International Journal of Signal Processing, Image Processing and Pattern Recognition
Vol.9, No.10, (2016), pp.187-194
http://dx.doi.org/10.14257/ijsip.2016.9.10.18

# Investigation on the Performance of FSO Communication Link Under Various System Parameters

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***Abstract***

*Optical Wireless Communication (OWC) also known as Free Space Optics (FSO) technology has many advantages such as availability of license-free spectrum, low deployment cost, large modulation bandwidth, low consumption of power, and small size. In this paper, the investigation on the performance of free space optical communication link has been done for different system parameters and transmission windows using OOK (on-off keying) modulation scheme. The performance of the system has been analyzed using Q Factor and SNR of the received signal as the performance metric. Also, the effect of atmospheric attenuation on the performance of the system has been analyzed by varying the link distance between the transmitter and the receiver for a specified transmission power level and bit rate. The performance of the system has also been investigated under different data transmission rates and transmission power levels using OPTISYSTEM simulation software.*

***Keywords***: *Free Space Optics, Atmospheric attenuation, Q Factor, SNR, Optical Power*

## 1. Introduction

FSO communication links are being deployed in various applications due to their numerous advantages such as high data transmission rates, availability of unlicensed spectrum, low cost of implementation, and small size [1]. FSO communication links make use of Laser diodes or LEDs in order to generate information carrying signal in near-infrared region *i.e.*, their operating wavelengths are 760-900 nm and 1510-1600 nm [2]. Laser diodes having 1550 nm as operating wavelengths are preferred in FSO communication links due to eyes safety concern. Also, the allowable power transmission limit in 1550 nm window is 50 times more than that in 850 nm transmission windows [3]. This factor of fifty allows an extra margin of 17 dB and hence, the information signal can be transmitted at higher data transmission rates for longer link distances. Most commonly used Laser diodes in FSO links are- Distributed Feedback Lasers (DFB) operating at 1550 nm wavelength, Fabry-Perot Lasers operating at 1550 nm wavelength, Vertical Cavity Surface Emitting Laser (VCSEL) operating at 850 nm wavelength and Nd-YAG Laser operating at 1064 nm wavelength.

Different modulation schemes can be used for FSO communication links. Commonly used modulation schemes in FSO communication links are on-off Keying (OOK), differential phase shift keying (DPSK), pulse position modulation (PPM), differential quadrature phase shift keying (DQPSK), and subcarrier intensity modulation (SIM) [4]. In this paper, OOK modulation scheme has been considered which is the simplest modulation scheme. The information is carried by embedding the information on the amplitude, frequency or phase of the optical carrier signal. The information signal is then encoded and transmitted towards the receiver in space as the propagation medium. At the receiver end, photodetectors are used to convert the optical signal into its electrical form

ISSN: 2005-4254 IJSIP

and further signal processing is done to obtain the information from the signal. Although FSO communication links have many advantages, it also suffers from many limitations such as absorption, scintillation, scattering, and atmospheric turbulences. These limitations can severely degrade the performance of the communication link [5]. The main reason for atmospheric turbulence is the temperature gradient and the variations in the velocity of the wind that result in the formation of air pockets and thus causing variation in optical refractive index of the air. When the information carrying optical signal travels through such environment, it causes fluctuations in the intensity of the optical signal received at the FSO link end. This phenomenon is also known as scintillation process [6]. The amount of scintillation effect is dependent on the time of the day and can vary on a very hot day. The effect of scintillation increases with the increase in propagation link distance and can adversely affect the BER performance of the system. The parameter which is used to measure the amount of scintillation is given by $\sigma_I^2$ and is also known as the normalized variance of intensity. The normalized variance of intensity is given by the equation

$$\sigma_{\mathrm{I}}^2 = \frac{\langle I^2\rangle - \langle I\rangle^2}{\langle I\rangle^2} \tag{1}$$

where I is the intensity of the received signal. For weak atmospheric turbulence conditions, the normalized variance of intensity is less than unity *i.e.*, $\sigma_I^2 < 1$ else $\sigma_I^2 > 1$.

