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Comparative Analysis of Free Space Optical Communication System for Various Optical Transmission Windows under Adverse Weather Conditions

Shaina* and Amit Gupta

Chandigarh University, Gharuan 140 413, India

Abstract

Free Space Optics (FSO) link offers gigabit per second data rates with less system complexity. However, the availability of link under various atmospheric conditions is a major concern. As these links are highly weather dependent, thus increase in signal attenuation under these conditions reduces the link efficiency. This paper evaluates the effects of bad weather conditions on FSO link having range 500 meters up to attenuation of 70 dB/km. The suitability of three optical transmission windows that are 850 nm, 1310 nm and 1550 nm, with the FSO link is analysed and compared in this work. Simulation parameters such as Quality factor, minimum BER and Eye diagram are taken into consideration. The results of analyzer for various transmission windows are compared to find out the most suitable wavelength of transmitter under adverse weather conditions for reliable communication.

Peer-review under responsibility of organizing committee of the Organizing Committee of IMCIP-2016

Keywords: Attenuation; BER Analyzer; Free Space Optics (FSO); Optical Transmission Windows; Spectrum Analyzer.

1. Introduction

The Free Space Optics (FSO) system has fascinated the attention of large numbers of users as it has proved to be the best solution the last mile problem for communication in urban areas[1,2]. It has come up as a better alternative to Radio Frequency (RF) technology for reliable and feasible deployment of communication networks[3]. Though the deployment of RF wireless networks is rapid having data rates up to several hundred Mps but the increase in traffic of users, range limitations and small available bandwidth has posed several drawbacks in the communication using this technology[4]. FSO technology can easily replace RF technology due to its very high bandwidth up to 2.5 Gbps. In fact, FSO is best suited for multi Gbps data rate communication. License free bands, robustness, high data rate transmissions, high security and negligible signals interference appear promising for high speed wireless communication[5,6].

The only drawback of the FSO link is that its performance is strongly dependent on atmospheric attenuations. Different atmospheric conditions like snow, fog and rain scatter and absorb the transmitted signal, which leads to attenuation of information signal before receiving at receiver end[7]. Maintenance of an apparent Line of Sight (LOS) between transmitter and receiver end is the main confront to set up communication through FSO technology especially

*Corresponding author. Tel.: +918054341848.
E-mail address: nagpalshaina92@gmail.com

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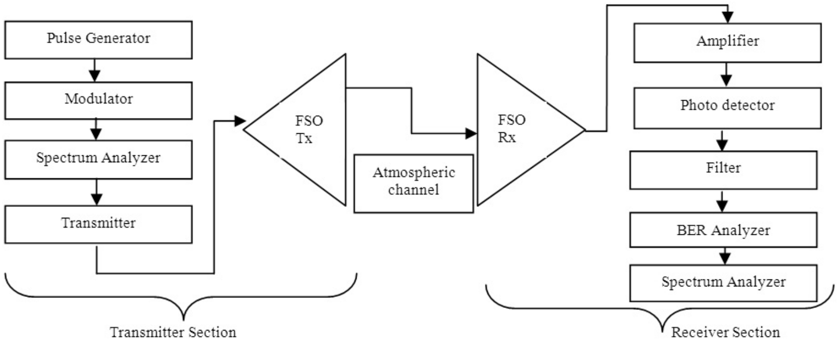


Fig. 1. Block diagram of FSO Link.

in the troposphere. As a result of attenuation caused by atmospheric conditions the range and the capacity of wireless channel are degraded[8]. Thereby restricting the potential of the FSO link by limiting the regions and times[9].

In order to completely exploit the remarkable bandwidth of FSO technology, it is required to properly characterize the influence of various weather conditions and to use the different optical windows of transmission to mitigate the effects of increasing signal attenuation[10]. In this paper, three optical transmission windows are considered that are 850 nm, 1310 nm and 1550 nm each having their own advantages. Equipments operating on 850 nm wavelength are usually cheaper than equipments operating at higher wavelengths. The window at 1310 nm has zero group velocity dispersion. And at 1550 nm the loss of optical fiber is minimum that is 0.2 dB/km[11]. Low loss means the distance between 3R repeater and Optical Amplifier can be large. 1550 nm is also a eye safe wavelength. Erbium Doped Fiber Amplifier (EDFA) can also be used in the FSO if the link is operating at 1550 nm. EDFA provides second largest peak gain at this wavelength[12].

