PERFORMANCE OPTIMIZATION OF FREE SPACE OPTICAL LINK

Preet Kanwal
Lecturer, MCPC, Jalandhar, Punjab, India

Abstract

The fibre optic cable technology is the best choice in the telecommunication industry now days. Fibre is the most reliable media for many applications in various areas and communication connectivity. However, using fibre optic is extremely uneconomical. However the RF Technology and copper wires are early used because of their demerits in particular areas. The percentage of copper technology use is higher than fiber, but it does not solve the bottleneck of connectivity problem and bandwidth capability limitation. Losses in copper cables increase with the frequency, the more information carried in copper conductors, the higher the losses. Therefore the most popular alternative for best communication is Free Space Optical (FSO). FSO provides higher bandwidth to the end user at a faster speed. Because of high bandwidth availability (currently capable of up to 2.5Gbps), a large amount of data can be transmitted through a narrow laser beam. FSO is also portable, quickly deployable and cost effective, costing on average one-fifth the cost of installing fibre optic cable. We have optimized the FSO link at data rate of 1.25Gbps at link length of 800 meters using NRZ modulation format. The proposed link can tolerate an additional attenuation of -5.02dB. It is also shown that the beam divergence can be increased to 2.5x10^{-3} and the system performance does not degrade even if these parameters are changed to this extent.

Keywords: FSO, NRZ, RF.

1. INTRODUCTION

Free-space optical (FSO) communication also known as wireless optical communication is a cost-effective and high bandwidth access technique and has compelling economic advantages. With the potential high-data-rate capacity, low cost and particularly wide bandwidth on unregulated spectrum, FSO communications is an attractive solution for the "last mile" problem to bridge the gap between the end user and the fiber-optic infrastructure already in place. In FSO communications, optical transceivers communicate directly through the air to form point-to-point line-of-sight links. The transmitter converts the electrical signal to an optical one and sends it through the atmosphere (free space). The receiver converts the optical signal back to an electrical signal. The quality of the transmission line is characterized by the realized bit-error rate (BER). Major impairments over FSO links are atmospheric attenuation and scatter phenomena that vary widely from one micrometeorological area to another. Included here are scintillation, scattering, beam spreads, and beams wander [3]. Scintillation is best defined as the temporal and spatial variations in light intensity caused by atmospheric turbulence. Such turbulence is caused by wind and temperature gradients that create pockets of air with rapidly varying densities and therefore fast-changing indices of optical refraction. The signal attenuation caused by scintillation effect depends on the time of day and can vary orders of magnitude during a hot day. It drastically increases with distance and can impact the BER performance (burst errors) on a milliseconds timescale.

2. SYSTEM DESIGN

The basic FSO link consists of a transmitter, FSO channel, and receiver. Most current FSO systems use in transmitters either LED or diode or semiconductor lasers (e.g. VCSEL) lasing at wavelength 800-850 nm or 1500- 1550 nm. Laser can be either CW with external modulation or directly modulated (for example with NRZ OOK or DPSK). Receivers can feature detectors based on either PIN or APD. Figure 1 shows a simple FSO link design under study with link parameters reported in [3]. Transmitter consists of PRBS generator at bit rate 1.25 Gb/s, NRZ Driver, and directly modulated LED at 1550 nm. Optical power out of transmitter is 1.3 dBm. FSO link has a 500 meters range with beam divergence angle of 3m rad. The environmental additional attenuation is specified by its mean value of –4.92 dB and standard deviation (sigma) of 1.9 dB. Receiver is a PIN/TIA (with Bessel-Thompson electrical filter with 1 GHz bandwidth) and is followed by BER Tester[13]. There are also Optical Meter, Spectrum, Eye Diagram, and Optical Waveform Analyzers. Next, to study FSO link performance dependence on stochastic variations in additional attenuation α and we can apply two simulation techniques: 1) parameter scan over the range of values for additional attenuation; 2) statistical Monte-Carlo runs where each time additional attenuation will take a random values according to specified values of mean and standard deviation and a type of statistical distribution.