In this paper, a weak atmospheric turbulence condition has been considered for fading of signal due to atmospheric turbulence. Weak atmospheric turbulence conditions are governed using log-normal density functions [7-8]. The attenuation of the information signal is based on FSO link range equation which combines atmospheric attenuation and geometrical aspects in order to calculate the total optical power received as a function of link distance and aperture size of the receiver. The link equation is given as

$$P_{received} = 10 - \left( \frac{A_{receiver}}{\pi \left[\frac{\theta}{2} \times L\right]^2} \right) \times T \times 10^{-\left(\frac{\alpha L}{10}\right)} P_{transmitted} + P_{background} \tag{2}$$

where $P_{received}$ denotes the total power of the received signal, $P_{transmitted}$ denotes the total power of transmitted signal, $A_{receiver}$ denotes the aperture area of the receiver, $\theta$ denotes the beam divergence angle, T is the net efficiency of transmitter-receiver pair, $P_{background}$ is the total power of optical background radiation, L is the link distance, and $\alpha$ is the atmospheric attenuation in dB/km. By combining geometrical losses and additional attenuation, equation (2) can be written as

$$P_{received} = 10 - (\alpha_{geometric} + \alpha_{attenuation}) P_{transmitted} + P_{background} \tag{3}$$

where $\alpha_{attenuation}$ denotes the additional attenuation in dB for a given link distance. The $\alpha_{attenuation}$ is given by the equation

$$\langle \alpha_{attenuation} \rangle = 4.34 \left(\ln\langle I\rangle - 0.5\sigma\, \sigma_I^2\right) \tag{4}$$

where $\sigma = 4.34\, \sigma_I$

The rest of the paper is organized as follows- In Section 2, simulation model and parameters are presented, and in Section 3, simulation results are presented and discussed. The conclusion is given in Section 4.

## 2. Design of FSO Communication Link

In this paper, a typical FSO communication link has been considered which consists of an optical transmitter, FSO propagation channel, and an optical receiver. In Figure 1, the model of FSO communication link used in this paper is presented.