The three wavelengths mentioned above are mainly chosen among large wavelengths in the spectrum due to the transmission properties of existing light sources best match with the transmission qualities of these optical windows. The attenuation of the information signal travelling in free space is much less at these wavelengths[13]. The attenuation of signal that deteriorates the quality of signal is mainly caused by two factors, absorption and scattering. So, these three optical transmission windows are preferred as compared to other wavelengths in infrared spectrum of light[14].

The paper focuses on finding the optical transmission window that is best suited for FSO link under the atmospheric factors chosen. Comparison is made in terms of Q factor, minimum BER, Eye diagram of received signal and power of signal using different windows of optical transmission. The remaining paper is structured as follows. In Section 2, the FSO system is explained. In Section 3, the output of FSO system is analyzed using output of BER analyzer. The analysis of system output in terms of signal power is outlined in Section 4, and the conclusions drawn are provided in Section 5.

2. System Description

The FSO link comprises of transmitter, atmospheric channel and the receiver. As shown in Fig. 1 the transmitter in the FSO link is used to transmit information signal in free space by modulating the electrical information signal into optical signal. The optical signal travels through free space which is captured by the receiver and is converted into an electrical signal. The transmitting module consists of a pulse generator, modulator, spectrum analyser and a transmitter. The pulse generator used in the link generates pulses that carry information in electrical form. Spectrum analyzer is used to display the scale of an input signal versus frequency within the complete frequency range of device. Then the signal is transmitted over free space through the transmitter. In the atmosphere, the signal is scattered, absorbed and attenuated as a result of turbulences and atmospheric variations[14]. Total attenuation of signal travelling through FSO communication link can be calculated as:

$$\alpha = \alpha \mathrm{fog}_\gamma + \alpha \mathrm{snow}_\gamma + \alpha \mathrm{rain}_\gamma + \alpha \mathrm{scattering}_\gamma\,, \ \mathrm{dB/km} \tag{1}$$

where, $\alpha =$ attenuation and $\gamma =$ is operational wavelength in μm.

The receiver on the other end includes an amplifier, photo detector, filter, BER analyzer and spectrum analyzer for properly retrieving the information signal. The amplifier used in the link improves the signal strength of received signal. The photo detector detects the incoming optical signal and after converting it to electrical form transmits the signal to filter. The filter reduces the environment noise and enables the passage of the desired wavelength of the signal through it. The BER analyzer is used to determine the accuracy of received signal. The Bit Error Rate (BER) is the average probability of correct bit identification out of total received bits[15].

3. System Model Analysis Based on Output of BER Analyzer

In this section, the performance of FSO system is analysed using BER analyzer. BER of 10^{-6} corresponds to on average one error per million bits. Ideally, the value of BER should be 10^{-9} as the maximum error rate present in the reception of bits for a reliable and long range communication system[8].

$$\text{Mathematically, BER} = \frac{\text{Number of Errors}}{\text{Total number of bits sent}} \tag{2}$$

BER can also be expressed in terms in signal to noise ratio of received information signal as[17,18]:

$$\text{BER} = \frac{2}{\pi.SNR} \cdot \exp\left(\frac{-SNR}{8}\right), \tag{3}$$

Output of the system is checked for three different optical transmission windows at different atmospheric attenuation values that are 5 dB, 20 dB, 40 dB and 70 dB respectively using BER analyser.

3.1 850 nm

The transmitter is operated at 850 nm, that is first optical transmission window to check the performance of FSO link. Figures 2, 3, 4, 5 are showing the output of the FSO system having operating signal wavelength of 850 nm. As the signal is transmitted through atmospheric channel it faces atmospheric attenuation. The results are clearly showing that even at attenuation of 70 dB, the value of Q factor is greater than minimum value required of 6 and minimum BER is less than 10^{-9}. The value of height of eye at 70 dB is 1.26308e-005 and received signal power is found to be 9.5739185e-006.

