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Implementation of Free Space Optics Link at Visible Light Red Spectrum

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Abstract— **Free space optics (FSO) system is an optical communication technology in which air or vacuum is used as medium for the transmission of signal from one place to another in the form of light propagating in free space. FSO meets the need of modern wireless communication by high speed connectivity, license free operation; long distance and high security are some of its various features which add its effectiveness. In this paper FSO link is analyzed for 650nm wavelength operation. Simulation results provide maximal link range of around 2540 meters using visible light red spectrum. The bit rate obtained for optimized link is 10Gbps. The performance of proposed link can also be improved for sustainability of communication channel in various weather conditions and is evaluated on the basic of parameter like BER, Q factor and eye diagram. For θdiv 0.2mrad and θdiv 0.5mrad the achieved values of quality factor (Q) are 13.05 and 12.38, bit error rate (BER) is and respectively.**

Index Terms— **quality factor, divergence angle, bit error rate, free space optics, attenuation**

I. INTRODUCTION

Free space optics (FSO) communication system is an optical technology which uses invisible beam of light through an air or medium (instead of fiber optics cable) to transmission of optical signal from one place to another. FSO technology is an independent protocol that can be fixed to any type of network topology. Terrestrial short range FSO system which generally point- to- point link between different building of a company and building on the campus can be used to supplement radio and optical fiber networks or wireless communication networks.

FSO link is mainly depends up on atmospheric attenuation and geometric attenuation. Atmospheric attenuation depends largely on weather condition like fog, haze, scintillation and rain [1]. Geometric attenuation can be controlled by changing the parameter like wavelength, aperture size, transmitter diameter and link range etc. it can be reduced by proper choice of the parameter like attenuation coefficient, modulation technique and wavelength. All of these condition act to alternate light and could block the light path in the free space. As a result, disturbance and interruption could occur in the communication process.

Before installing the FSO on the tall building, detailed investigation of weather condition have to be carried out. This is to ensure FSO will operate with minimal losses and sufficient transmission power, even during bad weather conditions. Generally 1550nm laser are preferred only for long distance communication. It had a high data range and supports high power beam levels. Major advantage of 1550nm laser has the features of eye safety, long life and effect of solar noise are less [2]. 850nm and 1310nm are not preferred due to low range, low power and speed of data rate about 2.5Gbps only [3], and other wavelength used are 650nm and 10µm.

10µm laser are more expensive in market but provides high switching speeds and 650nm laser are small size low cost, high power stability and support low data rate etc. In this paper propose a short range FSO system using 650nm red laser beam having maximum range of 2450m. Visible light communications technologies comprise a transmission of information or data using light beam that is visible to human eye.

Visible laser source can be used for high, power stable and continuous operation at 650nm has been developed for a long time and it's based on tremendous technical advance of currently available components at low price and efficient modulation techniques pang et al (1999a; 1999b; 2002) and pang (2004) built a system made up of high brightness LED's which reaches over 20m outdoor and can be provide the function of free space, wireless broadcasting of data or audio signal [4].

The major advantage of red laser, it can be cavity installed and no tacking devices requirement for short range and it does not require any spectrum license and can provide high speed connectivity at lower price. Performance parameters of the proposed systems were evaluated and analysis in detail and experimental system was described finally.

II. ARCHITECTURE

In Fig 2.1 shows the block diagram of FSO system having transmitter, receiver and atmosphere channel [5]. Transmitter modulates the binary pulse to optical pulse. Modulation can be of different type of technique like On- Off Keying (OOK), intensity modulation and pulse modulation etc.

The information message generated by a source fed the input signal to modulator. The modulator is used to achieve high data rate by a varying frequency, phase and amplitude used to carry out modulation.

Drive circuit is used to vary driver current in accordance with input data, so that binary pulse can be connected or modulated into optical pulse. The sources are highly directional LED's/ LASER's exhibiting high speed switching connection. Light beam can be laser sources or LED,

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characterized by its power, wavelength and beam divergence angles. There is a telescope in the transmitter to determine the size of the light beam and the direction of beam.

