Performance Evaluation of Free Space Optic Technology Using PPM and OOK Modulation

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ABSTRACT

The increasing trend in developing free space optic (FSO) system technology, which is expected to become an alternative for future high-speed wireless communications based on optical communication system, demands comprehensive performance observation of propagation parameters. So, this research proposes an FSO system model using pulse position modulation and on-off keying modulation by considering the influence and reliability of the system on distance, atmospheric conditions, and variations in aperture diameter. The test results include the bit error rate (BER), Q-factor, and optical and electrical signal-to-noise ratio (OSNR/ESNR) at a bit rate of 2.5 Gbps. Based on result observations of the reliability of the FSO system using PPM and OOK modulation at a bit rate of 2.5 Gbps and an optical lens diameter of 5 cm, the proposed system model is capable of meeting optical communication standards up to a transmission distance of 1 km. Meanwhile, in testing various atmospheric conditions with an optical lens diameter of 5 cm to a distance of 0.5 km, the system model is suitable for use in light fog, very light fog, and light mist to clear air conditions. However, in this test scenario, the system is not feasible for dense, thick, and moderate fog conditions. Furthermore, observations at a distance of 0.5 km show that by increasing the optical lens aperture diameter from 20 cm to 30 cm, the proposed system model can achieve BER values of less than 10^{-30} to 10^{-12} in thick fog conditions. In general, there is no significant difference between system performance, including BER, Q factor, and OSNR and ESNR values, whether using PPM modulation or OOK modulation, where the use of a wavelength of 1330 nm is more recommended than 1550 nm judging from the selected signal to noise ratio value.

Keywords: BER, FSO, OOK, PPM, Q-factor, SNR

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1. INTRODUCTION

Free space optic (FSO) is an alternative wireless technology based on an optical communication system that utilizes light propagation in free space for wireless information transmission. FSO technology has advantages over other wireless communications, such as higher bandwidth, cost-effectiveness, high transmission speed, and the absence of license requirement [1] [2]. This practical advantage can be used by placing the FSO transceiver in proximity to a window or on a building rooftop. Besides, FSO is also highly recommended for its robust data security features [1][2][3].

The performance of the FSO communication system depends on many parameters [4-7], encompassing parameters on the FSO transmitter side, notably the digital modulation process and optical modulation used. The optical digital modulation used includes on-off keying (OOK) and pulse position modulation (PPM), known for their resilience to noise. Additionally, the optical modulation process includes both direct and external optics [1].

During the data transmission process, the FSO communication system emits light through free space. However, the presence of fog particles can diminish visibility over land, thereby impacting transmission quality [8] [10]. Fog, defined as when visibility drops to close to 1 km, exists in various types, each associated with differing degrees of optical loss. For instance, radiation fog occurs when the ground is cooled through radiation. Visibility serves as a parameter to gauge atmospheric attenuation caused by fog particles.

In addition to the influence of atmospheric parameters, the performance of FSO is influenced by factors such as visibility. Visibility, defined as the distance at which an object or light can be clearly seen, plays a crucial role. Two-channel models, namely the Kim channel model and the Kruse model, can calculate the amount of atmospheric attenuation using visibility, [1] [10]. The Kim channel has a performance system with further atmospheric visibility conditions than the Kruse channel because the Kruse model is proposed for haze conditions, which have a lower damping effect than fog. This phenomenon is because the size of the smoke (haze) particles is smaller than the fog particles (fog). Therefore, the Kim equation model is more sensitive to fog conditions [9].

Several studies related to FSO system performance indicate that utilizing a wavelength of 1550 nm and a