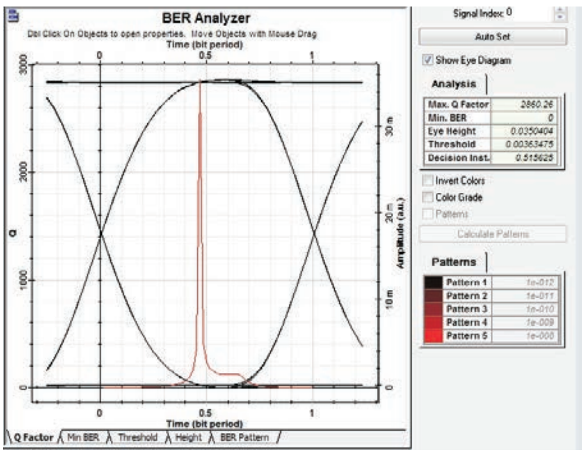


Fig. 2. Output of BER Analyser at Attenuation 5 dB/km.

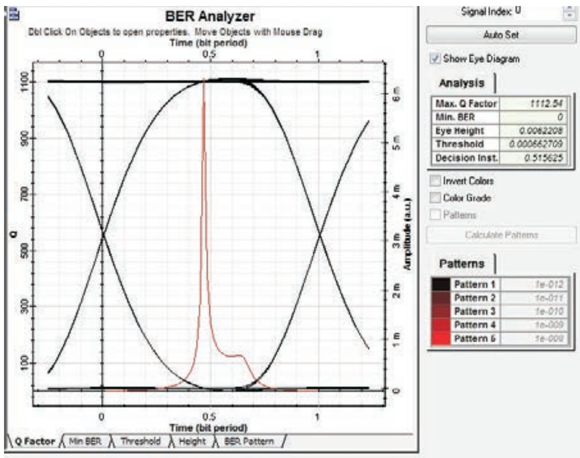


Fig. 3. Output of BER Analyser at Attenuation 20 dB/km.

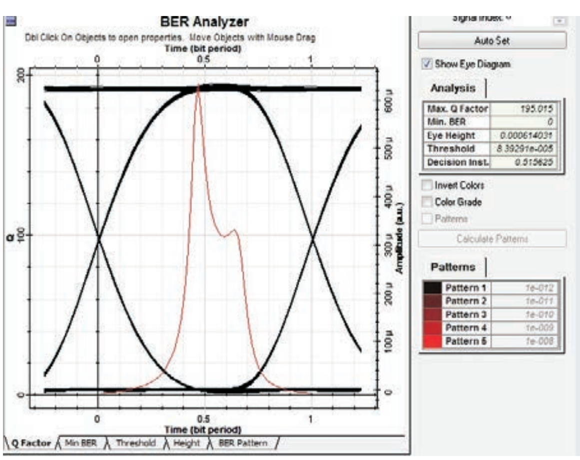


Fig. 4. Output of BER Analyser at Attenuation 40 dB/km.

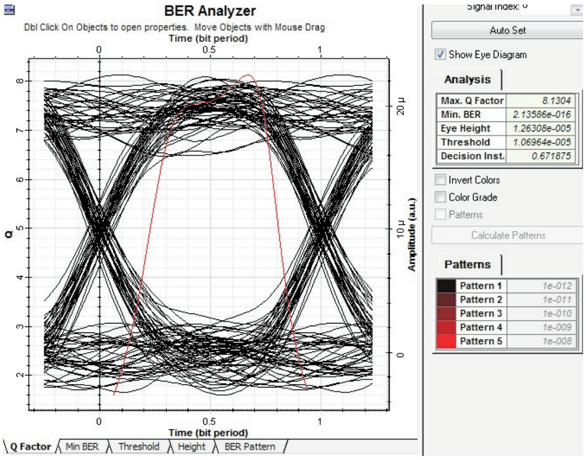


Fig. 5. Output of BER Analyser at Attenuation 70 dB/km.