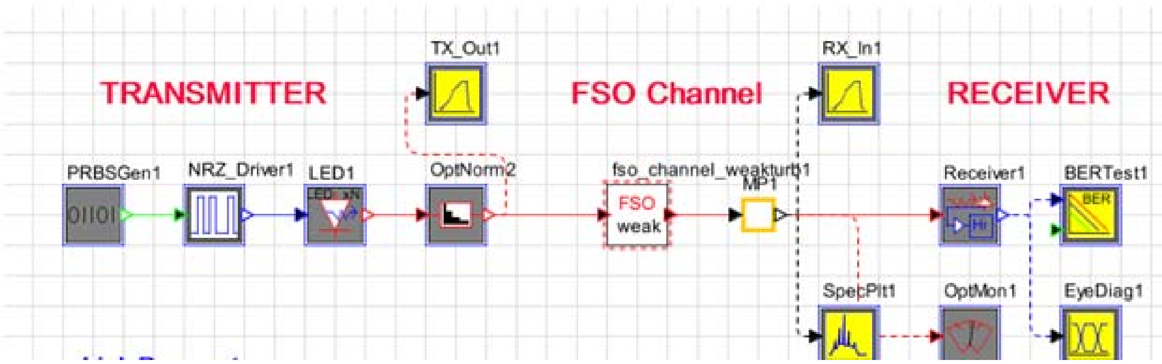


Fig 1 Free Space Optical Communication Link

FSO transmitter consists of PRBS generator that basically produces random bit codes that is the basic input signal codes required for driving the circuit which means the information to be transmitted. The NRZ driver converts the information to NRZ format to be provided to the LED to be processed and to be converted to light signal that is being presented to the FSO link [1] which is a wireless point to point communication in which the points have clear line of sight between them. This line of sight technology currently enables full duplex optical transmissions at gigabits per second speeds over metropolitan distances of a few city blocks to a few kilo-meters [6]. This is more than enough to support data, voice and video traffic, in addition providing for connectivity without deploying fiber optic cable or securing spectrum licenses. Typically, the optical transceivers are mounted on building rooftops or placed in large windows [2]. The link parameters utilised for the system are:

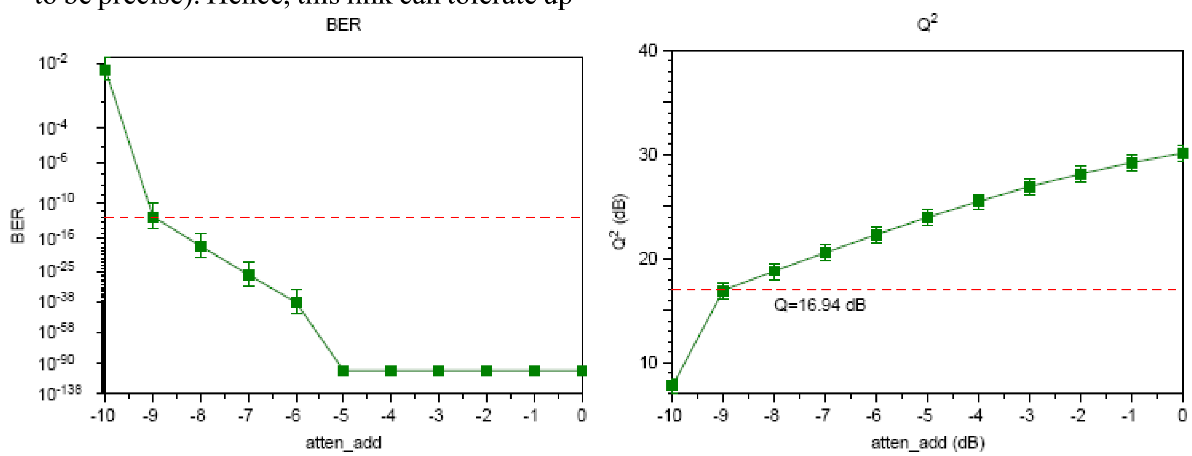
- ✓ Wavelength = 1550e-9
- ✓ Bit rate = 1.25e9
- ✓ Transmitter power = 1.3
- ✓ Distance = 500
- ✓ Divergence = 3e-3
- ✓ Additional Attenuation = -4.92
- ✓ Sigma = 1.9

