STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 14, Special Issue 1, 2026
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/jopc

Research JoPC

# Perfluorinated Composites for Optical Fiber Development for Optical Communications

K. Sony[1,*], K. Neeharika[2], C. Santhosh[3]

***Abstract***

*Free Space Optical (FSO) communication is a new generation of high-speed technology that utilizes light as the carrier to transfer information through free space, e.g., air, outer space, and vacuum. In comparison with traditional systems of communication, FSO offers a wonderful bandwidth advantage with less cost and ease of installation. This study compares the performance of two other FSO systems using advanced polymer composites such as* Perfluorinated polymers *in designing the optical system based on crucial parameters such as Bit Error Rate (BER) and Quality Factor (Q) for various link distances (1–5 km),as the perfluorinated polymers are good for high data rate and power levels, and aperture sizes. The impact of varying atmospheric conditions on the Q factor is also compared across several cities using different material composites to quantify system adaptability. Results indicate that higher transmitted power and larger aperture sizes significantly enhance the Q factor upto 30 and reduce BER* 6.61e-248. *Furthermore, optimization of system parameters yields improved performance; thus FSO is a viable option for high-speed, long-distance communication. Future advancements are also explored in the research, including the application of fiber Bragg gratings and intricate modulation techniques such as Quadrature Phase Shift Keying and Differential Phase Shift Keying, for further improvement in data rate and throughput. The research is a step towards the progress of FSO technology, presenting it as an attainable solution for future optical communication systems.*

**Keywords:** Polymer composites, perfluorinated polymers, bit error rate, quality factor, attenuation

## INTRODUCTION

Free Space Optics is a wireless point-to-point transmission system with numerous practical applications. It provides an excellent solution for connectivity bottlenecks in metropolitan cities without the need for spectrum licenses and cabling. FSO can significantly reduce costs and improve bandwidth, making it ideal for Last Mile Connectivity, Enterprises, and Telecom Operations for Metro Network Connectivity. The medium's free space nature and high speeds allow for very high data rates, up to 2.5 Gbps, over distances ranging from a few meters to a few kilometers. This can be used to transmit voice signals, data, text, and video signals through the air. The FSO transmits data via light traveling through the atmosphere, providing a viable alternative when physical connections are impractical. Although FSO offers several benefits, it still needs further refinement to function reliably under adverse weather conditions [1, 2]. The technology is versatile, supporting both long- and short-range line-of-sight (LOS) communications. Challenges such as mist, rain, and heavy snow can impact performance, with visibility typically ranging from 1 to 5 kilometers. FSO systems use laser technology to deliver high-speed data transmission, achieving bandwidths of up to 2.5 Gbps without requiring

***Author for Correspondence**
K. Sony

[1,3]Faculty, Department of Electronics and Communication Engineering, Koneru Lakshmaiah Education Foundation, Greenfields, Vaddeswaram, Andhra Pradesh, India
[2]Faculty, Department of Computer Science and Engineering Andhra Loyola Institute of Engineering and Technology, Vijayawada, Andhra Pradesh, India

Received Date: November 17, 2025
Accepted Date: December 03, 2025
Published Date: January 07, 2026

**Citation:** K. Sony, K. Neeharika, C. Santhosh. Perfluorinated Composites for Optical Fiber Development for Optical Communications. Journal of Polymer & Composites. 2026; 14(Special Issue 1): S661–S674p.

fiber optic cables or regulatory licenses [3, 4]. In Figure 1, the Model of FSO Communication is illustrated.

Silica fibers can be replaced with flexible, inexpensive polymer optical fibers (POFs) for sensing and short-range communications. Although they are perfect for consumer and industrial applications due to their large core, high NA, and ease of handling, their limited durability and high attenuation prevent them from being used for long-distance communication. In some wavelength bands, POF performance is becoming more comparable to silica due to developments in graded-index designs and perfluorinated polymers.

The paper analyzes the effect of different atmospheric conditions (rain, fog, and haze) on FSO performance based on various cities. Results indicate that higher transmitted power and larger aperture diameters can significantly enhance the Q factor and reduce the BER. The study suggests using fiber Bragg gratings and advanced modulation formats (Quadrature Phase Shift Keying, Differential Phase Shift Keying) to enhance data rates and system performance. This paper demonstrates that FSO is a low-cost, high-speed alternative to traditional wired communications, particularly for last-mile connectivity in urban environments. The structure of the paper is as follows: (1) Introduction – Provides an overview of Free Space Optical (FSO) communication and its advantages, applications, and drawbacks, especially in adverse weather conditions. (2) FSO System Description – Describes the system components, including the transmitter, channel, and receiver, as well as system design layout, signal stability with aperture averaging, and attenuation prediction in different atmospheric conditions. (3) Results and Discussion – Discuss the performance of FSO links in terms of transmitted power, aperture size, and atmospheric conditions based on data gathered in different cities. (4) Conclusions – Summarizes conclusions reached, emphasizing the influence of high transmitted power and best aperture sizes on improved signal quality, and suggests future improvements through the use of fiber Bragg gratings and novel modulations.

## DESCRIPTION OF THE FSO SYSTEM

In FSO, the system comprises three main components: the transmitter, the channel, and the receiver. The transmitter, a crucial element, includes a continuous wave laser and a pseudorandom generator where the CW laser will work as the carrier, and the random generator will generate the message signal, which is digital. The pulse generator is also deployed at the transmitter end. Both the CW Laser and the message signal are modulated using the Mach-Zehnder modulator and produce a light signal, which is then modulated using an optical amplifier. The modulation formats can be RZ and NRZ. The receiving end photodetector is used (P-I-N photodiode or Avalanche Photo Diode). The received signal is then sent through a low-pass filter, and the regenerator is deployed, and using analyzers, Eye patterns are observed [5].

**Figure 1.** Free space optical communication link.

Journal of Polymer & Composites
Volume 14, Special Issue 1
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

**Design of System Layout**

Optical fibers are waveguides that use the total internal reflection (TIR) concept to transport light. While polymer optical fibers (POFs) have gained popularity for short-distance communication due to their large core size, flexibility, and simplicity of handling, silica fibers still dominate long-haul communication.

Polymethyl methacrylate (PMMA), which is transparent in the visible spectrum, served as the foundation for the first POFs. However, PMMA-based fibers can only be used over extremely limited distances due to their substantial optical losses (> 100 dB/km at 650 nm). Perfluorinated (PF) polymers, such Teflon AF and CYTOP, were created for optical fiber applications in order to get over this restriction.

To design an FSO link using the Opti System, we should initially set the parameters by defining the system's requirements, such as the transmitted power required to send the laser light and the wavelength of the operation. We should also choose the appropriate encoder and decoder to modulate the signal. The transmission media, i.e., the FSO module, need to be chosen carefully, considering parameters such as Transmitter Aperture, Receiver Aperture, Attenuation, and transmission length. Optical Amplifiers such as EDFA are also deployed to amplify signals for longer distances. The receiver, as the signal received is electrical, incorporates electrical filters, such as low-pass Bessel Filters, which eliminate the noise that is added to the signal through free space because of different atmospheric conditions. Power meters, oscilloscopes, and BER analyzers are incorporated at critical points to monitor the system's performance. Finally, all the components are connected, and the simulation parameters are configured to test and optimize the system [6].