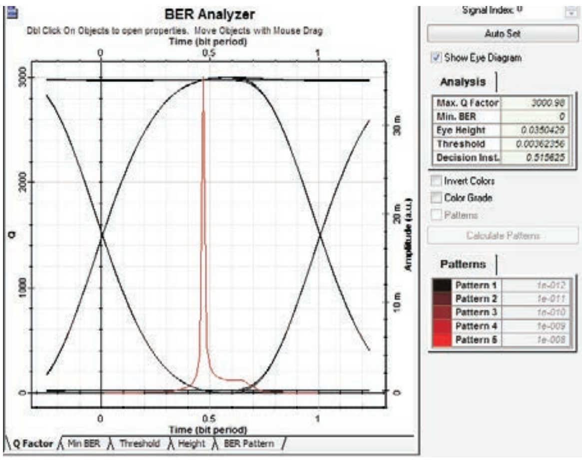


Fig. 6. Output of BER Analyser at Attenuation 5 dB/km.

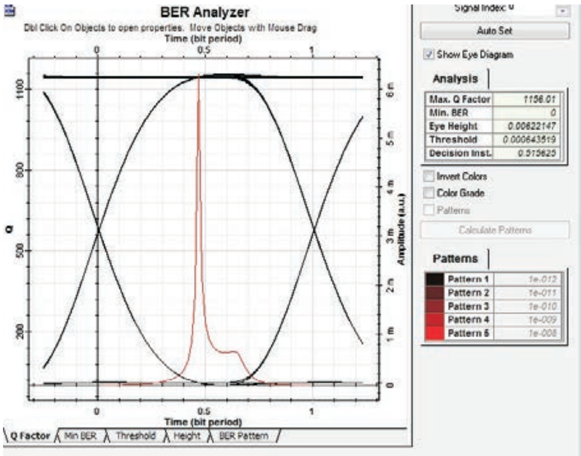


Fig. 7. Output of BER Analyser at Attenuation 20 dB/km.

3.2 1310 nm

The second optical transmission window chosen for evaluation of FSO link is 1310 nm. Figures 6, 7, 8 and 9 show the output of the FSO system at this wavelength. As the signal attenuation rises up to 70 dB the transmitter device operating at 1310 nm give optimum results but not as good as 850 nm. Q factor reduces to 7.95 and the minimum BER becomes 8.66465e-005. The height of eye diagram calculated at this wavelength is 1.22742e-005 and the received signal power is found to be 9.4198189e-006.

3.3 1550 nm

Figures 10, 11, 12 and 13 show the output of the FSO system at 1550 nm. At 70 dB attenuation the transmitter device operating at 1550 nm does not give optimum results as the Q factor reduces to 2.59 and the minimum BER is 0.00153508. The height of eye diagram is negligible. At high attenuation conditions first two optical transmission

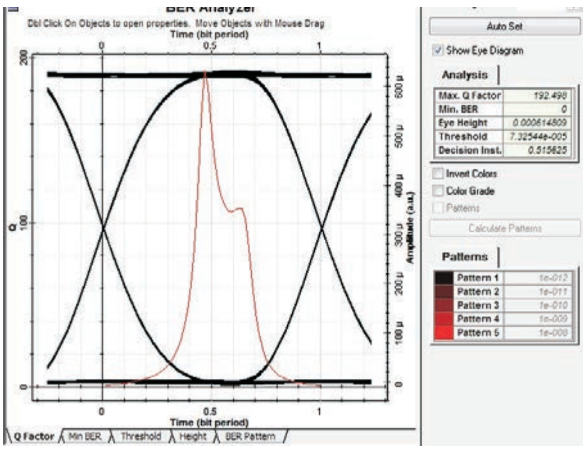


Fig. 8. Output of BER Analyser at Attenuation 40 dB/km.

