Mitigating the effects of Attenuation in Free Space Optics link using EDFA

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Abstract. Free space optics (FSO) communication is highly dependent on atmospheric turbulences and weather conditions through which the signal propagates. Due to propagation in free space, the signal gets attenuated and loses information until it reaches the receiver end. These factors affecting the communication in FSO technology generates the need of using amplifier in the link. All these factors can be overcome using amplifier in the link. In this work, the FSO link is designed and its performance is analysed with and without using amplifier. The use of amplifier in the FSO not only improves the signal quality but also increases the range of communication. This paper analyses the importance and effectiveness of the use of Erbium Doped Fibre Amplifier (EDFA) in FSO communication. The model is simulated and two important parameters that are bit error rate (BER) and received signal power are discussed using various powers of transmitters. The results are compared and plotted using Matlab simulation.

Keywords. Free space optics (FSO), Erbium Doped Fiber Amplifier (EDFA), Bit Error Rate (BER), Eye diagram, Received signal power

1. Introduction

The development of various optoelectronic devices and the increasing demand of high data rates and high bandwidth have played a very important role in the development of FSO in recent years. FSO is a line of sight technology in which data is transmitted over free space through light.

It guarantees very large bandwidth which in turn provides high data rate capabilities [1].
FSO technology has various advantages over existing radio frequency (RF) communications like license free communications, high bandwidth, very high data rate, less installation cost, negligible electromagnetic pollution. As the bandwidth of FSO technology is very large so it can support more number of users than RF technology thus improving the problem of data traffic [2-4]. FSO communication is the optimum solution for last mile problem. Various researches in this field have shown that FSO communication has proved its worth in point to point, point to multipoint communications and satellite communications.
Despite of being great potential, the widespread deployment of FSO link has been hampered by certain issues related to atmospheric variations. The communication of FSO link is very similar to optic fibre communication however the communication medium is free space through which light beam is transmitted to the receiver end. So the signal travelling through free space is affected by plethora of factors like weather, scattering, absorption of signal, distance between receiver and transmitter and various obstacles in the path of light beam, Research studies have shown that optical attenuations can reach up to 130 dB/km in heavy fog and snow environments that restrict FSO availability in such conditions

[5]. The solution lies in the use of EDFA in the FSO link to ensure a high overall link accuracy and reliability.
Different values of transmitter power in FSO link in the presence and absence of EDFA has been analysed in this paper to show the importance of amplifier for improving the communication. The performance of FSO link at different values of transmitter power has been compared by using and not using EDFA in the link.
The paper begins with a system description given in Section II. The importance and brief details of EDFA are given in Section III. Section IV summarizes results on system performance based on both analysis and simulation. Conclusions are then drawn in Section V.

2 System Model

A free-space optical communication system is composed of three basic parts: a transmitter, the propagation channel and a receiver. The generalized block diagram of FSO system is shown in figure 1.

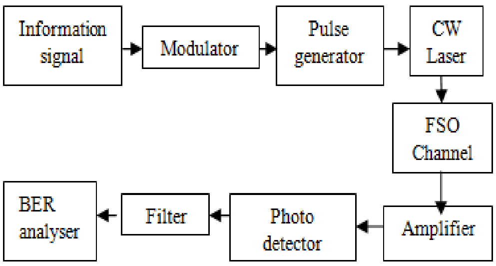

Figure 1 Block Diagram of FSO link

Table 1: System parameters

Operating parameter	Value and Unit
Operating signal wavelength	1550 nm
Link distance	500m
Signal transmitted power	10<P(mW)<100
Atmospheric attenuation	45 dB
Transmitter lens diameter	50 cm
Receiver lens diameter	20 cm
Amplifier Used	EDFA

The major challenge faced by FSO communication is distortion of information signal caused by atmospheric disturbances that result in signal scattering and absorption. The weather conditions and scintillations put a great effect on the transmitted signal [6-7], [14].
In order to reduce these atmospheric effects an erbium doped fibre amplifier is used in FSO link.
The signal transmitted from laser is collected by a lens, coupled to a fibre and amplified by an optical amplifier that is EDFA and the amplified signal is being detected by a photo detector. The received power on the receiver end is represented by Pr. Therefore, in order to increase the performance of FSO, there is a need to introduce amplifier in the FSO link to reduce the effects of noise generated by various atmospheric factors.
A systematic approach is provided in figure 2 to easily understand the evaluation of performance in free space communication. To start this analysis, the most important set of requirements are established first. These requirements come up from the goals that are desired from a free space optical communication system.
The process begins with the generation of light signal from electrical signal through optical sources. Various FSO communication inputs like modulation of transmission beam are provided to improve the strength of the signal. The signal transmitted over free space is highly affected by the atmospheric variations and scintillations. To improve the received signal mitigation techniques are applied. In this paper EDFA is used as one of the most important mitigation technique to improve the signal quality. After this the received signal is measured in terms of received signal power, BER, Eye diagram and Q factor.