A free space distance between transmitter and receiver know as atmospheric channel. Free space channel, so that there are number of factors that affects the signals like long range connectivity, bit error rate, data rate etc. the main factor that affects the signal are turbulence, absorption and beam divergence etc.

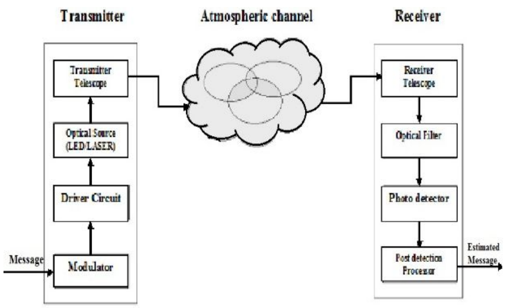

Fig 2.1 block diagram of FSO system

In optical communication system through the atmosphere channel. The intensity p (u, t) of the received optical signal can be written as [2],

$$P(u,t) = A(u,t)\ Ps(t)$$

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

The receiver consists of a receiver telescope, photo detector demodulator. Photo detectors convert the received optical field to an electronic signal which is demodulated and get it as decoded message at the end of process.

III. FREE SPACE CHANNAL MODAL

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.

$$LM = 10 \log Pr/S \qquad (3.1)$$

Receiver threshold is usually given by manufacturer and it range from -20dBm to -40dBm. Power at the receiver, can be expressed as [7]:

$$Pr = Pt * \frac{Arx}{(\theta L)^2} * e^{\alpha L} \qquad (3.2)$$

Where, Pr and Pt are power at the receiver and transmitter respectively. Arx is receiver aperture area, α atmospheric attenuation, θ divergence angle and L distance between transmitter and receiver. As show in the equation (3.2) is defined as power at the receiver is directly proportional to receiver aperture area and the transmit power, but inversely proportional to the divergence angle and link range.

Exponential part of the equation is related to atmospheric channel attenuation and it has the strongest influence on the link range quality. Another factor that adds to attenuation of the signals is laser 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 transmitter power
- Receiving optics collecting area
- Receiver sensitivity
- Transmitting beam width

The relation between transmitted and receiver power is given by the equation

$$Preciever = Ptransmitter \left(\frac{D^2}{L^2 \theta^2 div}\right)\left(10 - \frac{\gamma L}{10}\right) \tau transmitter * \tau recevier$$

Where, $P_{reciever}$ is the power received (dBm) at the receiver, $P_{transmitter}$ is the power transmitted (dBm), D is the diameter of the receiver, θdiv is divergence angle, γ is atmospheric attenuation factor (dBm), $\tau_{transmitter}$ and $\tau_{receiver}$are respective optical efficiencies. Each FSO terminal has a loss of 1.8dB at transmitter and receiver.

According to Beer- Lambert Law,

$$Lloss = (-\sigma l) \qquad (3.4)$$

Where, l (km) is the range of the laser transmitter and σ is the typical attenuation coefficient (0.1 for clear air). Power budget modal for FSO link is given by,

$$Preceiver = Ptransmitter - \alpha sys - \alpha atm \qquad (3.5)$$

Where, $\alpha_{atm}$is total atmospheric attenuation, α_{sys} is system attenuation which is also called as geometric loss. As the distance increases, the atmospheric loss increase and the power decrease. In this simulation 650nm wavelength is used [6]. The visible wavelength 650nm is also consumes less power, as it is easily noticeable. It also consumes less power, as it is operated around 5mW.

IV. PERFORMANCE EVALUATION

In this section we shall consider the situation of optical propagation in detail between two point's terrestrial applications for proposed FSO link. The stimulator used is optisystem. A low power red light laser diode, optical amplifier and a Si photodiode were employed with parameter given in Table 4.1 together with other parameters supposed in this stimulation.