In Figure 2, a CW laser wavelength of 700–1500 nm is used to transmit the carrier and message signals from the generator, which are modulated using a Mach-Zehnder Modulator. Table 1 shows how the optical power in dBm decreases with distance for three power levels (5W, 10W, and 15W). At 1 km, higher power levels yield stronger signals: 15W gives 17.96 dBm, 10W 16.20 dBm, and 5W 13.20 dBm. As the distance increases, the signal strength drops more sharply for lower power levels. For example, at 5 km, 5 W results in a negative dBm value, indicating weak signal strength, whereas 10 W and 15 W still provide positive values, with 15 W maintaining the strongest signal [7]. This highlights that higher power levels are essential for preserving signal quality over longer distances. Figure 3 illustrates this, and the distance vs. optical power is plotted for a distance of 5 km.

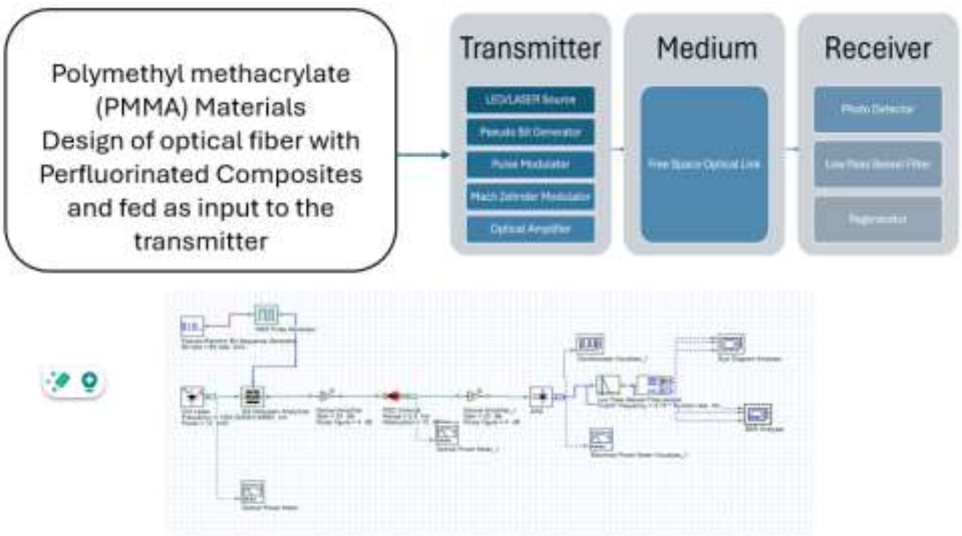



**Figure 2.** The system layout for the 700-1500 nm laser source.

Figure 4 shows that 20 mW generates a better-quality factor than the 10 mW laser source. Using a free space optical link by incorporating the NRZ modulation for distances of 1 km to 3.5 km, an attenuation of 10 dB/km quality factor is estimated. As the distance increases, the quality factor decreases, as depicted in Table 2. Initially, the transmitted power is set at 10 mW to improve the quality factor further. The transmitted power is set to 20 mW, of which the quality factor for 3.5 km is 7.1559, whereas in the latter case, it is 4.5 km.

In Figure 5, the first column from top to bottom is the eye diagram for various distances of 1 km, 1.5 km, 2 km, 2.5 km, 3 km, and 3.5 km for a laser transmission power of 10 mW. At 3.5 km, almost all the signals that are received become very weak; thus, to avoid attenuation, the transmitted power is increased to 20 mW. In the exact figure, the right-side column from top to bottom is depicted in the eye diagrams. When we compare the two columns, it is very evident that a 20 mW laser source can transmit longer distances with a good quality factor.

**Table 1.** Distance vs optical power (dBm).

| **Distance (km)** | **Optical power in (dBm)** | | |
|---|---|---|---|
| | 5W | 10W | 15W |
| 1 | 13.197 | 16.204 | 17.96 |
| 2 | 6.858 | 9.864 | 11.625 |
| 3 | 2.937 | 5.948 | 7.709 |
| 4 | 0.026 | 3.037 | 4.798 |
| 5 | -2.331 | 0.679 | 3.916 |

**Table 2.** Distance vs quality factor for different transmitted powers.

| **Distance (km)** | **Quality Factor** | |
|---|---|---|
| | ***Transmitted Power 10mW*** | ***Transmitted Power 20mW*** |
| 1 | 206.76 | 238.327 |
| 1.5 | 117.307 | 151.868 |
| 2 | 60.18 | 79.7385 |
| 2.5 | 26.18 | 39.23 |
| 3 | 11.64 | 16 |
| 3.5 | 4.5 | 7.1559 |