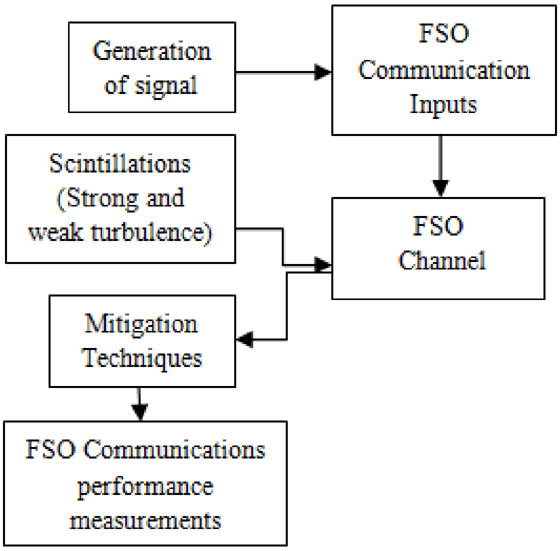

Figure 2: Flowchart of working FSO technology

3. Erbium Doped Fibre Amplifier

In paper, the focus is given on the importance of the use of amplifier in FSO link. An optical amplifier can be used by focussing the received signal onto a fibre, which then guides it through the fibre amplifier that is erbium doped fibre amplifier. The use of EDFA is preferred over other amplifiers as this approach promises better performance than the usual electronic amplification. In this the received signal can be made much stronger by removing the thermal noise floor that usually limits performance. Optically amplified systems are more difficult to analyze due to the presence of signal dependent noise. EDFAs are used to provide amplification in long distance optical communication with fibre loss less than 0.2 dB/km by providing amplification in the long wavelength window near 1550 nm. The principle of rare earth doped fibre amplifier is the same as that of lasers excepting that such amplifiers do not require a cavity whereas a cavity is required for laser oscillation [8-10],[15] .
The rate equations of the amplifier can be written as:

Let N_u , N_m and N_g denote the population of the three states. If W_p is the pumping rate, W_s is the rate of absorption of photons from the signal and T_{ij} is the lifetime of spontaneous emission from the state i to the state j , the rate equations can be written as:

$$\frac{dNg}{dt} = \frac{Nm}{Tmg} + Ws(Nm - Ng) - Wp(Ng - Nu) \quad (1)$$

$$\frac{dNm}{dt} = \frac{Nu}{Tum} - Ws(Nm - Ng) \qquad (2)$$

$$\frac{dNu}{dt} = -\frac{Nu}{Tum} + Wp(Ng - Nu) \qquad (3)$$

Population inversion implies that $N_m > N_g$. For steady state conditions, the time derivatives vanish. Since the lifetime of the state u is much smaller than the lifetime of the state m, the population of the excited state is essentially given by the Boltzmann distribution.
The gain of the amplifier can be described as the ratio of the output signal power to input signal power is the gain of an amplifier. Gain of EDFA depends on the pump power as well as on the pump wavelength.

$$\text{Gain(in dB)} = 10 \log_{10} \frac{Pout}{Pin} \quad (4)$$

Noise figure (NF) of EDFA is a measure of the quality of amplification. It is defined as the quotient of the signal to noise ratio (SNR) of the input signal to that of the output signal. N.F. is also measured in logarithmic scale as

$$NF = \frac{(SNR)input}{(SNR)output} \quad (5)$$

4 Results and discussions

The work includes the analysis of the performance of the FSO link in the presence and absence of amplifier. The results are described using parameters like received power, Q factor, height of eye diagram and minimum bit error rate

(BER). The wavelength used is 1550nm as it is most commonly used as 3rd window of optical communication and is safe for human eye [11-12],[16] . Using non return to zero (NRZ) modulator the output is taken along BER analyser.