Table 4.1 stimulation parameters

Parameter	Value
Laser	Controlled pump laser
Wavelength	650nm
Data rate	10Gbps
Threshold current	20ma
Link range	2540m, 2205m
Modulation	NRZ

Divergence beam	0.2, 0.5mrad
Slope efficiency	0.5 W/A
Transmitter aperture diameter	7cm
Receiver aperture diameter	13cm
Transmitter loss	-1dB
Receiver loss	-2dB
Additional attenuation	-17.5dB/Km
Geometric loss	-7.26dB
Maximum current	300ma
Power	5mW

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 and attenuation etc. For analyze the optical power, between transmitter and receiver simulation provides power meter and spectrum analyze 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 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 existing conditions. The simulation parameters of proposed FSO link are shown in table 4.1. The results are obtained for different angle θdiv, receiver aperture diameter, attenuation etc. we achieved maximum range up to 2540 meters with 650nm red laser and data rate of 10Gbps. The values of θdiv selected is 0.2mrad. The link has been optimized under attenuation values of -17.5 dB/ km. we shall also include transmitter and receiver loss 1dB and 2 dB respectively. The link can tolerate geometric attenuation of -7.26dB. The reference value of Q is 9.46 with an acceptable BER of the total attenuation that the proposed link can tolerate is -24.76 dB.

V. STIMULATION RESULT AND DESCRIPTIONS

An experimental performance analysis using simulation of proposed FSO link using optical amplifier, NRZ modulation scheme is carried out and optimized results are discussed. The transmitter laser source was a 5mW at wavelength 650nm 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 electronics structure includes photo- PIN- diode, data interface and amplifier.

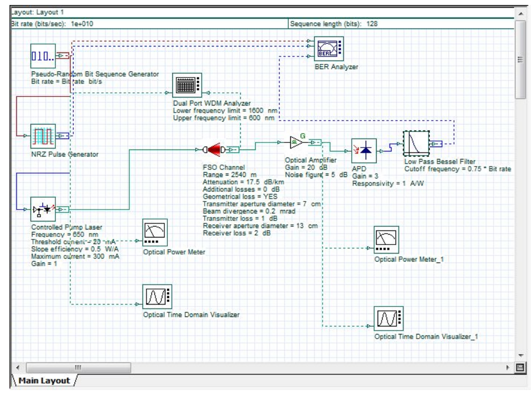

Fig 5.1 Proposed FSO Link

The transmission experiment was performed outdoors be with divergence angle θdiv is 0.2 mrad and 0.5 mrad respectively, attenuation of 17.5dB/km and receiver aperture 13cm. In reference paper [6] BER and Q factor was 1.41* 10^{-21} and 9.46 respectively with link range up to 1000m with divergence angle θdiv is 0.3mrad and data rate 1.25Gbps.

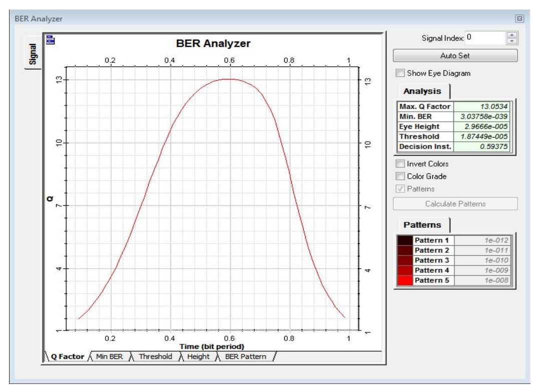

Fig 5.2 BER and Q factor of proposed link with θdiv = 0.2 mrad up to 2450m using CPL

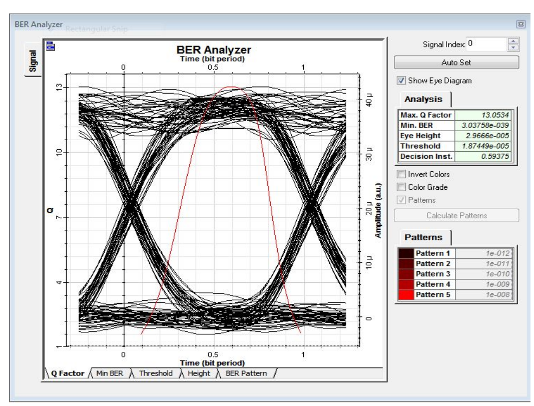

Fig 5.3 eye diagram of proposed FSO link with θdiv = 0.2 mrad up to 2540m using CPL

In Fig 5.2 and Fig 5.3 shows the BER and Q factor of proposed link with θdiv 0.2 mrad and 0.5 mrad respectively. For θdiv 0.2 mrad on optimized FSO link the BER attained is 3.03*$10^{-39}$and values of Q is 13.05 with link range 2540m at data rate of 10Gbps. For 0.5 mrad BER attained is 1.52*10^{-35} and Q is 12.38 with link range 2205m at data rate of 10Gbps.