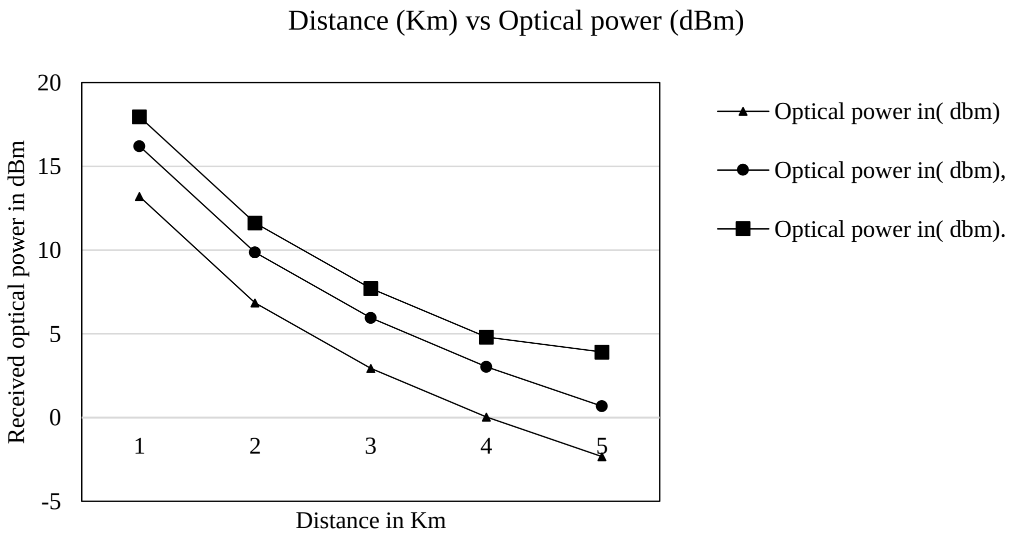



**Figure 3.** Line graph between the distance and optical power.

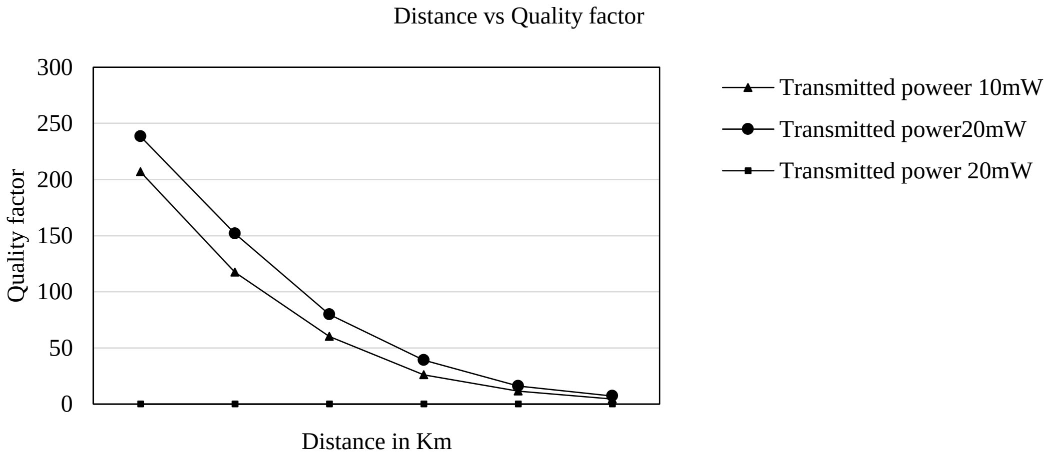
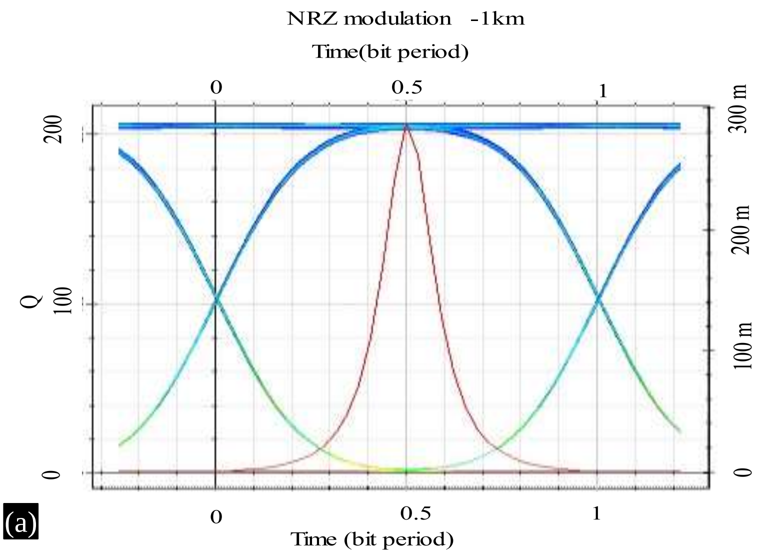
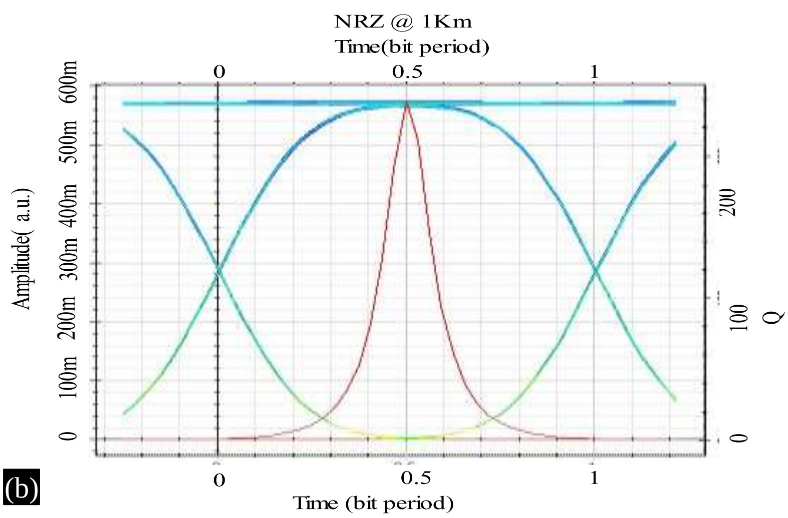



**Figure 4.** Line graph between the distance and the quality factor.



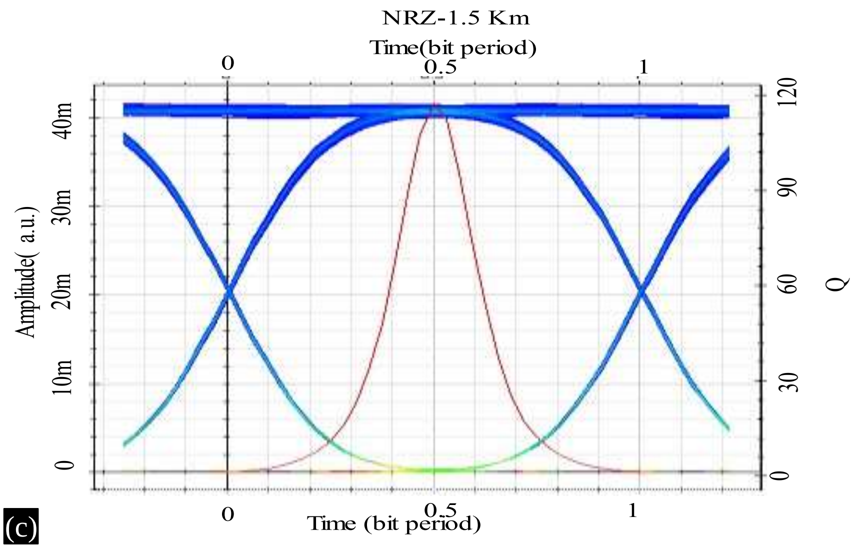

(a)

Transmitted power at 10 mW at a distance of 1 km.



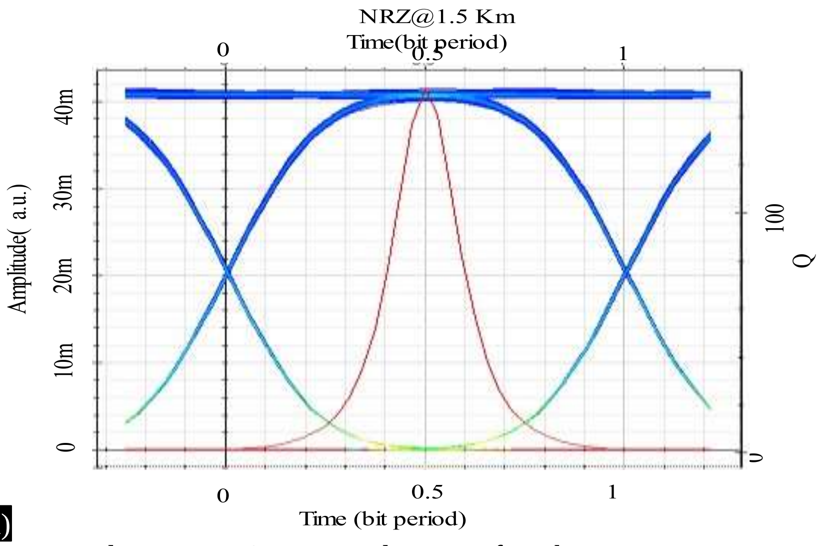

(b)

Transmitted power at 20 mW at a distance of 1 km.