3. RESULTS AND DISCUSSIONS

Performance of the modelled optical communication link is gauged on the basis of Eye opening, Q-factor, BER and additional attenuation. The output has been obtained on the sample basis that illustrates that higher the attenuation, worse is the performance. The results have been obtained in order to ensure the optimal functioning of the system over entire wavelength range.

3.1. Performance evaluation of BER, Q-factor and Optical Power

The results of the parameter scan are shown in fig. 2 and 3. Assume that the BER performance requirement is equal or less than 10-12 we can see that additional attenuation should be less than –9 dB to satisfy the BER requirements [5]. Total FSO channel loss is a sum of geometrical and additional attenuations. The geometrical loss for given parameters here is about -20 dB (-19.92 dB to be precise). Hence, this link can tolerate up to –29 dB losses in FSO channel. Fig.5 shows optical power into receiver v/s attenuation. The threshold value of additional attenuation (-9 dB) corresponds to received power of –27.6 dBm. The change in receiver input power due to variation in additional attenuation causes the change in BER. Second, we apply a statistical approach, which will be more representative taking into account the statistical nature of signal fading in FSO systems.



(a) (b)

Fig 2 (a) BER v/s additional attenuation and (b) Q factor v/s Additional Attenuation (BER = 1e-12)

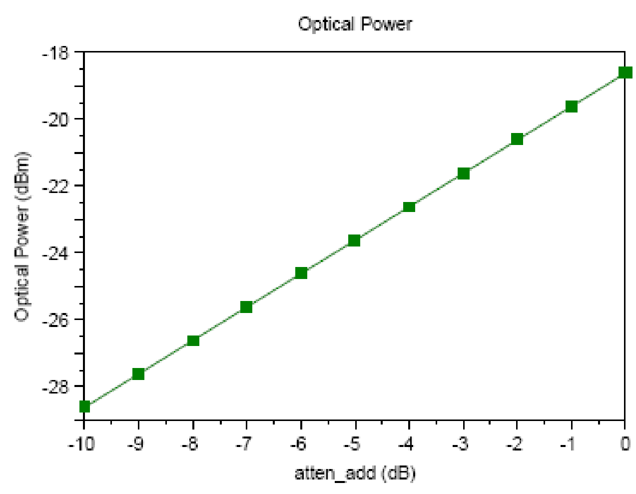


Fig 3 Input optical power to the receiver v/s additional attenuation of FSO channel.

3.2. NRZ Modulation format

The performance evaluation of the NRZ modulation format has been analyzed in terms of bit error rate (BER), Q factor (Q^2 (dB)) and eye diagrams against additional attenuation. The Optimization parameters that are taken into consideration in this case are Distance (distance) and Additional Attenuation (atten_add). At a distance of 500m, the response shown in the form of eye diagram is:

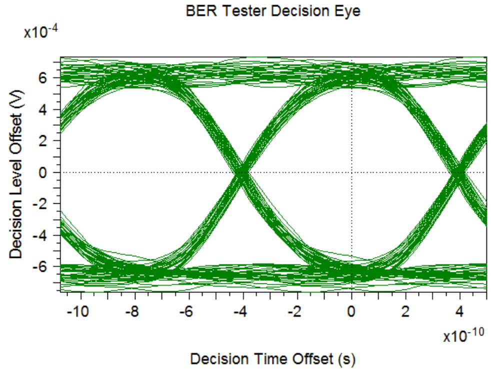


Fig.4 Eye Diagram at a distance of 500m with link parameters

Fig.5 and 6 shows the Q^2 (dB) characteristics with respect to distance and additional attenuation respectively