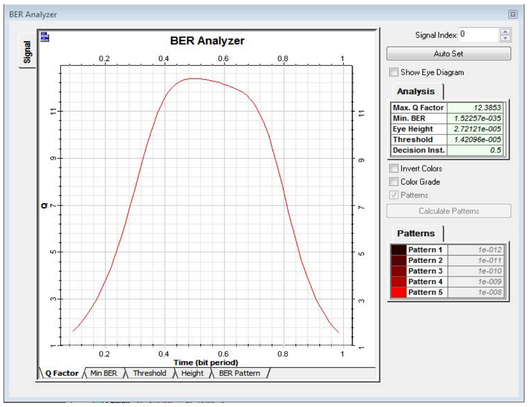

Fig 5.4 BER and Q factor of proposed link with θdiv = 0.5 mrad up to 2205m using CPL

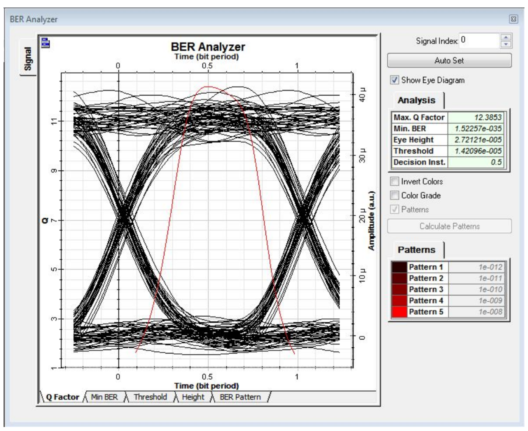

Fig 5.5 eye diagram of proposed FSO link with θdiv = 0.5 mrad up to 2205m using CPL

In Fig 5.3 and Fig 5.4 shows the eye diagram for θdiv 0.2 mrad and 0.5 mrad respectively. The black lines shows the eye diagram and red line indicates BER curves and shows BER curves of the specified link of attenuation 17.5dB/ Km having range 2540m and 2205m respectively.

Therefore use of low- cost red light laser diode for short distance makes this link interesting for private users. By suing red light 650nm laser good reliability and availability can be achieved by using this system for given data rates and even higher. The eye diagram in Fig 5.3 and Fig 5.5 shows that the signal has been received with less or no error. It has an eye opening of 2.96* 10^{-05} and 2.72* 10^{-05} for θdiv 0.2 mrad and 0.5 mrad respectively.

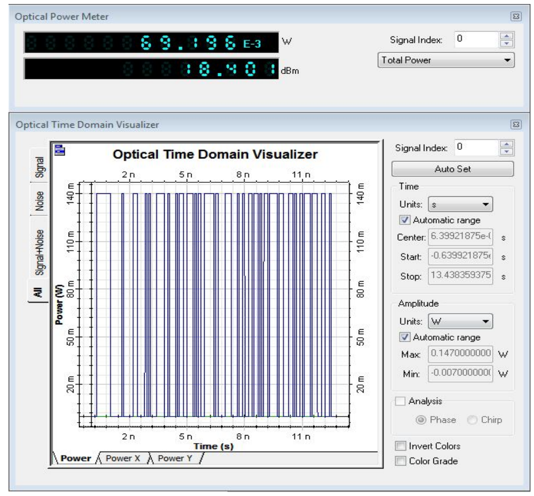

Fig 5.6 transmitted optical power for link range 2540m and 2205m at θdiv = 0.2mrad and θdiv = 0.5 mrad using CPL

In fig 5.6 shows transmitted optical power spectrum of the optimized link for length 2450m. The spectrum of the transmitted power also shows the peak wavelength at 650nm. Optical power transmitted is 69.196* 10^{-06} Watts calculated by the power meter.