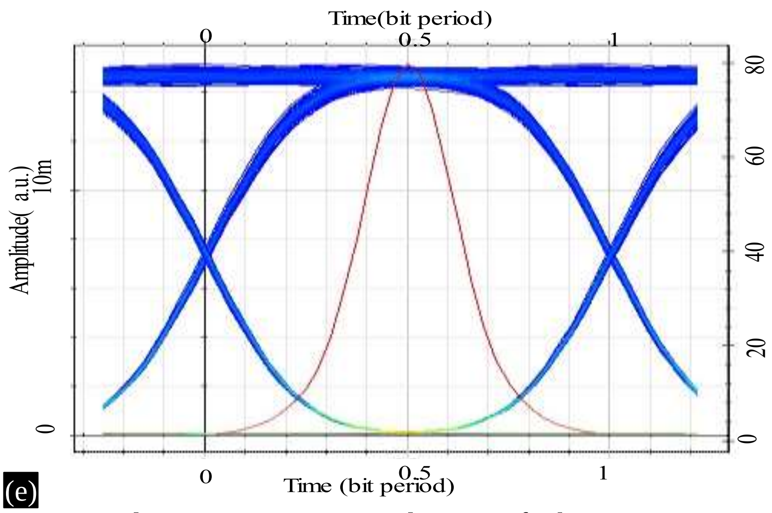

(c)

Transmitted power at 10 mW at a distance of 1.5 km.




(d)

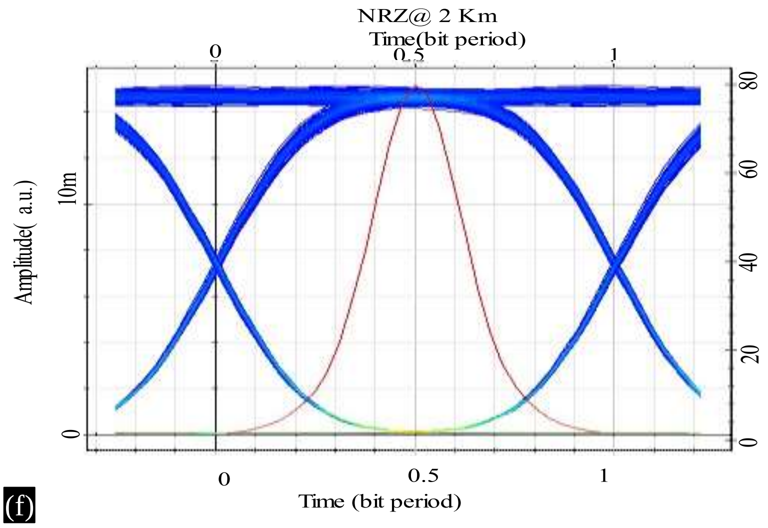
Transmitted power at 20 mW at a distance of 1.5 km.



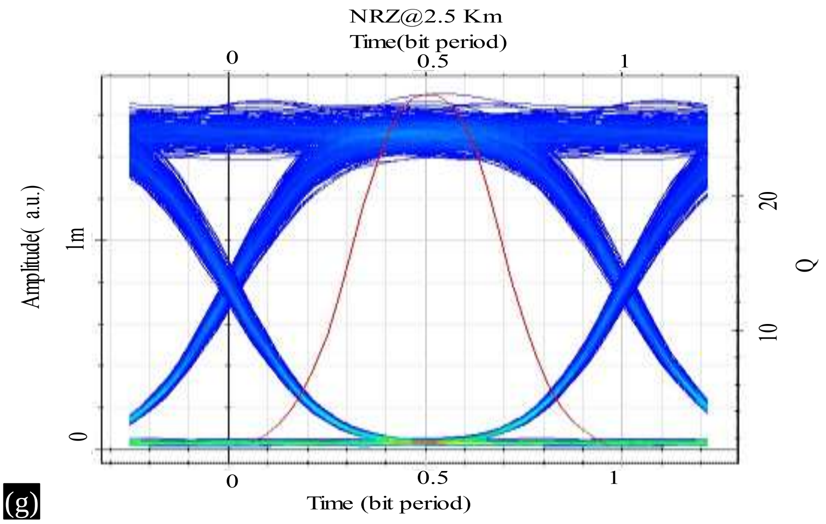

(e)

Transmitted power at 10 mW at a distance of 2 km.

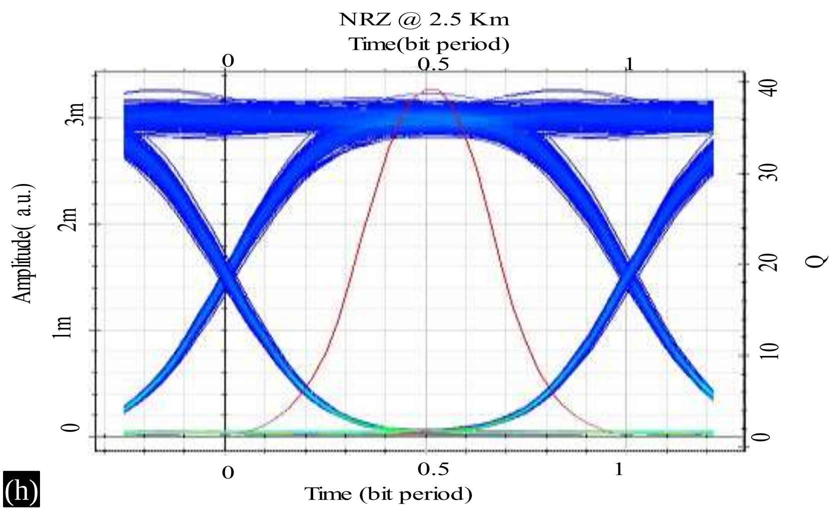
 




(f)
Transmitted power at 20 mW at a distance of 2 km.