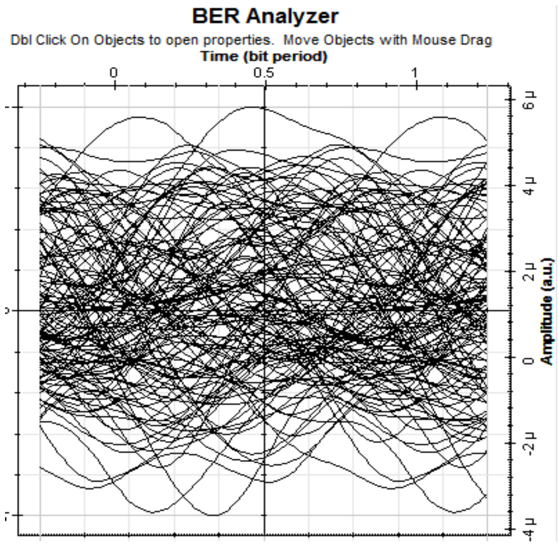

Fig 3: Output of BER analyser at 10mw without using amplifier

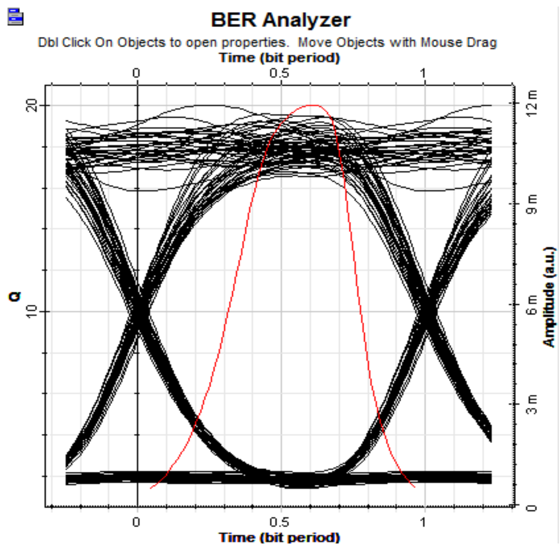

Fig 4: Output of BER analyser at 10mw with amplifier

Figure 3 and 4 illustrate the output of BER analyser at transmitter power 10 mW for FSO link in the presence and absence of EDFA. It can be clearly visualised that the absence of EDFA in the link at such low transmission powers make it impossible for link to properly function at long distances. The output of BER analyser without the use of amplifier is showing that no information is received at the receiver end. The entire data is lost during transmission along free space. However, after the installation of amplifier in the link at this transmission power is providing the Q factor of the received signal as 20, thus showing the reliable communication took place as the signal received is amplified regenerated properly by the EDFA placed before photo detector.

It can be clearly visualised in figure 4 that received signal is having much better quality than previous case. In this case, the minimum BER of signal is 1.1753e-089, the height of eye diagram is 0.00842736 and power of the received signal is found to be 4.82299056 mW.