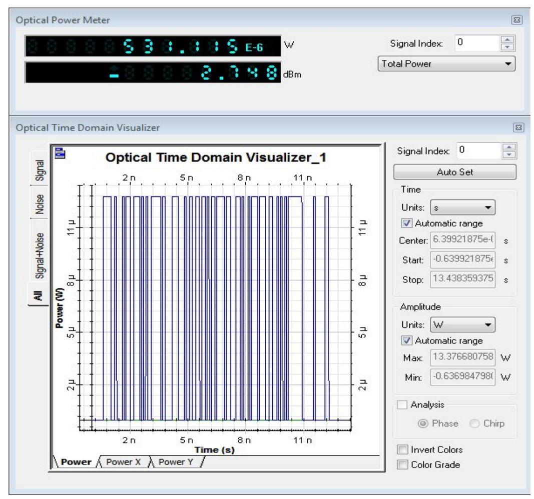

Fig 5.7 received optical power for link range 2540m at θdiv = 0.2 mrad using CPL

For analyzed the loss of optical power at receiver end can be calculated by using the spectrum analyzer at receiver end. Fig 5.7 shows received optical power spectrum of the optimized link for 2540m at θdiv = 0.2mrad. Optical power received is 531.115*10^{-06} Watts calculated by the power meter.

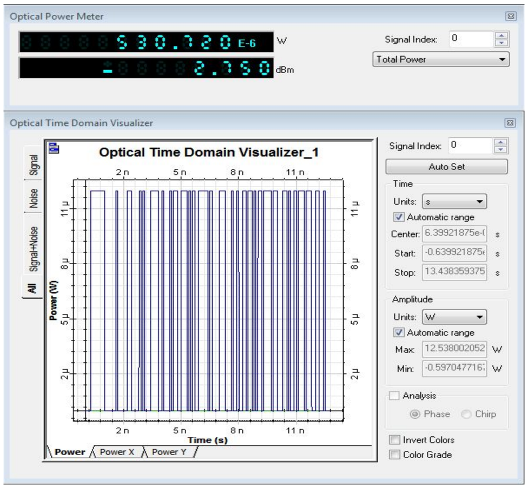

Fig 5.8 received optical power for link range 2205m at θdiv = 0.5 mrad using CPL

In fig 5.8 shows received optical power spectrum of the optimized link for 2205m at θdiv = 0.5mrad. Optical power received is 530.720* 10^{-06} Watts calculated by the power meter.

The spectrum of the received power also shows in Fig 5.7 at θdiv is 0.2 mrad and Fig 5.8 at θdiv is 0.5 mrad respectively by using optical time domain visualizer also the peak wavelength at 650nm. The result shows the reducing of optical power to a great extent after travelling a distance of 2540m and 2205m for θdiv is 0.2 mrad and 0.5 mrad respectively.

CONCLUSIONS

Performance parameters of a FSO system utilizing 650nm wavelength red laser were calculated. We also describe our fundamental experiment based on a 650nm wavelength laser diode.

650nm lasers are cheaper, high speed operation, supports low data rates, consume less power 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.

Atmosphere transmission of 650nm 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 2540m and 2205m for θdiv of 0.2 mrad and θdiv 0.5 mrad respectively at 10Gbps data rate with NRZ modulation scheme. By using the other wavelength like 1550nm and 850nm we should also increase range and data rate of link.

The optimized FSO links following conclusions were made:

- The calculated BER and Q factor for the proposed FSO link are 3.03*$10^{-39}$and 13.05. The optimized FSO link range of 2540m is achieved at divergence of 0.2 mrad using NRZ modulation scheme.
- The optimized FSO link by using NRZ modulation at divergence of 0.5 mrad maximum 2205m range is achieved scheme and calculated BER and Q factor for proposed FSO link are 1.52* 10^{-35} and 12.38 respectively.
- The total attenuation for atmospheric losses, geometric losses, transmitter losses and receiver losses can tolerate on proposed FSO link is -24.76 dB/ km.

Therefore at θdiv 0.2 mrad and 0.5 mrad we attained BER 3.03*$10^{-39}$and 1.52*10^{-35}, Q is 13.05 and 12.38 with link range 2540m and 2205m respectively at data rate of 10Gbps by using NRZ modulation scheme which are in permissible limits.

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