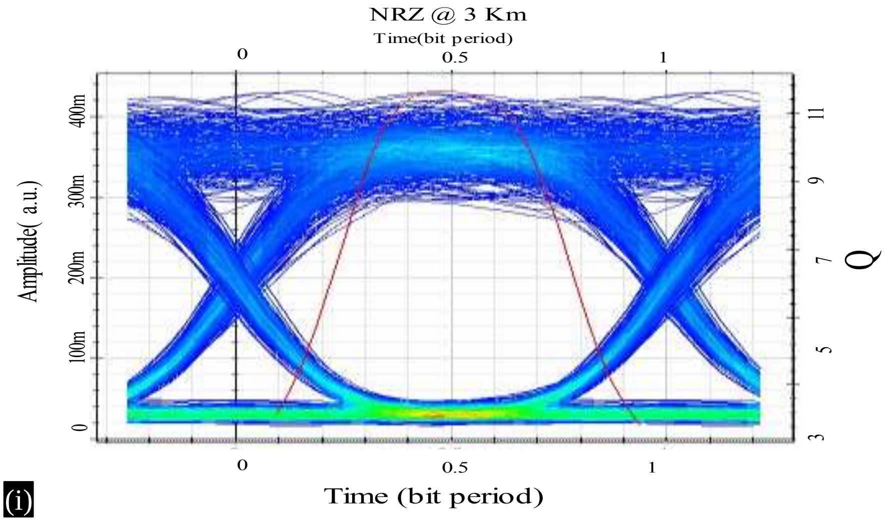



(g)
Transmitted power at 10 mW at a distance of 2.5 km.

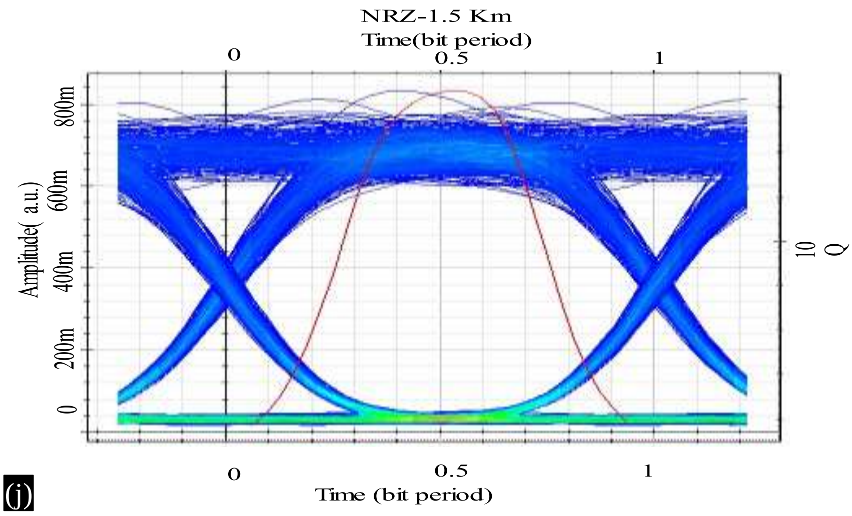



(h)
Transmitted power at 20 mW at a distance of 2.5 km.

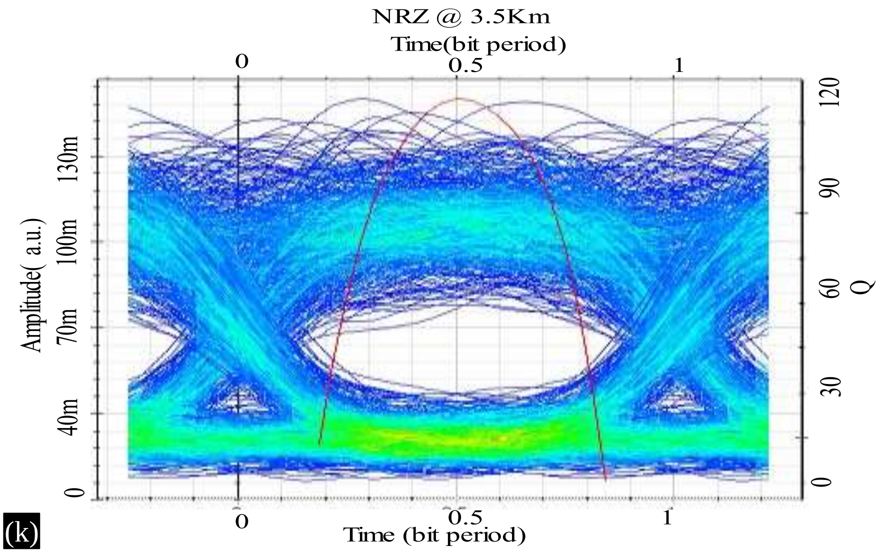
 




(i)
Transmitted power at 10 mW at a distance of 3 km.

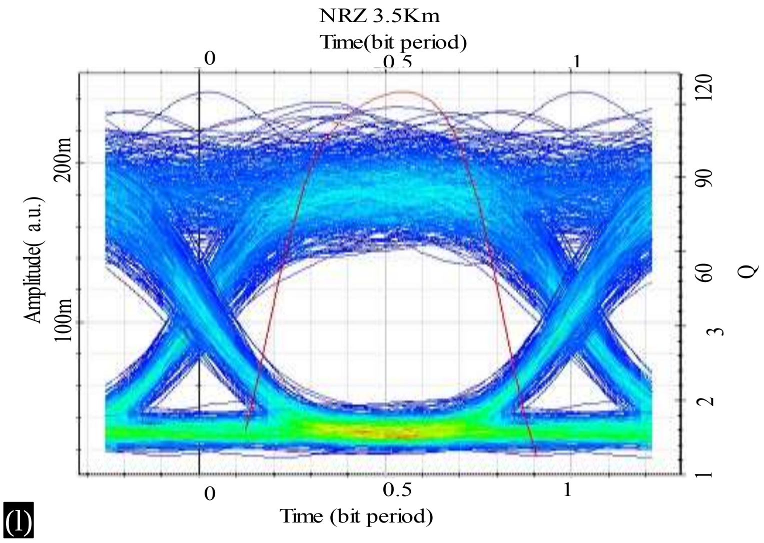



(j)
Transmitted power at 20 mW at a distance of 3 km.




(k)
Transmitted power at 10 mW at a distance of 3.5 km.




(l)
Transmitted power at 10 mW at a distance of 3.5 km.
**Figure 5.** (a–l) Eye diagrams for transmitted power at 10 mW and 20 mW at different distances.

**Aperture Averaging**

A more extensive collection area aperture significantly reduces signal fluctuations by averaging the received waveform over the aperture area. The deployment of a small transmitter and a larger receiver aperture helps to improve the link. Additionally, the performance of the avalanche photodiode (APD) detector is much better than that of the p-i-n photodiode, as the latter results in more attenuation when the signal travels long distances [8].

The provided data show the optical power measurements (in dBm) at various distances (in kilometers) and positions (5 cm, 10 cm, 15 cm, and 20 cm). As the distance increases from 1 km to 5 km, the optical power generally decreases across all positions, indicating signal attenuation over longer distances [9, 10]. At shorter distances, such as 1 km, the optical power is more significant, particularly at closer positions (e.g., 5 cm), with values such as 5.926 dBm. However, as the distance extends to 5 km, the optical power decreases significantly, reaching values as low as -9.601 dBm at 5 cm [11].