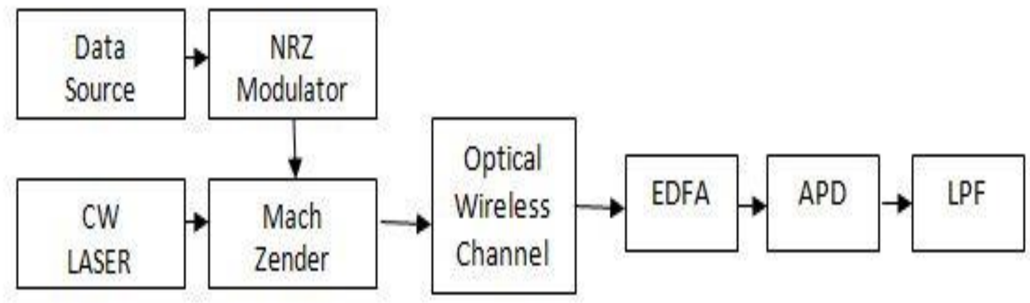



**Figure 1. FSO Communication Link**

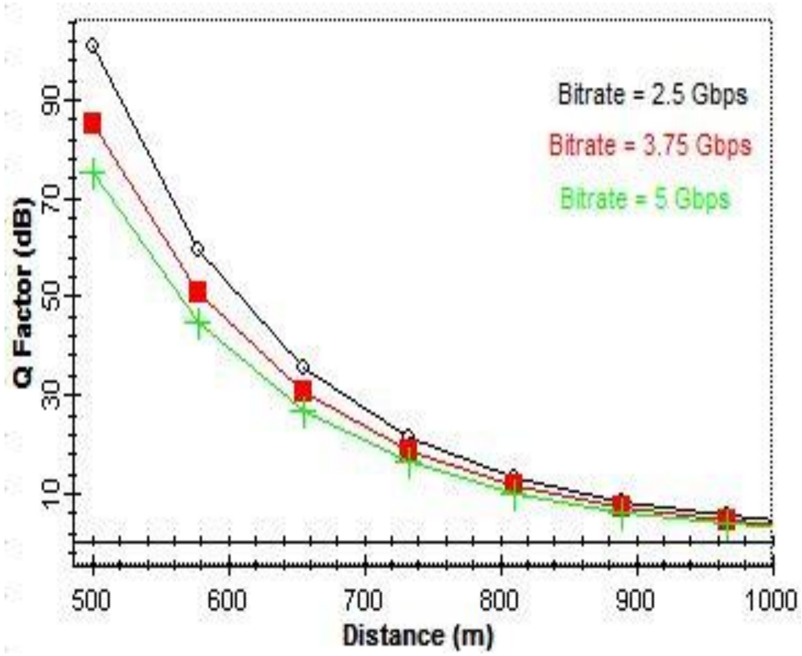
The transmitter section consists of a PRBS generator as the data source which generates binary data at 2.5 Gbps data rate followed by an NRZ modulation driver which converts the binary signal into an electrical signal, and a Mach-Zender modulator which modulates the electrical signal with the optical carrier signal produced by continuous wave (CW) laser. The optical output power of the transmitter is 6 dBm. The link distance of FSO system is 1000 m with 0.25 mrad divergence angle. The simulation parameters used in this paper are given in Table 1.

**Table .1 Simulation Parameters**

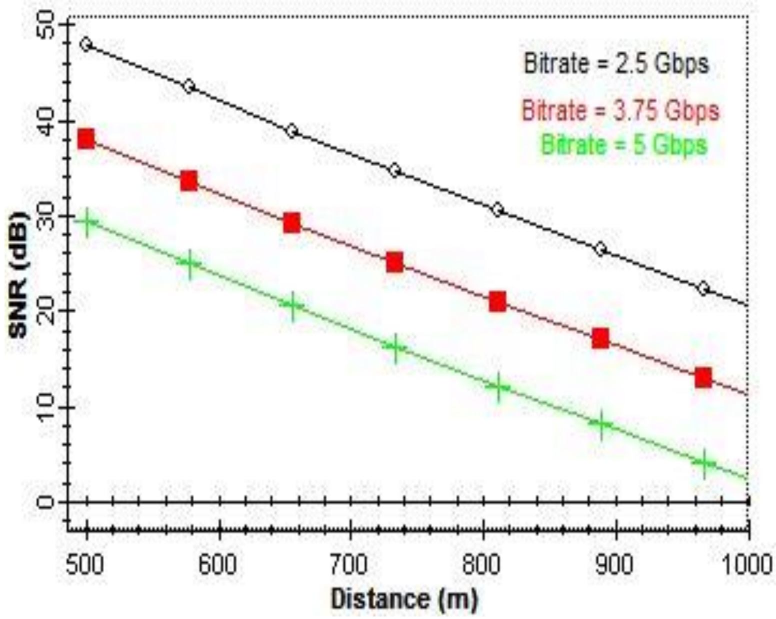
| S No | Parameter | Value |
|---|---|---|
| 1. | Bit Rate | 2.5-5 Gbps |
| 2. | Transmission Power Level | 4-6 dBm |
| 3. | Link Distance | 500-1000 m |
| 4. | Divergence Angle | 0.25 mrad |
| 5. | Operating wavelength | 1550 nm |
| 6. | Rx Antenna Aperture | 20 cm |
| 7. | Tx Antenna Aperture | 10 cm |
| 8. | APD Responsivity | 1 A/W |
| 9. | Attenuation | 25 dB/km |

## 3. Results and Discussion

In this paper, an FSO communication link has been designed using OPTISYSTEM simulation software consisting a transmission length of 1000 m, aperture diameter of transmitting antenna 5 cm, aperture diameter of receiving antenna 20 cm, beam divergence angle 0.25 mrad, operating wavelength 1550 nm, line width 10 MHz and transmission power level of 6 dBm.




