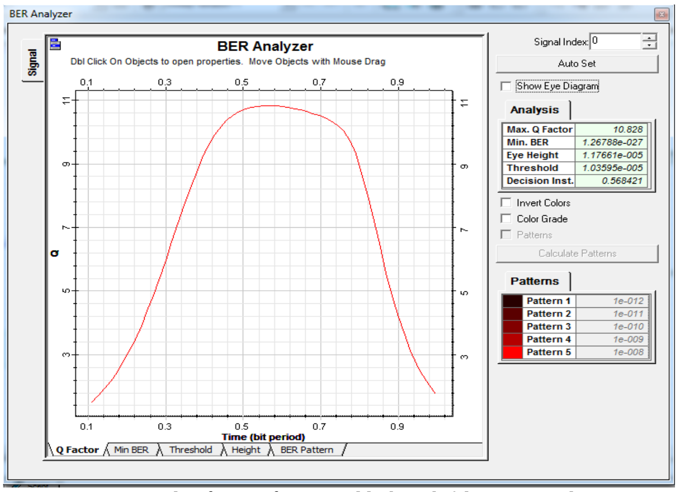

Figure 14: BER and Q factor of proposed link with θdiv =0.6mrad up to 1300 meters using DML.

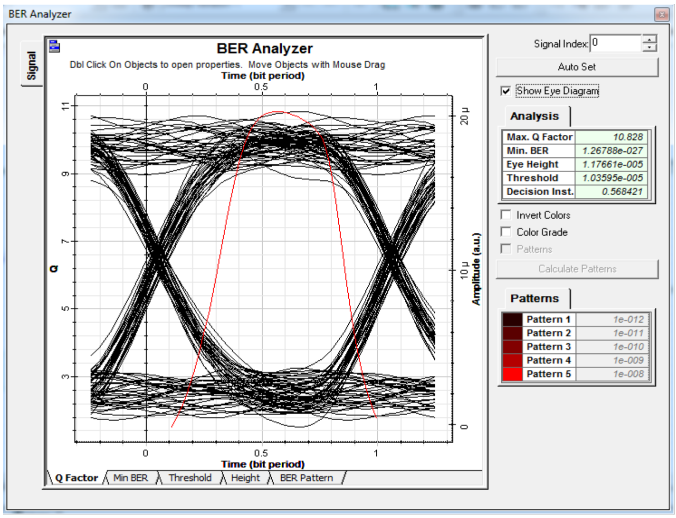

Figure 15: EYE Diagram of Proposed FSO link with θdiv =0.6mrad up to 1300 meters using DML.

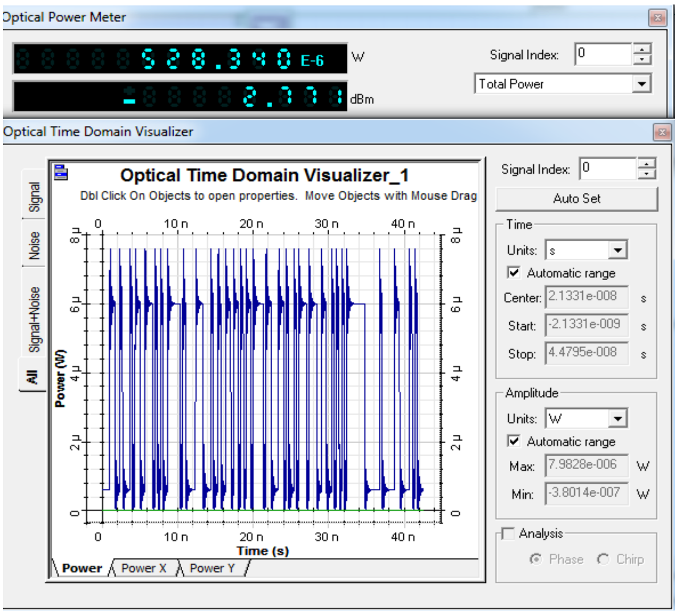

Figure 16: Received Optical Power for Link Range 1300 meters at θdiv= 0.6mrad using DML.

The comparison of link performance for directly modulator Laser and Controlled pump laser is shows in Table 2

PARAMETER	DIRECT MODULATOR LASER		CONTROLLED PUMP LASER	
	Θdiv 0.3 mrad	Θdiv 0.6 mrad	Θdiv 0.3 mrad	Θdiv 0.6 mrad
BER	$3.62*10^{-24}$	$1.26*10^{-27}$	$5.04*10^{-32}$	$1.09*10^{-30}$
Q	10.07	10.82	11.71	11.45
LINK RANGE	1500 Meters	1300 Meters	2020 Meters	1820 Meters
EYE HEIGHT	$1.05*10^{-005}$	$1.17*10^{-005}$	$1.32*10^{-005}$	$1.28*10^{-005}$
DATA RATE	3Gbps	3Gbps	3Gbps	3Gbps
TRANSMITTED POWER	$2.74*10^{-3}$	$2.74*10^{-3}$	$69.20*10^{-3}$	$69.20*10^{-3}$
RECEIVED POWER	$528.14*10^{-6}$	$528.34*10^{-6}$	$527.95*10^{-6}$	$527.88*10^{-6}$
FREQUENCY	650nm	650nm	650nm	650nm
POWER	5mw	5mw	20ma	20ma

Table 2: Difference between DML and CPL

it is clear that in Table 2 using the CPL optical source the achieved value for θdiv 0.3mrad and 0.6mrad we attained BER $5.04*10^{-32}$ and $1.09*10^{-30}$, Q is 11.71 and 11.45, with link range 2020 meters and 1820 meters respectively at data rate of 3Gbps which are in permissible limits. For the proposed FSO link by using CP Laser provides improved performance as compared to DM laser.

VII. CONCLUSIONS

Performance parameters of a short-range FSO system utilizing red light Laser Diode were calculated. We also describe our fundamental experiment based on a 650 nm wavelength laser diode. 650nm lasers are cheaper, consume less power, supports low data rates, high speed operations and licenses not required but it has some drawbacks, Like it is suitable only for short range communications and restricted output power of red laser due to eye safety problem. Atmospheric transmission of 650 nm laser beam was analyzed. The performance analysis of FSO Link at 650nm wavelength has been studied. It is accomplished that 650nm can be used for a maximum range of 2020 meters and 1820 meters for θdiv of 0.3 mrad and θdiv of 0.6 mrad respectively at 3 Gbps data rate with NRZ modulation scheme. By using the other wavelengths like 1550nm and 850nm we should also increase range and data rate of link. The optimized FSO links following conclusions were made:

(1) The calculated BER and Q factor for the proposed FSO link are $5.04*10^{-32}$ and 11.71 respectively. The optimized FSO link range of 2020 meters is achieved at divergence of 0.3 mrad using NRZ Modulation scheme.

(2) The optimized FSO link by using NRZ Modulation at divergence of 0.6 mrad maximum 1820 meters range is achieved scheme and calculated BER and Q factor for the proposed FSO link are 1.09*10^{-30} and 11.45 respectively.

(3) The total attenuation for atmospheric losses, Geometric losses, transmitter losses and receiver losses can tolerate on proposed FSO link is -33.26dB/km .

Therefore at θdiv 0.3mrad and 0.6mrad we attained BER 5.04*10^{-32} and 1.09*10^{-30}, Q is 11.71 and 11.45, with link range 2020 meters and 1820 meters respectively at data rate of 3Gbps by using NRZ Modulation scheme which are in permissible limits.

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