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Performance Evaluation of Free-Space Optical Communication Systems Using Visible Light Bands

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Abstract: Evaluating the Performance of Free-Space Optical Systems with Visible Light Bands FSO communication systems using visible light bands form a revolutionary concept of developing new generation high-speed, high-capacity data link solutions where conventional fibre-optic or radio frequency links may not suffice. This paper provides a comprehensive evaluation of the performance of FSO systems utilizing visible light bands by focusing on critical performance metrics: It also highlighted Q-factor, bit error rate, and the eye diagrams.

A detailed elaboration of the Q-factor analysis is presented since this parameter controls the signal quality and system performance levels. The Q-factor is evaluated in terms of the BER to analyse the effects of multiple operational parameters, including atmospheric conditions, optical power levels, and modulation schemes, on the reliability and efficiency of the given communication link. Analysing these factors, we can characterise their impact on signal quality and stability of the system.

Canonical examples incorporate eye diagrams as parts of a complete signal quality assessment system where we can look for problems such as signal deterioration, noise, and other types of perturbations that can influence performance. Our evaluation also includes simulations and practical experiments for comparing various FSO configurations and operation conditions.

This paper thus demonstrates the opportunities and risks related to the use of visible light FSO systems and provides important knowledge regarding their applicability in urban and remote locations. Here we outline potential approaches to increasing the efficiency of the system's functioning and suggestions on means for increasing the signal-to-noise ratio and decreasing the error rate. The submitted work benefits the progress of FSO technology, as it promotes the creation of stable and reliable communication channels in various operation conditions.

***Index Terms* - Free Space optical communication, Visible light Bands, light-emitting diode, Bit Error Rate, Quality factor**

I. Introduction

Free-space optical communications have presented the researchers as the best solution for data transmission with higher speeds than fibre optic and radio-frequency communication. Where conventional communication infrastructure may be inadequate or infeasible, FSO systems, using visible light to transmit information, have the capability to offer high bandwidth and data transfer rates.

The main advantage of visible light FSO systems is observed high data link capacity and immunity to RF signal interference in dense population centers and nomadic regions, where electromagnetic spectrum competition is an issue. FSO systems do not entail the complicated installation and continuous maintenance that fibre-optic systems demand since the FSO systems use line-of-sight optical links and can be quickly set up for either temporary or permanent use.

Nevertheless, several factors can reduce the operational capabilities enjoyed by the visible light FSO systems, such as atmospheric and environmental interference and the characteristic properties of the signal emitted. The Q-factor and bit error rate are always considered when evaluating the feasibility of such systems. The Q-factor is a representation of the signal-to-noise ratio which determines the operating range of the system and the possible attainable error rates while maintaining a high data integrity guarantee. The B.E.R, on the other hand, gives an impression of a busted system, in that it records the incidence of erroneous data that is relayed to the user.

Also, information regarding the received signal quality and possible distortion affects is provided by eye diagrams. To evaluate other effects, such as loss of signal and noise contamination, which can adversely impact the system, these diagrams can further be studied. On a related note, a performance assessment of a visible light FSO communication system is carried out in this paper by analyzing the Q-factor, the bit error rate, and the eye diagram. Additionally, it is demonstrated through modelling and practical evaluation how performance and reliability of the system can be affected by its parameters. The focus of our study is to expand the knowledge on advantages and disadvantages of visible light FSO systems and to develop some practical recommendations regarding the use of such systems in various scenarios.

In this way, we also continue to contribute to the improvement of FSO technology and address the need for fast and reliable communication which is essential in today's transmission of data.

II. Free space optical communication

FSO utilizes advanced point-to-point and point-to-multipoint transmission systems, using cutting-edge laser beams. This innovative approach not only offers high-capacity data transfer but also boasts robust security measures and interference resistance - all while operating on an unlicensed frequency. With such a powerful combination of features, it's no wonder that FSO is quickly becoming the go-to solution for broadband access. As we know, weather patterns can greatly impact any technology's performance throughout the year and in different seasons.

However, FSO has proven its reliability by consistently delivering excellent operational results regardless of environmental conditions. When implementing optical wireless communication methods like FSO, accurately determining the distance between sender and recipient is crucial to ensuring seamless connectivity. That's why OWC applications are divided into five categories based on range: ultra-short range, short-range, medium-range, long-range, and ultra-long range- as depicted in Figure 1 below.