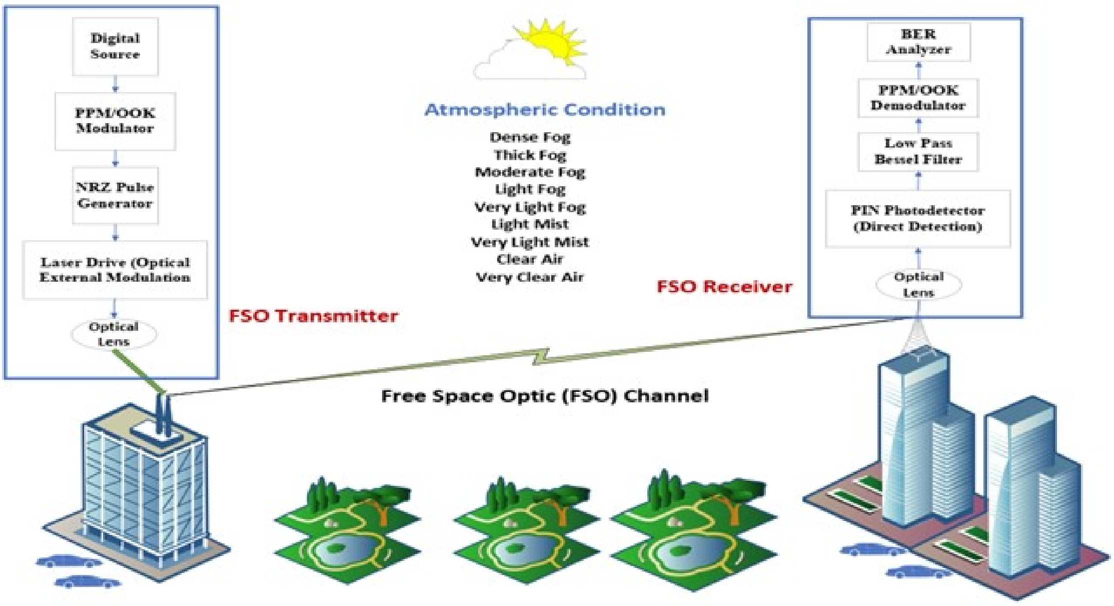

Fig. 1: *Proposed Model of FSO Communication System Using PPM and OOK Modulation.*

link range of 150 m using electro-absorption modulation obtains optimal simulation results with a BER value below 10^{-100} [5]. BER values tend to increase with the use of PSK and FSK modulation [5].

Further research focusing on bandwidth usage, data speed, and data efficiency using OOK, PPM, and digital pulse interval modulation (DPIM) schemes shows that PPM modulation exhibits higher power efficiency compared to OOK and DPIM modulation. Conversely, DPIM modulation has a high ion transmission capacity, making it more efficient in both transmission capacity and bandwidth than OOK modulation [7].

Therefore, this research comprehensively proposes an FSO system model employing Pulse Position Modulation (PPM) and On-Off Keying (OOK) modulation at a bit rate of 2.5 Gbps, considering transmission parameters and atmospheric conditions. This research uses an external optical modulation method, utilizing a continuous wave laser on the transmitting side and a direct detection method using a PIN Photodetector on the receiving side. The test parameters observed include variations in wavelength, distance, aperture diameter, and changes in weather conditions. The test results analyzed in this research include bit error rate (BER), Q factor, and optical and electrical signal-to-noise ratio (SNR).

2. PROPOSED MODEL AND METHOD OF FSO COMMUNICATION USING PPM AND OOK MODULATION

This research proposes a model of FSO system employing 4-PPM and OOK modulation, utilizing an optical external modulation and direct detection system. The FSO system model based on block diagram system includes an FSO transmitter, FSO medium channel, and FSO receiver, as shown in Figure 1. The simulation was performed using the OptiSystem 19.0 program, which included the pseudo-random bit sequence (PRBS), OOK, and PPP modulator functions as electrical signal sources.

The electrical signal is coupled with a CW laser source 1310 nm and 1550 nm and 10 dBm of transmission power in an MZM Modulator before being transmit by the FSO channel. On the receiving end, it is caught and measuring using a photodiode and BER analyzer.

On the transmitting side, source information is generated from a pseudo-random bit sequence (PRBS). PRBS provides bits of information in the form of electrical signals, designed to emulate the characteristics of random data. Its formulation is expressed as follows [11][12].

$$N = T_w B_r \tag{1}$$

$$N_G = N - n_l - n_t \tag{2}$$

where T_w represents the global time window parameter, and B_r is the bitrate parameter. The number of bits produced is denoted as N_G, with n_l representing the count of leading zeros and n_t indicating the count of trailing zeros. Subsequently, the series of bits is forwarded to the PPM and OOK sequence generator. PPM, a pulse modulation technique, adjusts the position of the pulse according to the voltage of the information signal. As the information signal voltage increases, the PPM pulse moves farther from the unmodulated pulse position [5].

PPM modulation offers several advantages, including a high level of power efficiency compared to other baseband modulation techniques, as well as a higher level of noise immunity and transmission efficiency. However, PPM requires greater bandwidth and signaling complexity [5][7]. In PPM modulation, bits depend on