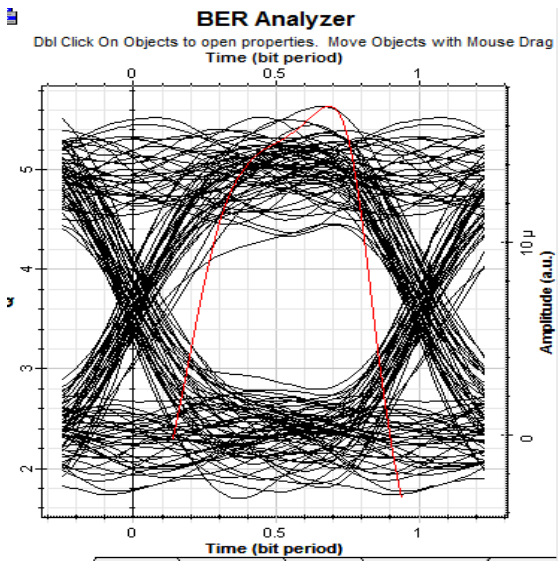

Fig 5: Output of BER analyser at 50mw without using amplifier

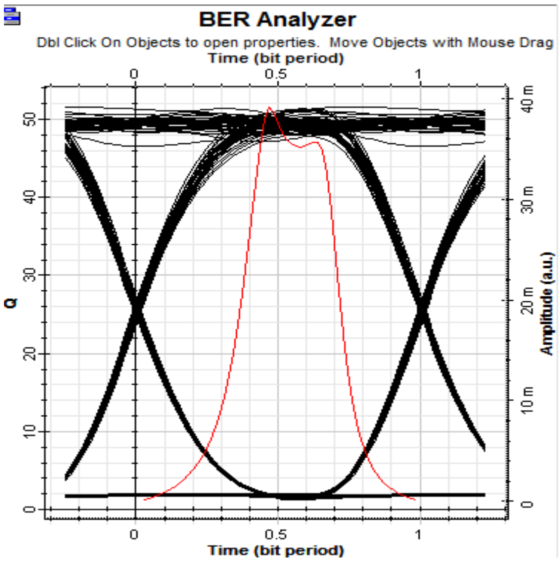

Fig 6: Output of BER analyser at 50mw with amplifier

As the power of transmitter is increased to 50 mW the FSO link not containing amplifier is still giving the Q factor less than 6 at output of BER analyser showing lot of disturbance and noise in received signal. Whereas the FSO link having amplifier is giving much better results. The difference between both the links can be clearly seen from figure 5 and 6.The minimum BER that was 8.48869e-009 without the use of amplifier becomes zero after using amplifier in the link that indicates the error rate reduces to zero. Similarly the received power of the signal increases to 18.150628mW when amplifier is employed in the link.

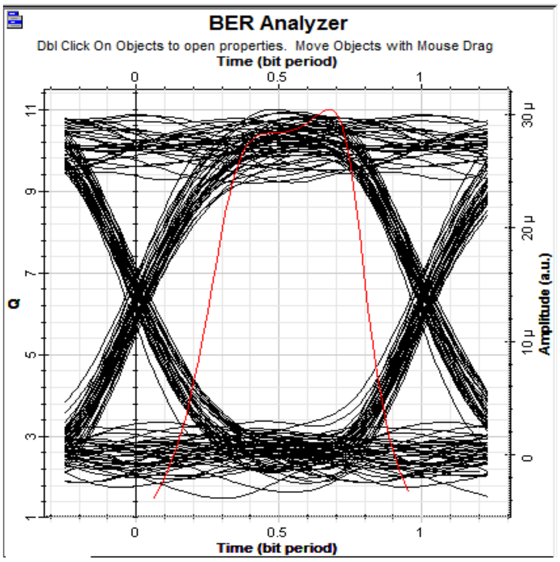

Fig 7: Output of BER analyser at 100mw without using amplifier

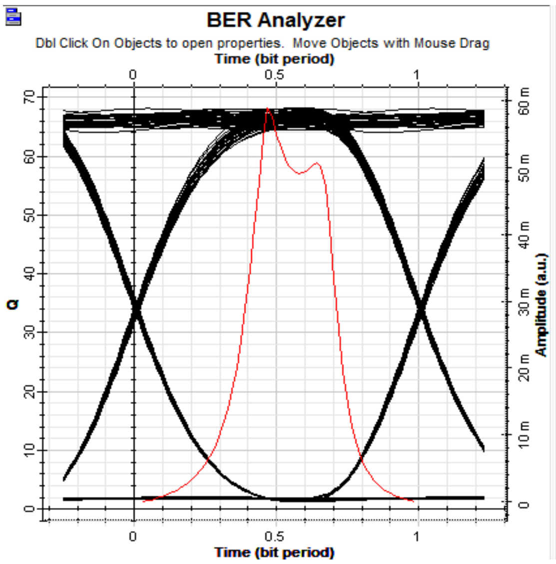

Fig 8: Output of BER analyser at 100mw with amplifier

Figure 7 and 8 are the output of BER analyser at transmitter power 100 mW. In the absence of amplifier, though the Q factor is more than 6 but the received power of the signal is very less. In the other case when amplifier is used in the link the results can be observed. Value of Q factor, minimum BER, Eye height and received signal power is much better than previous case that clearly shows the importance of employing amplifier in the FSO link. Additionally by employing amplifier in the link the range of communication link can also be increased.

Table 2: Comparison among the parameters of FSO link with the use and without using EDFA

	Without using Amplifier in FSO link			Using Amplifier in FSO link		
Power of Transmitter	10mW	10mW	10mW	10mW	50mW	100mW
Max. Q factor	0	0	0	20.0308	51.6072	68.2757
Min. BER	1	1	1	1.1753e-089	0	0
Eye height	0	0	0	0.00842736	0.0347076	0.0541479
Received signal power(mW)	0.039148e-009	0.039148e-009	0.039148e-009	4.82299056	18.150628	26.645354

Table 2 shows the comparison of results among the two FSO links with presence and absence of EDFA in terms of minimum BER, Q factor, received signal power and height of eye diagram values at the output of BER analyser.