(a)

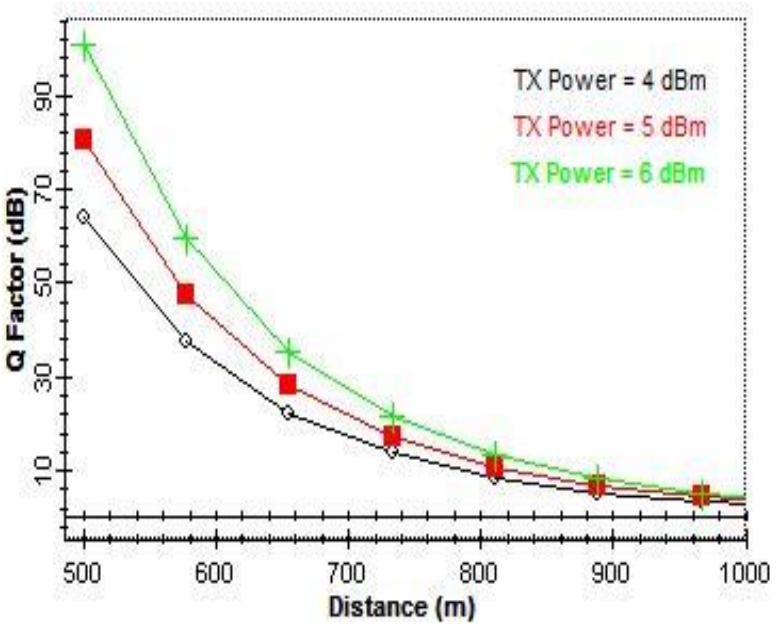



(b)

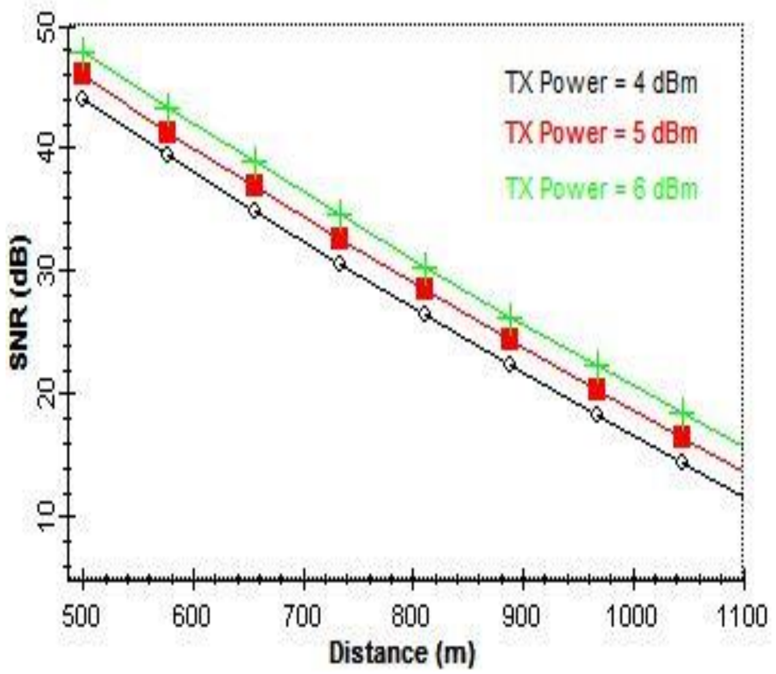
**Figure 2(a). Q Factor v/s Link Distance for Different Data Transmission Rates (b) SNR v/s Link Distance for Different Data Transmission Rates**