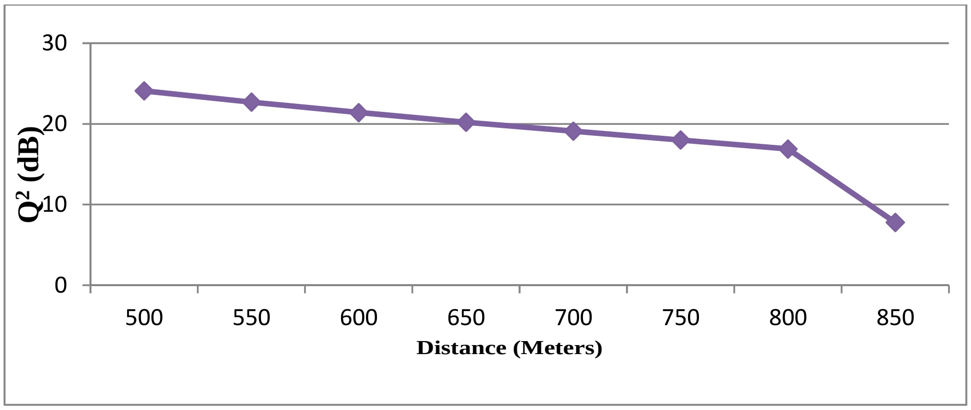


Fig.5 Q^2 (dB) v/s Distance Characteristics

Fig.5 shows that the quality of the system responds well up to the distance of 800 meters. But it reduces after that i.e. the quality of the system gradually degrades at 850meters of distance. So the distance of 800 meters is an optimized distance and the system can work well up to this distance.

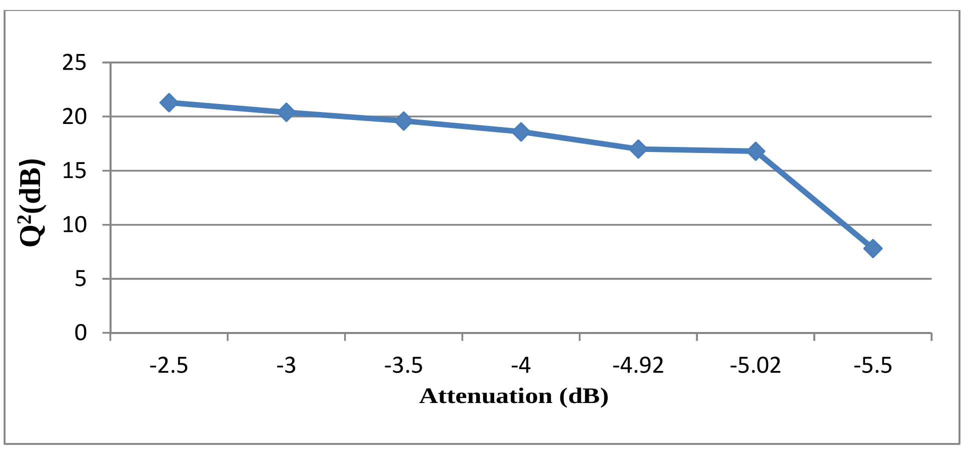


Fig.6 Q^2 (dB) v/s Additional Attenuation [dB] characteristics

Fig. 6 shows that the quality of the system is good at the additional attenuation of -5.02 dB. That means the system can respond well and it can handle the additional attenuation of this much value without degrading its quality. But after this value, the quality of the system degrades and so -5.02dB is an optimized value.