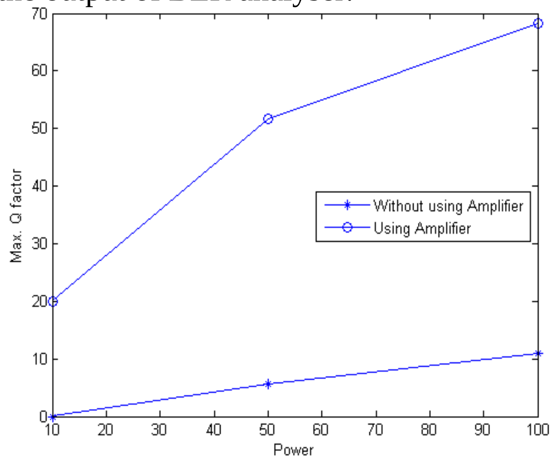

Fig 9: Characteristic curve of Q factor versus transmitted power

It can be visualised that the curve of Q factor is becoming sharper and the value of Q factor is increasing with the use of EDFAs in the link at same attenuation condition. The obtained Q factor is more in case of presence of EDFAs which shows that the received signal quality is good with the presence of EDFAs in the optical wireless link as illustrated in figure 9.

Similarly with the introduction of EDFA in the link, BER reduces to zero at 50 mW and 100 mW power of transmitter, that clearly indicates there is no error in the received signal at these powers. Similarlywhen the EDFA is absent from the link the received power of the signal is very less which has been improved by the amplifier many times from the previous value.

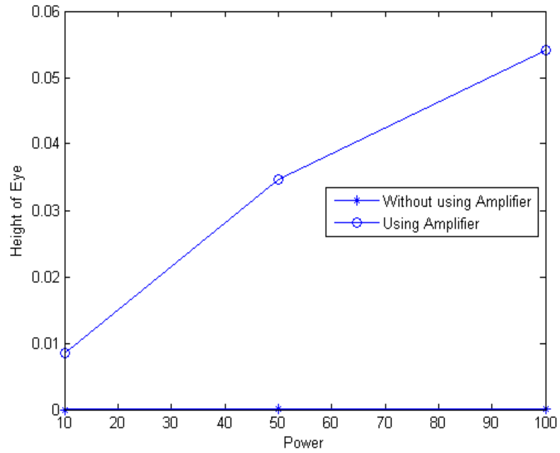

Fig 10: Characteristic curve of height of eye diagram versus transmitted power

As indicated in figure 10, the height of the eye diagram of the signal even at very small power i.e. 10mW is more than the optimum value due to presence of EDFA, whereas communication in free space at such low power without using EDFA is not possible.

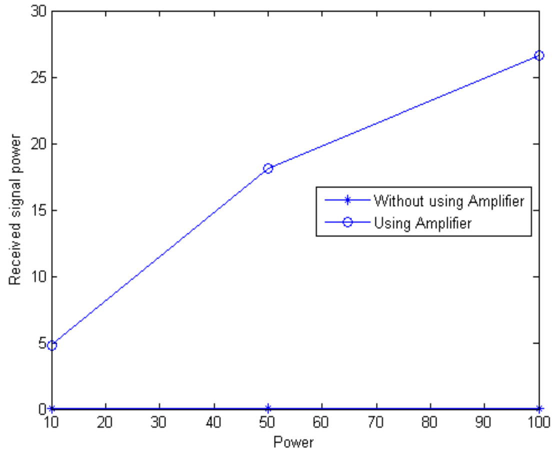

Fig 11: Characteristic curve of received power versus transmitted power

Figure 11 shows that with the presence of EDFA in the the power of received signal increases as compared to absence of EDFA in the link. The received signal has optimum strength that it can easily be sensed at receiver with high accuracy. It can be clearly seen that with the introduction of EDFA in the link the output of BER analyzer is improved thus increasing the overall capacity, accuracy and efficiency of free space optical communication.

Conclusion

This investigation presents the simulation results of presence and absence of EDFA in a FSO link. The results of simulations of FSO link has been observed in terms of BER, Q factor, received signal power and eye diagram values. A significant reduction in values of BER and increase in value of Q factor is observed with the introduction of EDFA's in the link. It is thus concluded that the introduction of optical amplifiers in the link increases the capacity, accuracy and reliability of the link in highly attenuated channels.

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