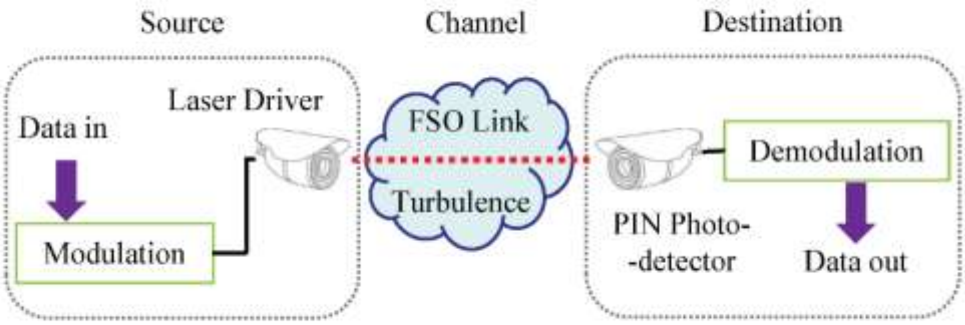

Fig 1: FSO Communication Channel

Signal attenuation primarily occurs in the wireless channel due to atmospheric effects, which can substantially weaken the signal. The overall attenuation is determined using the following computation:

$$\alpha_{Total} = \alpha Fogy_{\gamma} + \alpha Snow_{\gamma} + \alpha Haze_{\gamma} + \alpha Rainy_{\gamma} + \alpha Mist_{\gamma}, dB/km \quad (1)$$

where α represents the attenuation and
γ is the operational wavelength in micrometres.

III. Visible light bands

The wavelengths of visible light, which range from about 380 nm to 750 nm, make up the tiny portion of the electromagnetic spectrum that is visible to the human eye. Each of the hues that make up the visible spectrum corresponds to a particular range of wavelengths as shown in figure 2:

Violet: Approximately 380–450 nm
Blue: Approximately 450–495 nm
Green: Approximately 495–570 nm
Yellow: Approximately 570–590 nm
Orange: Approximately 590–620 nm
Red: Approximately 620–750 nm

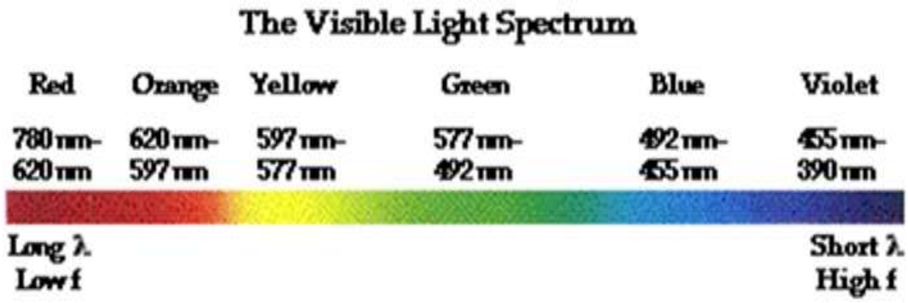

Fig 2: Visible Light Spectrum

This continuous spectrum of visible light is the result of these colors blending. Within this spectrum, each hue corresponds to a distinct wavelength, and the way that various wavelengths are absorbed and reflected by objects determines how these colors are seen.

IV. Analysis of Simulation Design and Setup

The proposed FSO System is depicted in Figure 3. At the transmitter end, a Bit sequence operating at a 1 Gbps data rate, modulates the signal using Non-Return-to-Zero On-Off Keying (NRZ-OOK) format to produce the electrical signal. This electrical signal is then sent to the LED. The modulated optical signal is transmitted through the FSO channel with a 6 km link span.

In the FSO channel, the optical transmitter and receiver apertures are set to 10 cm and 10 cm in diameter, respectively. The beam divergence is 1 mrad, typical of commercial FSO systems. The Photodetector detects and demodulates the signal before it is filtered by a low-pass Bessel filter with a 0.75 GHz cut-off frequency.