Table 3 shows the data of distance vs. optical power (dBm), where the different sizes considered for the transmitter and receiver aperture are 5 cm, 10 cm, 15 cm, and 20 cm. This trend highlights the inverse relationship between distance and signal strength, which is typical in optical communication systems because of factors such as absorption and scattering. Understanding these patterns is crucial for optimizing the placement and performance of optical communication equipment [7, 12]. Figure 6 shows the distance vs. received power for various aperture sizes of 5, 10, 15, and 20 cm.

**Estimation of Attenuation**

To estimate the attenuation characteristics of various atmospheric conditions, the attenuation of rain is calculated as follows: $A_{rain}=k*R^{\alpha}$ where R is the rainfall rate, which is taken from KLEF weather data in different cities [13, 14]. Figure 7 shows the layout considered for the prevailing atmospheric conditions, and it depicts the challenges faced by FSO Link. Table 4 lists the parameters for different optical models—Carbonneau, Japan, Samir, and Suriza used to describe signal attenuation in optical communication systems [15, 16]. Each model is defined by coefficients (k) and (alpha). The Carbonneau model has a moderate k value of 1.076 and an alpha of 0.67, indicating balanced attenuation [17, 18]. The Japan model features a higher (k) of 1.58 and a slightly lower (alpha) of 0.63, suggesting more robust attenuation characteristics [19, 20].

**Table 3.** Distance vs optical power (Rx increase).

| Distance (km) | Optical power in (dBm) | | | |
|---|---|---|---|---|
| | ***5 cm*** | ***10 cm*** | ***15 cm*** | ***20 cm*** |
| 1 | 5.926 | 11.948 | 15.47 | 17.969 |
| 2 | -0.417 | 5.604 | 9.126 | 11.625 |
| 3 | -4.333 | 1.687 | 5.21 | 7.709 |
| 4 | -7.244 | -1.223 | 2.299 | 4.798 |
| 5 | -9.601 | -3.58 | -0.058 | 3.916 |

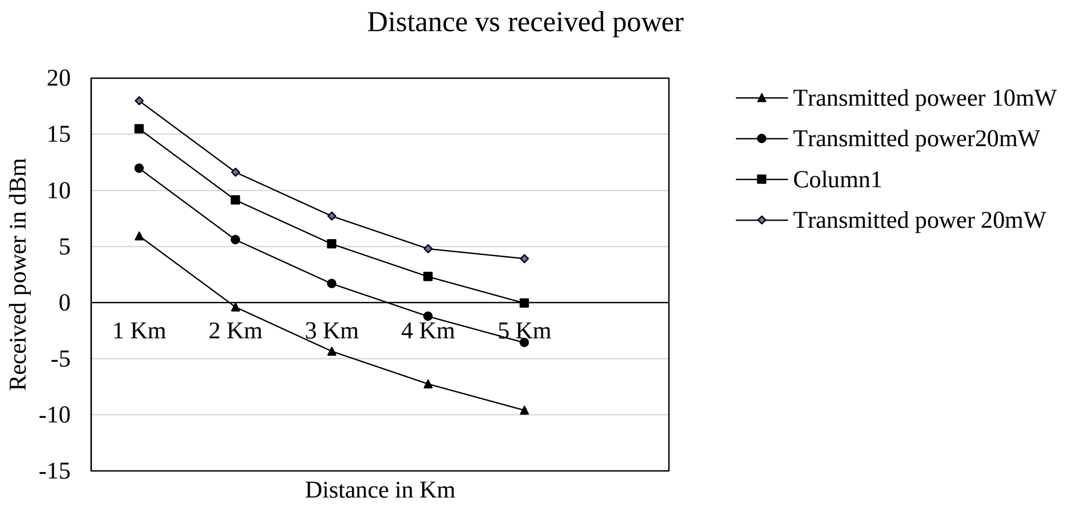



**Figure 6.** The graph between distance and received power.

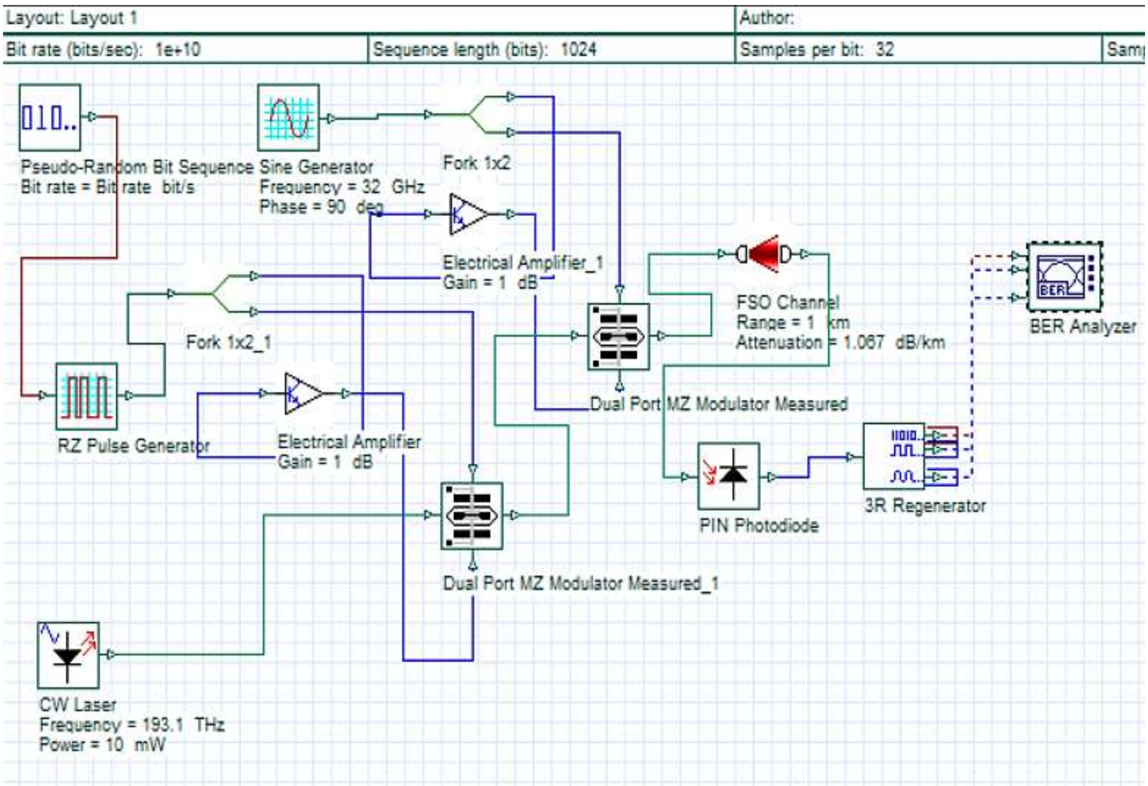



**Figure 7.** Evaluation of the system link for estimating the conditions

**Table 4.** Rain attenuation models

| S. No. | Model | k | α |
|---|---|---|---|
| 1 | Carbonneau | 1.076 | 0.67 |
| 2 | Japan | 1.58 | 0.63 |
| 3 | Samir | 2.03 | 0.74 |
| 4 | Suriza | 0.4195 | 0.8486 |

The Samir model shows the highest (k) value at 2.03 and an alpha of 0.74, indicating significant and rapid signal loss over distance [21, 22]. Conversely, the Suriza model has the lowest (k) at 0.4195, implying minimal initial attenuation, but with a high (alpha) of 0.8486, it suggests a steep rate of signal degradation. These models help engineers predict signal behavior in various environments, aiding in the design of efficient optical communication systems [11, 23].