Figure 2(a), and 2(b), show the graph between Q Factor and SNR for varying transmission distance at different data transmission rates. From the simulation results it can be observed that there is a considerable decrease in Q Factor value which lies in the range [97, 86, 75] dB and [15, 10, 7] dB for link distance of 500-1000 m in case of transmission bit rates of 2.5 Gbps, 3.75 Gbps and 5 Gbps respectively. Further it can be observed that there is considerable decrease in the value of SNR of received signal which lies in the range [49, 38, 30] dB and [27, 17, 6] dB for link distance of 500-1000 m in case of transmission bit rates of 2.5 Gbps, 3.75 Gbps, and 5 Gbps respectively.



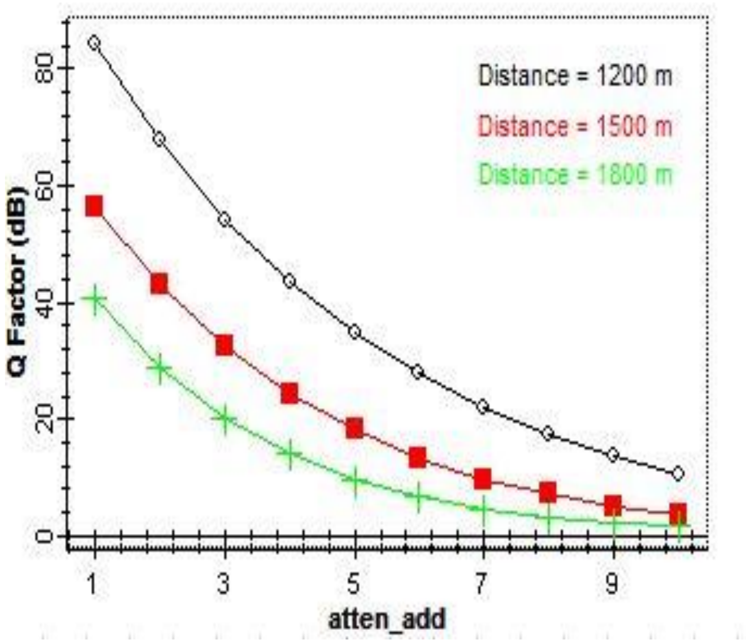

(a)



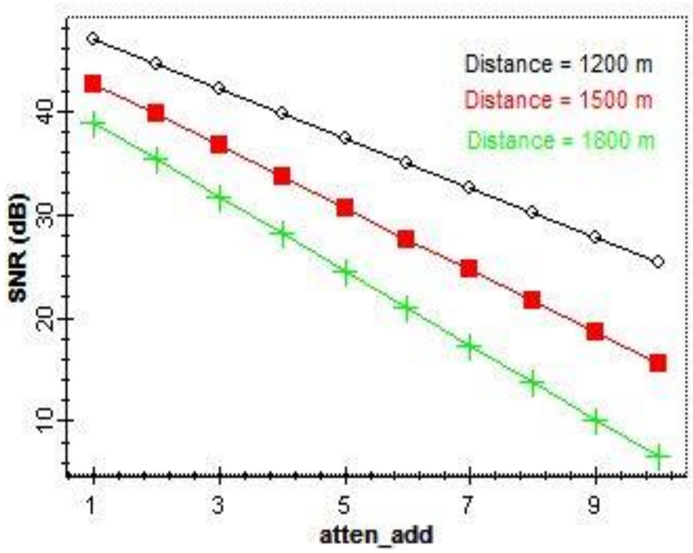

(b)

**Figure 3(a). Q Factor v/s Link Distance for Different Data Transmission Power Levels (b) SNR v/s Link Distance for Different Data Transmission Power Levels**

Figure 3(a), and 3(b), indicate the graph of Q Factor and SNR for varying transmission distance at different transmission power levels. It can be observed from the results that there is a considerable decrease in the value of Q Factor which lies in the range [99, 80, 67] dB and [10, 9, 7] dB for link distance of 500-1000 m in case of transmission power levels of 6 dBm, 5 dBm, and 4 dBm respectively. Also, it can be observed from the results that there is a considerable decrease in the value of SNR values of received signal which lies in the range [48, 46, 44] dB and [16, 13, 11] dB for link distance of 500-1000 m in case of transmission power levels of 6 dBm, 5 dBm, and 4 dBm respectively.