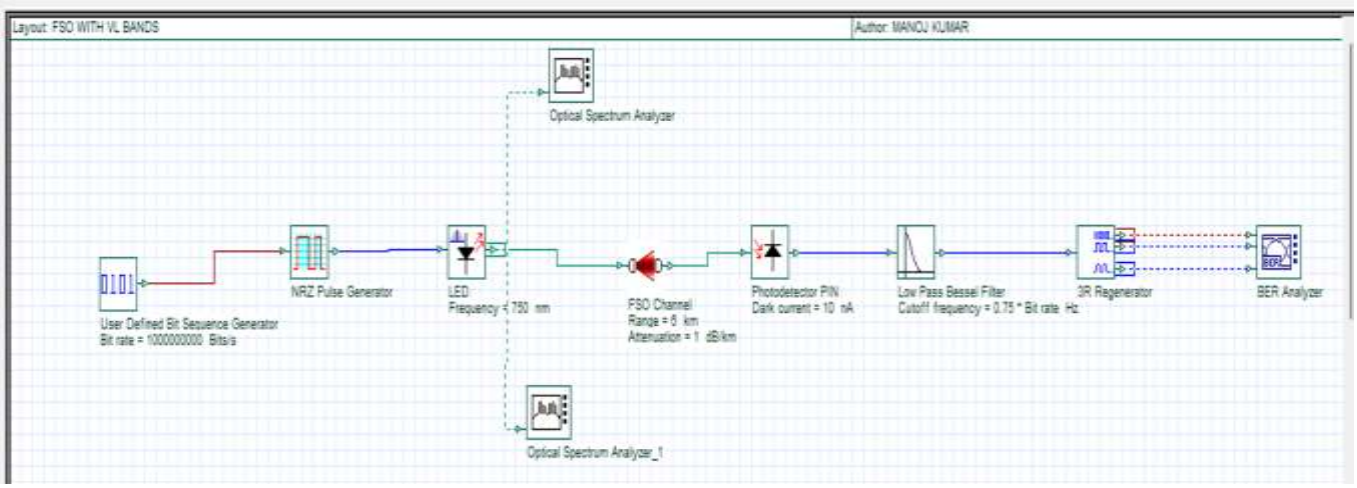

Fig 3: Simulation Setup

Table 1: FSO system parameters

Parameters	Value
Data Rate	1 Gbps
FSO Link Range Transmitter aperture diameter Beam divergence angle Receiver aperture diameter	 6 km 10cm 1 mrad 10cm
LED Wavelength	 Change as per VL bands
PIN photodiode Responsivity Dark current	 1A/W 10nA

V. Results & Discussion

KSE-100 index is an index of 100 companies selected from 580 companies based on sector leading and market capitalization. It represents almost 80% weight of the total market capitalization of KSE. It reflects different sector company's performance and productivity. It is the performance indicator or benchmark of all listed companies of KSE. So, it can be regarded as universe of the study. Non-financial firms listed at KSE-100 Index (74 companies according to the page of KSE visited on 20.5.2015) are treated as universe of the study and the study have selected sample from these companies.

The study comprised of non-financial companies listed at KSE-100 Index and 30 actively traded companies are selected on the bases of market capitalization. And 2015 is taken as base year for KSE-100 index. In evaluating the performance of Free-Space Optics system, the quality metric known as the Q-factor, along with Bit Error Rate (BER) and eye diagrams, are commonly used. These metrics are crucial in assessing the performance of optical fiber communication System, as they are related to electrical signal-to-noise ratio and BER. Specifically, the Q-factor is an indicator of SNR in digital optical communication, with a higher Q-factor signifying better signal quality.

The connection between BER and the Q-factor is expressed by the following equation:

$$\text{BER}=\frac{1}{2}erfc\left(\frac{q}{\sqrt{2}}\right) \quad (2)$$

where erfc represents the complementary error function.