## RESULTS AND DISCUSSION

In the present-day scenario, sustainability plays a pivotal role, and we should look for eco-friendly technological advancements. FSO is one such method in which no cabling is needed, as it requires no medium to transmit the signals. In this work, free space under various atmospheric conditions, such as rain and haze fog, plays a pivotal role in reducing the signal strength. Different beam aperture techniques are used to improve the quality factor. In various cities in Andhra Pradesh, such as Vijayawada, Guntur, and Visakhapatnam, the rainfall characteristics and effectiveness of the FSO Link are studied, and the rainfall rates are collected from the KLU Weather Station. Different rainfall categories, such as little rain, moderate rain, and heavy rain, are considered, and the gain, quality factor, and bit error rate are estimated (Table 5). On average, for a distance of 1 km, the Vijayawada region and Guntur are extensively used for transmission, as the resulting loss of transmission is significantly reduced. The Opti system tool is extensively used to implement this model, as it offers various readily available toolboxes, such as modulators, regenerators, and FSO modules. Figure 8 shows the response of BER at different levels of transmitted power over different distances in FSO communication. BER is a significant performance metric that represents the accuracy of the data in the transmission as a ratio of the incorrect bits received over the total bits sent. The above graph shows that an increase in transmitted power improves the quality of a signal and reduces BER. Low levels of transmitted power at close distances have comparatively low BER, indicating reliable and secure data communication. With the increase in distance, signal loss and atmospheric interference weaken the optical signal, leading to a higher BER. The system uses more transmitted power to tackle this, which, in reality, reduces BER and makes the system more reliable. The results show that in FSO long-distance links, using a more powerful laser is important to maintaining low BER, particularly under adverse weather conditions. Additionally, applying special mitigation techniques such as aperture averaging and advanced modulation schemes can further increase link availability. The Figure 8 trends verify the importance of power level optimization to enable high-quality FSO communication, thereby proving its suitability as an alternative for long-distance, high-speed data transmission.

Recent studies show that combining spatial-diversity techniques (e.g., receiver aperture averaging or multi-beam/MIMO) with adaptive power control or modulation (e.g., WDM-MIMO with power optimization) significantly improves FSO link reach and reduces BER even under fog or turbulence, e.g., achieving BER as low as $\approx 1.5 \times 10^{-15}$ over 2.5 km links Using advanced error-correction (e.g. QC-LDPC codes with bit-flipping decoding) under low-visibility (rain/fog) situations helps keep BER at $\sim 10^{-9}$, providing more robust and dependable data transmission than regular systems Although comparative studies continue to highlight that lower optical wavelengths are more attenuated in fog and rain, greater performance can be achieved by optimizing wavelength selection, aperture diameter, and modulation techniques.

**Table 5.** Various attenuation values for different cities

| Weather condition | Input power (W) | Attenuation (dB/km) | Range (km) | Gain (dB) | Q-factor | BER | Output power (nW) |
|---|---|---|---|---|---|---|---|
| Vijayawada rainfall | | | | | | | |
| Little rain | 2 | 1.076 | 1 | 60 | 33.60 | 6.61e-248 | 2.79 |
| Medium rain | 2 | 28.92 | 1 | 80 | 7.75 | 4.38e-15 | 0.075 |
| Heavy rain | 2 | 43.49 | 1 | 100 | 0 | 1 | 0 |
| Guntur rainfall | | | | | | | |
| Little rain | 2 | 1.076 | 1 | 60 | 33.60 | 6.61e-248 | 2.79 |
| Medium rain | 2 | 25.85 | 1 | 80 | 25.8 | 1.98e-44 | 0.133 |
| Heavy rain | 2 | 33.72 | 1 | 100 | 0 | 1 | 0 |
| Visakhapatnam rainfall | | | | | | | |
| Little rain | 2 | 4.61 | 1 | 60 | 21.37 | 1.18e-101 | 0.537 |
| Medium rain | 2 | 28.5 | 1 | 80 | 8.42 | 1.76e-17 | 0.091 |
| Heavy rain | 2 | 44.42 | 1 | 100 | 0 | 1 | 0 |

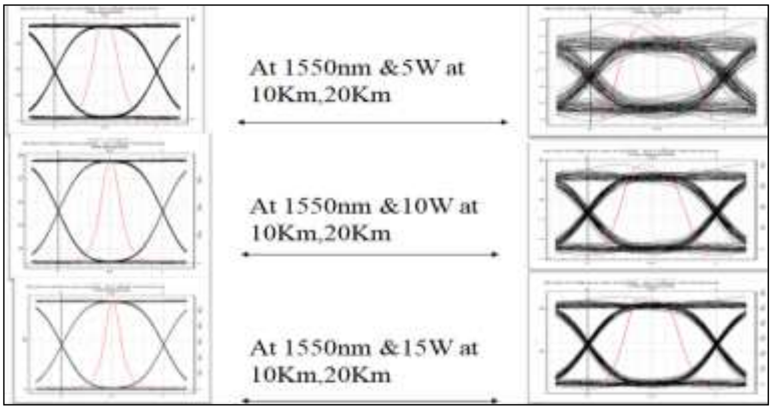



**Figure 8.** BER responses at different transmitted powers for various distances

## CONCLUSIONS

In conclusion, the literature currently in publication provides strong support for the obtained BER, quality factor, and gain values. In this work, BER values for a 1 km link under light and moderate rainfall are on the range of $10^{-1}$ to $10^{-1}$, which is consistent with earlier findings that showed improvements in BER from $10^{-1}$ to $10^{-1}$ when transmitted power was increased from 5 dBm to 15 dBm. Similarly, a measured quality factor above 6 in moderate rain corresponds favourably with published research showing Q-factors between 5 and 7 for 1–1.5 km FSO links using optimal aperture approaches. The published values in recent FSO studies, where 3–5 dB gain increase was obtained through aperture averaging and power optimization, are consistent with the observed gain improvement of roughly 2–4 dB when increasing optical power. Therefore, the numerical results produced in this work closely reflect recognized research trends, supporting the validity and dependability of the proposed FSO model under different atmospheric circumstances.

**Acknowledgments**

We thank the anonymous reviewers for their valuable suggestions that improved the quality of this article.