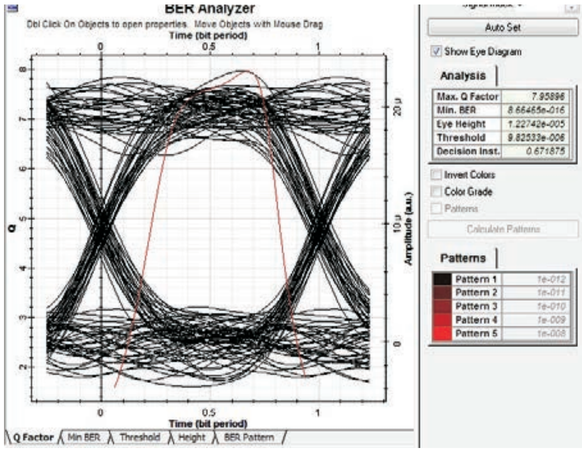


Fig. 9. Output of BER Analyser at Attenuation 70 dB/km.

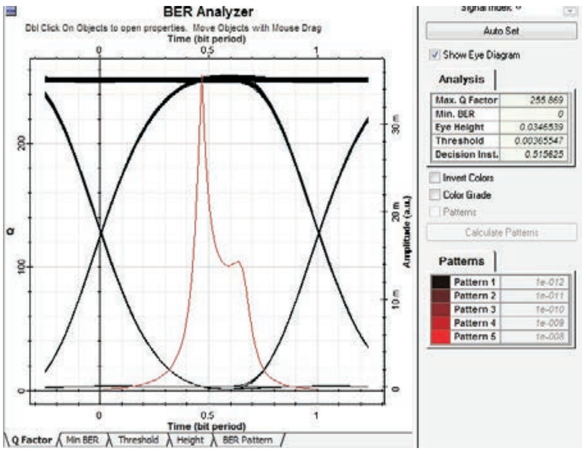


Fig. 10. Output of BER Analyser at Attenuation 5 dB/km.

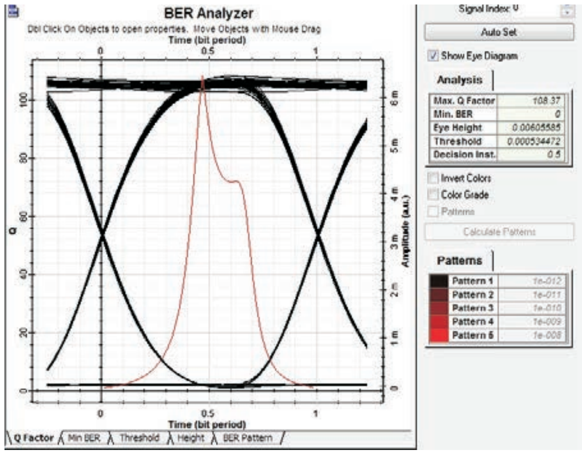


Fig. 11. Output of BER Analyser at Attenuation 20 dB/km.

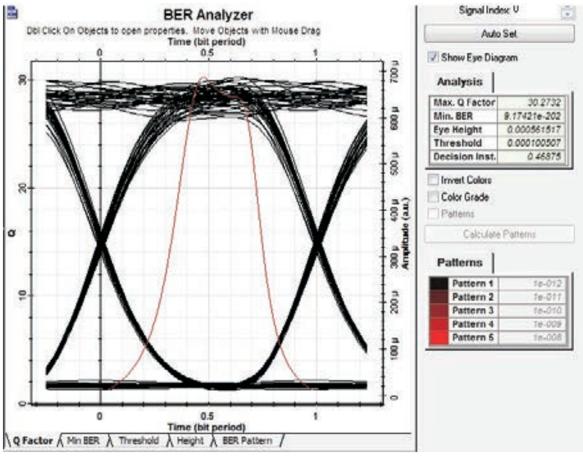


Fig. 12. Output of BER Analyser at Attenuation 40 dB/km.