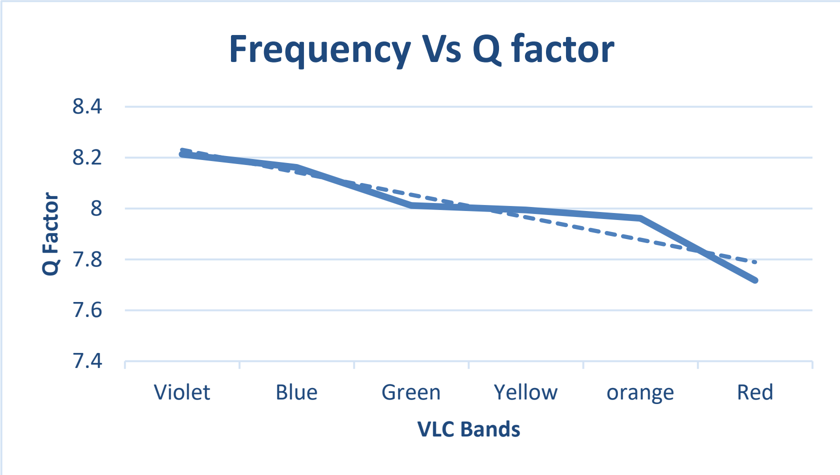

Fig 4: Frequency Vs Q Factor

After a thorough examination, as illustrated in Figure 4, it is evident that the Q-factor experiences a decline with an increase in frequencies. This suggests that signal strength weakens at higher frequencies within the FSO channel. To be specific, violet and blue frequency bands show greater Q-factors implying superior signal quality and enhanced bandwidth capabilities compared to other frequency ranges within the span of 6 km. Through careful analysis depicted by Figure 4, we can see how increasing frequencies result in diminishing Quality factors (Q-factors). It's safe to say that this downward trend signals weaker signals being transmitted through the Free-Space Optical (FSO) channel at high-frequency levels. Notably though, our attention is drawn towards violet and blue frequency bands which exhibit relatively higher Q-factors indicating exceptional signal quality and boosted bandwidth performance when compared to their counterparts operating within up to 6 km.

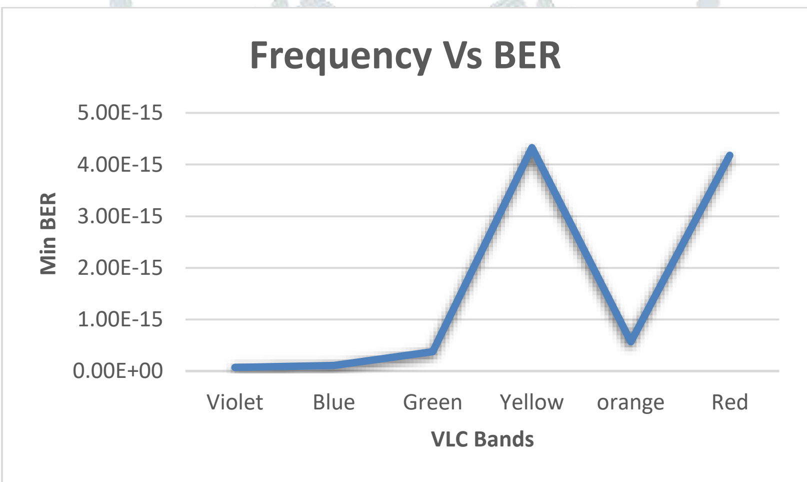

Fig 5: Frequency Vs BER

As Shown in the Figure 5, the Error should be less in violet & Blue compared to other bands. This is to say that the violet and blue bands provide superior performances in terms of error reduction and good signal integrity. Thus, during optimum 6 km operation range in FSO systems, the use of violet and blue frequency bands is preferable due to better signal quality with less error occurrence**.**