(a)




(b)

**Figure 4(a). Q Factor v/s Varying Attenuation and Link Distance (b) SNR v/s Varying Attenuation and Link Distance**

Figure 4(a), and 4 (b), indicate the graph between Q Factor and SNR of received signal for varying link distance and attenuation respectively. It can be observed from the results that there is a considerable decrease in the value of Q Factor which lies in the range [83, 57, 40] dB and [12, 6, 5] dB for attenuation addition of 1 to 10 dB in case of link distance of 1200 m, 1500 m, 1800 m respectively. Further, it can be seen from the results that there is a considerable decrease in the value of SNR which lies in the range [49, 43, 40] dB and [31, 20, 12] dB for attenuation addition of 1 to 10 dB in case of link distance of 1200 m, 1500 m, 1800 m respectively.

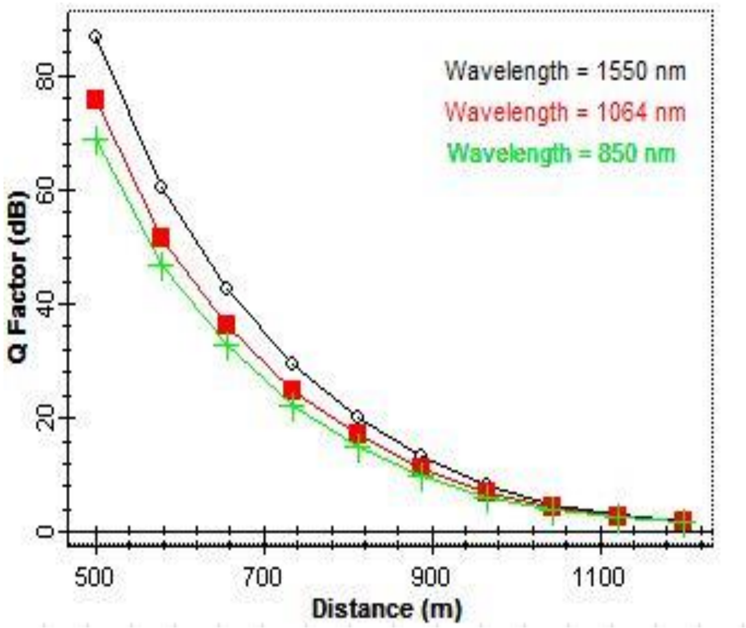



**Figure 5. Q Factor v/s Link Distance for Varying Operating Wavelengths**

Figure 5, shows Q Factor for varying link distance for different values of operating wavelengths. From the results presented it can be seen that there is a considerable decrease in Q Factor values which lie in the range [85, 78, 71] and [7, 5, 4] for link distance of 500-1000 m for operating wavelength of 1550 nm, 1064 nm and 850 nm respectively.

## 4. Conclusion

In this paper, the performance of an FSO link has been investigated taking Q Factor and SNR values of received signal as performance parameters. From the results, it can be concluded that operating wavelength of 1550 nm gives the best performance as compared to other FSO wavelength bands in weak turbulence conditions. It can also be concluded that increasing the transmitting power of optical signal results in higher values of Q Factor and SNR of received signal hence better system performance. Further, it can be concluded that with the increase in data transmission rates of for a given distance, the performance of the FSO system degrades. Moreover, it can be concluded that as the additional attenuation increases, the Q Factor and SNR of received signal considerably decreases and hence the performance of the system degrades. Above presented results reported the investigation of different parameters that play a significant role in the performance of FSO communication system.

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