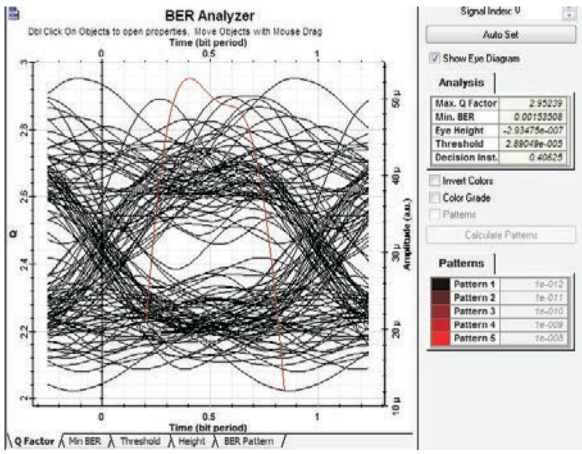


Fig. 13. Output of BER Analyser at Attenuation 70 dB/km.

Table 1. Comparison among Bit Error Rate of the Signal received at the link using different Optical Transmission Windows under effects of Attenuation.

Attenuation(dB/km)	850 nm	1310 nm	1550 nm
5	0	0	0
20	0	0	0
40	0	0	9.17421e-202
70	2.13586e-016	8.66465e-016	0.00153508

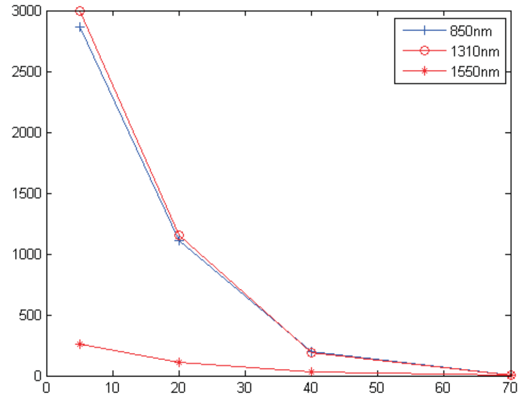


Fig. 14. Comparison of Quality Factor of system at different Optical Windows.

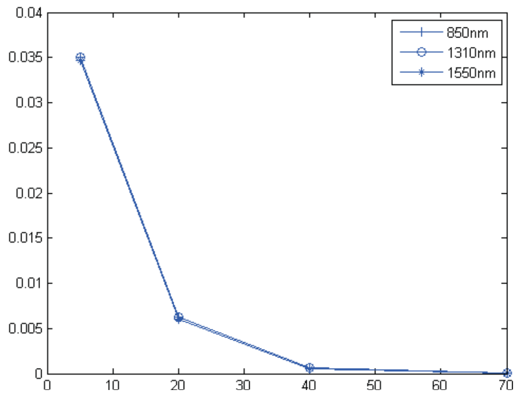


Fig. 15. Comparison of Height of Eye taken at different Optical Windows.

windows give better results than 1550 nm. The received signal power at this window is same as 1310 nm that is 9.4198189e-006.

Table 1 shows the comparison of the BER performance of link using different optical windows at various values of attenuation. The first optical window has shown least BER as compared to both high optical transmission windows. Figures 2–13 have illustrated that BER increases with increasing value of attenuation for all three optical transmission windows. 1310 nm window has offered lower bit error rate as compared to 1550 nm window. As the BER is negligible for all three windows at low attenuation conditions, so 1550 nm should be preferred due to safety of users. But at high attenuation conditions 1310 nm is useful due to less BER, high Q factor and safer as compared to 850 nm transmission window.

Graphical representation of quality factor shown in Fig. 14 above compares the performance of FSO link for different optical windows. It can be clearly visualised that the window at 1310 nm is giving better results as compared to other two optical windows. Similarly in Fig. 15, the comparison of height of eye taken at various values of attenuation for different optical windows is also contributing to the fact that this window is optimum for use at high attenuation conditions.

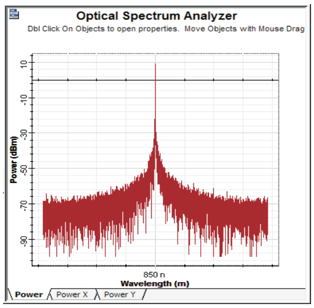
4. System Model Analysis Based on Output of Spectrum Analyzer

A spectrum analyzer is a precision measuring device that displays the dispersion of power of an light source over a defined value of wavelength. It traces power in the vertical scale and the wavelength in the horizontal scale. Its applications include testing laser and LED light sources[10].