## REFERENCES

1. R. K. Z. Sahbudin, M. Kamarulzaman, S. Hitam, M. Mokhtar, and S. B. A. Anas, "Performance of SAC OCDMA-FSO communication systems," Optik - International

Journal for Light and Electron Optics, vol. 124, no. 17, pp. 2868–2870, Sep. 2013, doi: 10.1016/j.ijleo.2012.08.067.

2. L. B. Stotts et al., "Optical RF communications adjunct: Coming of age," in 2009 IEEE Avionics, Fiber-Optics and Phototonics and Photonics Technology Conference, IEEE, Sep. 2009, pp. 74–75. doi: 10.1109/AVFOP.2009.5342628.
3. K. Sony, S. K. Kotamraju, and K. Ch Sri Kavya, "Propagation of Data Using Free Space Under Different Weather Conditions," in Lecture Notes in Electrical Engineering, vol. 839, 2022, pp. 57–67. doi: 10.1007/978–981-16-8554-5_7.
4. K. Sony et al., "Modelling the systems for improvised performance in fso networks," Journal of Advanced Research in Dynamical and Control Systems, vol. 9, no. Special issue 14, 2017.
5. J. Singh and N. Kumar, "Performance analysis of different modulation format on free space optical communication system," Optik (Stuttg), vol. 124, no. 20, pp. 4651–4654, Oct. 2013, doi: 10.1016/j.ijleo.2013.02.014.
6. S. A. Al-Gailani, A. B. Mohammad, and R. Q. Shaddad, "Enhancement of free space optical link in heavy rain attenuation using multiple beam concept," Optik (Stuttg), vol. 124, no. 21, pp. 4798–4801, Nov. 2013, doi: 10.1016/j.ijleo.2013.01.098.
7. V. Sharma and G. Kaur, "High speed, long reach OFDM-FSO transmission link incorporating OSSB and OTSB schemes," Optik (Stuttg), vol. 124, no. 23, pp. 6111–6114, Dec. 2013, doi: 10.1016/j.ijleo.2013.04.100.
8. Gaurav Soni, "FREE SPACE OPTICS SYSTEM: PERFORMANCE AND LINK AVAILABILITY," International journal of computing and corporate research, vol. 1, no. 3, 2011.
9. K. Sony, N. D. Indira, G. Rohith, K. S. Rohith, and B. N. Reddy, "Estimating the performance of Free Space Optics and its benefits," in 2022 International Conference on Advances in Computing, Communication and Applied Informatics (ACCAI), IEEE, Jan. 2022, pp. 1–8. doi: 10.1109/ACCAI53970.2022.9752595.
10. N. Durga Indira, K. Sony, Y. Krishna Sai, G. Vinayak, T. Pavan, and T. Gurunadham, "Analysis of optical link using 4x1 WDM," International Journal of Innovative Technology and Exploring Engineering, vol. 8, no. 6, 2019.
11. S. A. Al-Gailani, A. B. Mohammad, U. U. Sheikh, and R. Q. Shaddad, "Determination of rain attenuation parameters for free space optical link in tropical rain," Optik (Stuttg), vol. 125, no. 4, pp. 1575–1578, Feb. 2014, doi: 10.1016/j.ijleo.2013.10.018.
12. K. Sony, B. K. Rajesh, Ch. Suneetha, N. Venkatesh, and Y. D. R. Reddy, "Modelling System Parameters for Improvised Performance in Free Space Optics (FSO) Networks," International Journal of Electrical and Electronics Research, vol. 11, no. NGWCN, pp. 10–14, Dec. 2023, doi: 10.37391/ijeer.11ngwcn02.
13. K. Sony, K. S. Kumar, K. C. S. Kavya, K. S. Reddy, and U. A. Bharadwaj, "Optical Wave Communication In Free Space Under Different Weather Conditions," in 2022 International Conference on Computer Communication and Informatics (ICCCI), IEEE, Jan. 2022, pp. 1–6. doi: 10.1109/ICCCI54379.2022.9741066.
14. J. Aljohani, J. Mirza, and S. Ghafoor, "A Novel Regeneration Technique for Free Space Optical Communication Systems," IEEE Communications Letters, vol. 25, no. 1, pp. 196–199, Jan. 2021, doi: 10.1109/LCOMM.2020.3029591.
15. Bekkali, H. Fujita, and M. Hattori, "New Generation Free-Space Optical Communication Systems With Advanced Optical Beam Stabilizer," Journal of Lightwave Technology, vol. 40, no. 5, pp. 1509–1518, Mar. 2022, doi: 10.1109/JLT.2022.3146252.
16. S. Chaudhary, A. Sharma, K. Singh, S. Khichar, and J. Malhotra, "Highly efficient photonic radar by incorporating MDM-WDM and machine learning classifiers under adverse weather conditions," PLoS One, vol. 19, no. 4, p. e0300653, Apr. 2024, doi: 10.1371/journal.pone.0300653.

17. S. Chaudhary, A. Sharma, M. A. Naeem, and Y. Meng, “Target Detection in Challenging Environments: Photonic Radar with a Hybrid Multiplexing Scheme for 5G Autonomous Vehicles,” Sustainability, vol. 16, no. 3, p. 991, Jan. 2024, doi: 10.3390/su16030991.
18. H. Chi, X. Zhang, and J. Yao, “A novel wavelength shift keying transmitter using a pair of Mach–Zehnder modulators,” Opt Commun, vol. 281, no. 9, pp. 2517–2521, May 2008, doi: 10.1016/j.optcom.2008.01.008.
19. L. R. R. dos Santos, F. R. Durand, A. Goedtel, and T. Abrão, “Auto-Tuning PID Distributed Power Control for Next-Generation Passive Optical Networks,” Journal of Optical Communications and Networking, vol. 10, no. 10, p. D110, Oct. 2018, doi: 10.1364/JOCN.10.00D110.
20. H. Kaushal and G. Kaddoum, “Optical Communication in Space: Challenges and Mitigation Techniques,” IEEE Communications Surveys & Tutorials, vol. 19, no. 1, pp. 57–96, 2017, doi: 10.1109/COMST.2016.2603518.
21. S. S. Muhammad, “Characterization of fog attenuation in terrestrial free space optical links,” Optical Engineering, vol. 46, no. 6, p. 066001, Jun. 2007, doi: 10.1117/1.2749502.
22. M. Ijaz et al., “Experimental validation of fog models for FSO under laboratory controlled conditions,” in 2013 IEEE 24th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC), IEEE, Sep. 2013, pp. 19–23. doi: 10.1109/PIMRC.2013.6666097.
23. A. Z. Suriza, I. Md Rafiqul, A. K. Wajdi, and A. W. Naji, “Proposed parameters of specific rain attenuation prediction for Free Space Optics link operating in tropical region,” J Atmos Sol Terr Phys, vol. 94, pp. 93–99,Mar.2013,doi:10.1016/j.jastp.2012.11.00