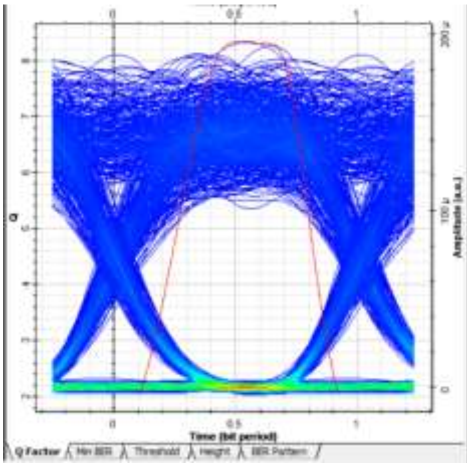

Fig 6: Violet Band

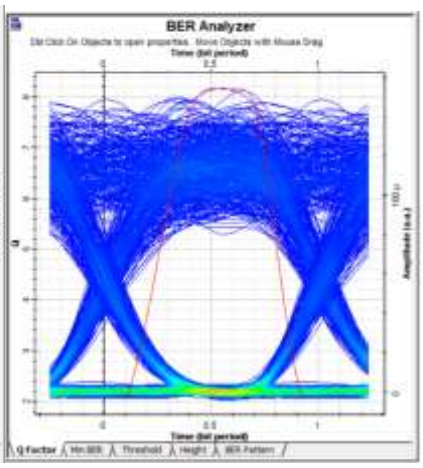

Fig 7: Blue Band

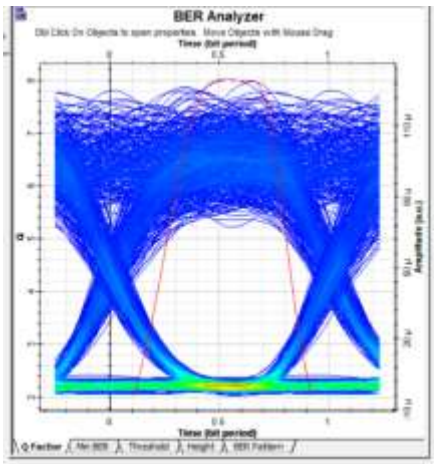

Fig 8: Green Band

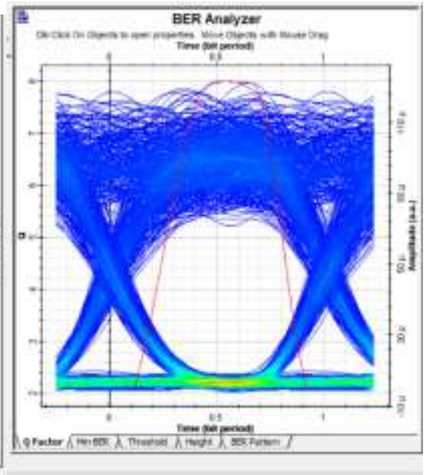

Fig 9: Yellow Band

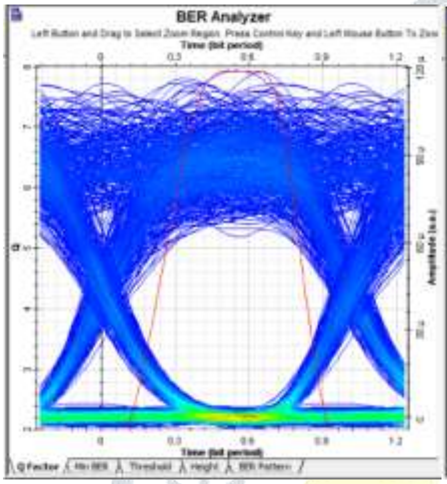

Fig 9: Orange Band

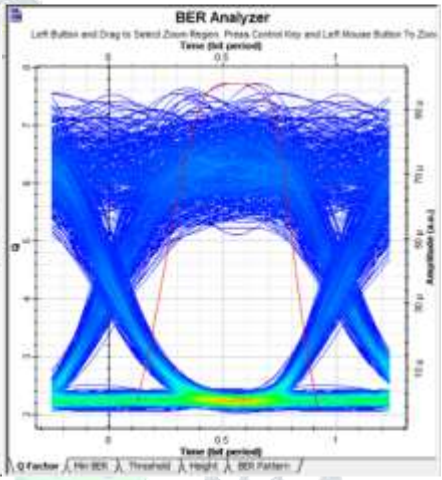

Fig 10: Red Band

Conclusion:

This research evaluates the performance of free-space optical FSO Comm systems using visible light bands, especially looking at the quality factor (Q factor), bit error rate (BER), and eye diagram. What we find from our investigation is that the FSO systems under visible light can deliver data at very high speed with great tolerance to motion and with limited interferences. However, their performance is mediated by environmental parameters such as atmospheric conditions and optical power levels.

Q-factor is important to determine high error tolerance versus a high data rate to ensure good communication is done while eye diagrams offer information on signal quality as well as any distortion. However, the use of visible light FSO suffers from certain disadvantages that must be apprehended for the best experience.