Table 2 below shows the comparison of output of spectrum analyser before and after transmission using three optical transmission windows that are 850 nm, 1310 nm and 1550 nm. It shows the signal power at the transmitter in the case of different optical windows. The power in all the cases is same before transmission that is 14.83085 dBm.

However, the output of spectrum analyser after the signal attenuation of 70 dB shows the reduction in signal power. It can be visualised that the signal power at the receiver in the case using different optical windows after undergoing

Table 2. Comparison of the power of signal before and after transmission using three optical windows.

<table>
<tr><th>Window</th><th>850 nm</th><th>1310 nm</th><th>1550 nm</th></tr>
<tr><td>Output of Analyzer before transmission</td>
<td>
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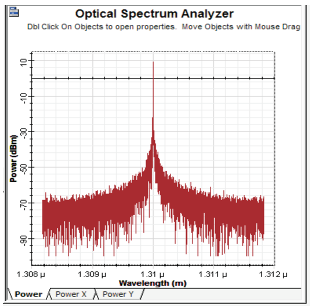
<td>
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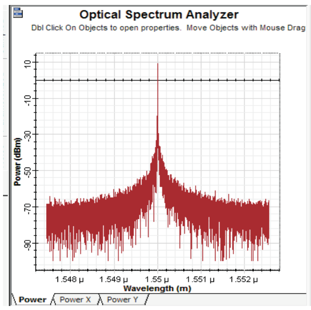
<td>
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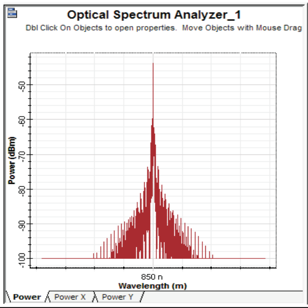
<tr><td>Output of Analyzer after undergoing attenuation of 70 dB at Receiver end</td>
<td>
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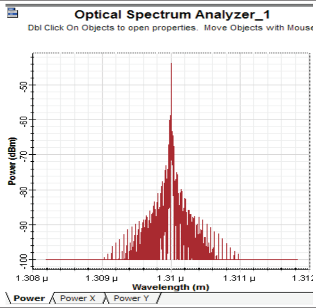
<td>
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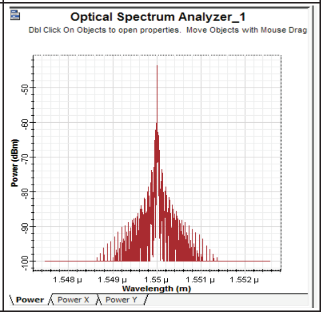
<td>
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attenuation of 70 dBm in case of 850 nm is −40.8880 dBm, in case of 1310 nm is −40.9990 dBm and for 1550 nm the signal power is −40.7786 dBm.

5. Conclusions

The FSO communication link has been investigated under the different atmospheric conditions using three optical transmission windows that are 850 nm, 1310 nm and 1550 nm. It is observed that under low attenuation conditions, at 1550 nm wavelength, propagation distance is maximized and BER is minimized. So, 1550 nm should be preferred at low attenuation conditions. According to the simulation results, it is found that the 850 nm operational optical window leads to the large Q factor and height of eye and therefore the decreased bit error rates at high attenuation conditions. However, the second optical transmission window i.e 1310 nm also giving better results at high attenuation conditions and is safer as compared to 850 nm window for users. So, 1310 nm window is best for transmission in high levels of attenuations.

References

[1] E. Leitgeb, M. Gebhart and U. Birnbacher, Optical Networks, Last Mile Access and Applications, *Journal of Optical Fiber Commun. Res.*, vol. 2(1), pp. 56–85, (2005).

[2] J. C. Ricklin, S. M. Hammel, F. D. Eaton and S. L. Lachinova, Atmospheric Channel Effects on Free-Space Laser Communication, *Journal of Optical Fiber Communications*, vol. 3(2), pp. 111–158, (2006).

[3] X. Zhu and J. M. Kahn, Free Space Optical Communication Through Atmospheric Turbulence Channels, *IEEE Transactions on Communications*, vol. 50(8), pp. 1293–1300, (2002).