4. OPTIMIZATION RESULT

At a distance of 800 meters, the Q^2 (dB) ranges between 17 and 19.8 while keeping the additional attenuation to be -5.02 and the beam divergence to be $2.5x10^{-3}$ and at the same values of the distance, attenuation and beam divergence, the BER value ranges from 10^{-12} to 10^{-23} which is acceptable and Eye diagrams of these ranges are shown below:

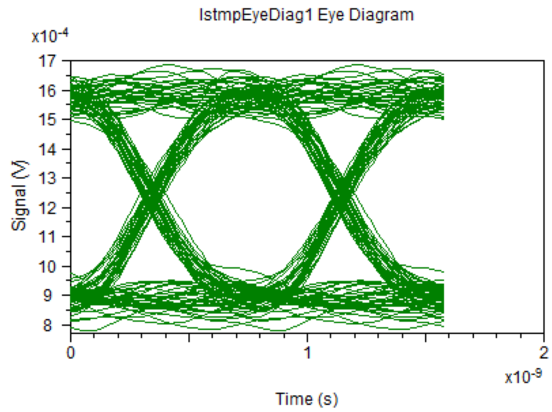


Fig.7 Eye Diagram of the Optimized Parameters

This eye diagram shows that at a distance of 800meters, with an additional attenuation of -5.02dB, the quality of the system is good and eye diagram shows a good response. So, these are the optimized parameters and the system responds well under these conditions.

REFERENCES

[1] Free-Space Optical Communication With Spatial Modulation and Coherent Detection Over H-K Atmospheric Turbulence Channels, Journal of Light-wave Technology (Volume: 33, Issue: 20, Oct.15, 15 2015)

[2] Survey on Free Space Optical Communication: A Communication Theory Perspective, IEEE Communications Surveys & Tutorials (Volume: 16, Issue: 4, Fourthquarter 2014)

[3] Ahmed M. Mahdy, Jitender S. Deogun, "Optimizing Free Space Optics for City-Wide wireless Networks", Proceedings of the Sixth International Conference on Networking, 2007.

[4] Jia Li, John Q Liu and Desmond P Taylor, "Optical Communication using Subcarrier PSK Intensity Modulation through Atmospheric Turbulence Channels", IEEE Transactions on Communication, Vol.55, No. 8, August, 2007.

[5] Hideaki Kotake, Shinichiro haruyama Masao Nakagawa,Kiyotaka Seki, Kouhoku-ku Yolohama,Kamagawa, "BER Characteristics of Ground to Train communication System using Free Space Optics Technology" ICTON, 2007.

[6] M Awan, P. Brandl, E. Leitgeb, F. Nadeem, L. Csugai-Horvath, R. Nebuloni "Transmission of high data rate Optical Signals in Fog and Snow conditions", IEEE 2008.

[7] F. Nadeem, E. Leitgeb, M.S. Awan, G. Kandus, "Comparison of different models for prediction of attenuation from visibility data", IEEE 2009.

[8] Vladimir Tejkal, Miloslav Filkal, Jan Sporik, Pavel Reichert, "Possibilities of increasing Power Budget in Optical Networks", Vol.1, No. 4, December, 2010.

[9] Carl Brannlund, "High Speed Electronics for Free Space Optical Communication between Spacecraft", 2008.

[10] M. Grabner, V. Kvicera, “On the Relation between Atmospheric Visibility and the Drop Size Distribution of Fog for FSO Link Planning”, September 2009.

[11] F. Nadeem, M. S. Awan, E. Leitgeb, M. S. Khan, S. Shiekh Muhammad, G.Kandus, “Comparing the Cloud Attenuation for Different Optical Wavelengths”.

[12] Gary Shaulov, Jigesh Patel, Brent Whitlock, Pablo Mena, Robert, “Simulation assisted design of free space optical Link”, IEEE 2008 M. Loschnigg, P.Mandl, E. Leitgeb, “Long term Performance Observation of a Free Space Optics Link”, IEEE 2009.

[13] Sachin M. Kale, Asif Kar, “Comparison of the BER performance of coherent and spatially partially coherent light beams in optical wireless systems”, 2010.

[14] Wajdi Al-Khateeb, Md Rafiqul Islam, Myat Tun, “Rain Fade Analysis for Practical Free Space Optic Link in Tropical Region”, 2011 4th International Conference on Mechatronics (ICOM), 17 – 19 May 2011, Kuala Lumpur, Malaysia, May 2011.