The potential areas for further investigation of FSO should include optimization of the system parameters, further investigation of different types of modulation and multiplexing, and investigation of combining FSO with other types of networks. Therefore, this investigation enhances the knowledge dissemination of FSO technology, which has a promising future when applied in today's advanced communication network.

REFERENCES

[1] Modar Dayoub and Hussein Taha, "Evaluation of Optimal Visible Wavelengths for Free-Space Optical Communications," Telecom, Volume 6, Issue 3, August 2025.

[2] Anass Kharbouche, Hamza Ouamna, Zhour Madini, Younes Zouine, "Performance analysis of a multi-user outdoor visible light communication system using wavelength division multiplexing (WDM) with RZ-OOK and NRZ-OOK modulations for V2X communications", e-Prime - Advances in Electrical Engineering, Electronics and Energy, Volume 11, Article no 100900, March 2025.

[3] Aanchal Sharma, Sanmukh Kaur," Performance Estimation of Outdoor Visible Light Communication System Over FSO Link Employing ML Techniques", International Journal of Communication systems, Volume 38, Issue 4, March 2025.

[4] Faizan Shafi, Awanish Kumar, Rangaswamy Nakkeeran, "Performance Analysis of Free Space Optical Networks Under External Limiting Factors", Results in Optics, Volume 14, Article Number 100615, February 2024.

[5] Vidyashree. P, Prof. Ramya C, "Free Space Optics Technology", International Journal of Research Publication and Reviews, Vol 5, no 4, pp 4446-4452, April 2024.

[6] J. A. Lee, M. R. Kim, and T. S. Park, "Recent Advances in Hybrid Free-Space Optics and Visible Light Communication Systems," IEEE Communications Letters, vol. 27, no. 4, pp. 931–934, Apr. 2023.

[7] S. Y. Tan, X. F. Chen, and D. K. Wong, "Hybrid Optical Wireless Communication Systems for Smart Cities: Challenges and Opportunities," Journal of Lightwave Technology, vol. 41, no. 9, pp. 2493–2505, Sep. 2023.

[8] Siti Hajar Ab Aziz. "Performance Analysis of a Hybrid Free-Space Optics/Visible Light Communication System", Asian Journal of Electrical and Electronic Engineering, Vol. 2, No. 2, 2022.

[9] Kavita, Jagtar Singh, "Matlab based Simulink Modelling and Performance Analysis of Free Space Optical Communication System: A Review", International Journal on Future Revolution in Computer Science & Communication Engineering: Vol. 8, No. 4, 2022.

[10] R. M. Rodriguez, L. F. Oliveira, and N. J. Santos, "Integration of Free-Space Optics and Visible Light Communication for Enhanced Connectivity," Journal of Lightwave Technology, vol. 39, no. 7, pp. 2043–2055, Jul. 2021

[11] M. H. B. Khan, A. S. Ahmed, and T. A. Hussain, "Impact of Weather Variability on Optical Wireless Communication Systems: Insights and Solutions," IEEE Transactions on Communications, vol. 69, no. 1, pp. 89–102, Jan. 2021

[12] M. Z. Chowdhury, M. K. Hasan, "Optical Wireless Hybrid Networks: Trends, Opportunities, Challenges, and Research Directions," IEEE Communications Surveys and Tutorials, pp. 930–966, April 2020.

[13] Gupta and N. Patel, "Next-Generation Optical Wireless Communication Systems: Trends and Future Directions," Optics Express, vol. 28, no. 24, pp. 35107–35120, Dec. 2020.

[14] Helen Vedanayagi and Anita R. "Implementation of 5G in Guided and Unguided Optical Communication Systems with Cellular Frequency Bands" was published in the International Journal of Trend in Scientific Research and Development (IJTSRD), ISSN: 2456-6470, Volume 3, Issue 6, October 2019.

[15] Z. Huang et al., "Hybrid optical wireless network for future SAGO-integrated communication based on FSO/VLC heterogeneous interconnection," IEEE Photonics Journal, pp. 1–10, 2017.

[16] N. A. M. Nor et al., "10 Gbps all-optical relay-assisted FSO system over a turbulence channel," 2015 4th International Workshop on Optical Wireless Communications, IWOW 2015, no. September, pp. 69–72, 2015.