[4] E. Leitgeb, T. Plank, M. Loschnigg and P. Mandl, Free Space Optics in Different (Civil and Military) Application Scenarios in Combination with Other Wireless Technologies, *16th IEEE International Conference on Telecommunications Network Strategy and Planning Symposium (Networks)*, pp. 1–7, (2014).

[5] M. Grabner and V. Kavicera, Multiple Scattering in Rain and Fog on Free-Space Optical Links, *Journal of Lightwave Technology*, vol. 32(3), pp. 513–520, (2014).

[6] P. S. Andre, A. N. Pinto, J. L. Pinto, T. Almeida and M. Pousa, Selective Wavelength Transparent Optical Add-Drop Multiplexer Based on Fiber Bragg Gratings, *Journal of Optimum Communication*; vol. 24(3), pp. 222–229.

[7] A. Vavoulas, H. G. Sandalidis and D. Varoutas, Weather Effects on FSO Network Connectivity, *Journal of Optical Commun. Networks*, vol. 4(10), pp. 734–740, (2012).

[8] M. Baskaran, S. Ethiraj and T. Gokulakrishnan, Eliminating the Effects of Fog and Rain Attenuation for Live Video Streaming on Free Space Optics, *International Journal of Systems, Algorithms & Applications*, vol. 2, (2012).

[9] M. Ijaz, Z. Ghassemlooy, J. Perez, V. Brazda and O. Fiser, Enhancing the Atmospheric Visibility and Fog Attenuation using a Controlled FSO Channel, *IEEE Photonics Technology Letters*, vol. 25(13), pp. 1262–1265, (2013).

[10] S. Saini and A. Gupta, Investigation to Find Optimal Modulation Format for Low Power Inter-Satellite Optical Wireless Communication, *Eleventh International Conference on Wireless and Optical Communication Networks*, pp. 1–4, (2014).

[11] A. E. N. A. Mohammed, A. N. Z. Rashed and M. S. F. Tabour, Transmission Characteristics of Radio Over Fiber (ROF) Millimetre Wave Systems in Local Area Optical Communication Networks, *International Journal of Advanced Networks and Applications*, vol. 2(6), pp. 876–886, (2011).

[12] F. Nadeem, V. Kvicera, M. S. Awan, E. Leitgeb, S. Muhammad and G. Kandus, Weather Effects on Hybrid FSO/RF Communication Link, *IEEE Journal on Selected Areas in Communication*, vol. 27(9), (2009).

[13] S. Sarkar, S. Dixit and B. Mukherjee, Hybrid Wireless Optical Broadband Access Network (WOBAN): A Review of Relevant Challenges, *IEEE/OSA Journal on Lightwave Technology*, vol. 25(11), pp. 1233–1239, (2006).

[14] A. K. Majumdar and J. C. Ricklin, Free Space Laser Communications, *Principles and Advantages, Berlin: Springer*, (2008).

[15] A. E. N. A. Mohamed, H. A. Sharshar, A. N. Z. Rashed and A. El-Nabawy, Integrated Service Quality Enhancement of Wireless Optical Communication Systems for Long Haul Transmission Distances, *Canadian Journal on Electrical and Electronics Engineering*, vol. 2(12), pp. 557–570, (2011).

[16] A. Gupta, R. S. Kaler and H. Singh, An Inimitable Scheduling Technique for Optical Burst Switched Networks, *Optik-International Journal for Light and Electron Optics*, vol. 124(8), pp. 689–692, (2013).

[17] S. Bloom, E. Korevaar, J. Schuster and H. Willebrand, Understanding the Performance of Free-Space Optics, *Journal of Optical Networking*, vol. 2(6), (2003).

[18] M. Jeong, J. Lee, S. Kim, S. Namgung, J. Lee, M. Cho, S. Huh, Y. Ahn, J. Cho and J. Lee, Weather-Insensitive Optical Free-Space Communication Using Gain-Saturated Optical Fiber Amplifiers, *IEEE Journal of Lightwave Technology*, vol. 23(12), (2005).