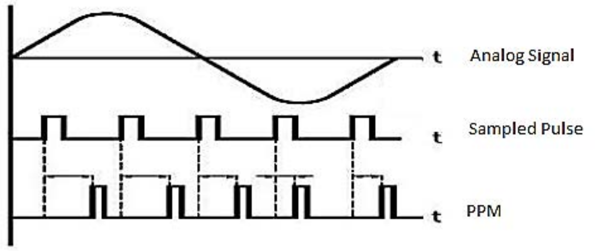

Fig. 2*: Pulse Position Modulation [13].*

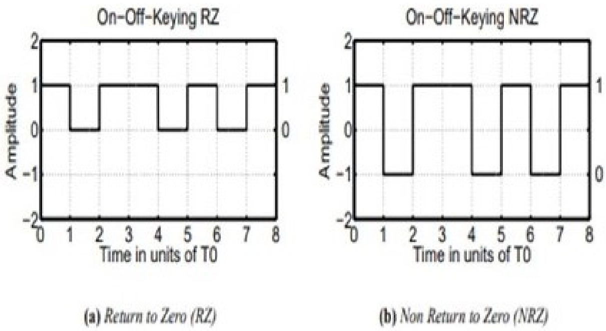

Fig. 3*: OOK Modulation [2].*

the modulation index (L), which results in the symbol period smaller than the bit period, as shown in Figure 2.

In PPM modulation, the symbol interval is divided into subintervals, with the duration of this symbol interval given by the following formula [5]:

$$T = \frac{log_2 L}{R_b} \tag{3}$$

where T is the symbol interval duration, L is number index of bit, and R_b is bit velocity. L is calculated by formula (4), where M is number of bits [7].

$$L = 2^M \tag{4}$$

On the other hand, OOK modulation is widely used in FSO systems. In OOK modulation, the presence or absence of an information signal represents data transmission. A value of 1 is assigned to a bit when there is an information signal, while a value of 0 is assigned when there is no information signal [2][7].

OOK modulation comes in two types, namely, non-return-to-zero (NRZ) and return-to-zero (RZ), as depicted in Figure 3. In NRZ-OOK, a bit value of 1 corresponds to a high-power level, while a bit value of 0 is associated with a low power level. In contrast, in RZ-OOK, the value of bit 1 is expressed with the first half period at a high-power level and the second half period at a low power level, whereas the value of bit 0 is indicated by a low power level [4][7]. The OOK-NRZ modulation waveform can be represented as follows:

$$X(t) = \sum_k a_k P_{peak} P_{Tb}(t - kT_b) \tag{5}$$

where: $P_{Tb} = 1$, $0 \le t \le T_b$ $P_{Tb} = 0$, other $a \in \{0,1\}$ and the peak power is calculated by equation (6).

$$P_{peak} = 2P_{avg} \tag{6}$$

The next stage involves the optical conversion process using an external optical modulation system with a Mach-Zehnder Modulator with a Continuous Wave laser optical source, which has an input power of 10 dBm. The Mach-Zehnder modulator, functioning as an optical intensity modulator, operates on the principle of interferometry, consisting of two 3 dB couplers connected by two waveguides at the same wavelength. Through electro-optical effects, an externally applied voltage is used to vary the refractive index in the waveguide branches. The equation that describes the general characteristics of the MZ modulator output intensity is as follows [1]:

$$E_{out}(t) = E_{in}(t) .\cos(\Delta\theta(\mathrm{t})) .\exp(\mathrm{j}\Delta\phi(\mathrm{t})) \tag{7}$$

where E_{in} is the input intensity signal, $\Delta\theta$ is the phase difference between the two branches of the modulator, and $\Delta\phi$ is the signal phase change. The CW laser phase noise is formulated using the probability density function [1]:

$$f(\Delta\varphi) = \frac{1}{2\pi\sqrt{\Delta \mathrm{f}\,\mathrm{dt}}}.e^{-\frac{\Delta\varphi^2}{4\pi\Delta \mathrm{f}\,\mathrm{dt}}} \tag{8}$$

where $\Delta\varphi$ is the phase difference between two successive time instants, and dt is the time-discretization. A Gaussian random variable for the phase difference between two successive time instants has been assumed, with zero mean and a variance equal to Δf, the laser line-width (equivalent to the full width half maximum (FWHM) of the laser power spectrum).

In the FSO channel, the geometric loss is calculated using the transmitter and receiver aperture diameters, as well as beam divergence angle, as shown in equation 9 [1], [12].

$$P_{Rec\ eived} = P_{Transmitted} \frac{d_R^2}{(d_T + \theta R)^2} 10^{\frac{-TX}{10}} \times 10^{\frac{-RX}{10}} \times 10^{\frac{-AD}{10}} \times 10^{-\alpha\frac{R}{10}} \tag{9}$$

where d_R is the receiver aperture diameter (m), d_T is the transmitter aperture diameter (m), θ is beam divergence (mrad), R is the range (km), α is atmospheric attenuation (dB/km), *TX* is transmitter loss (dB), *RX* is receiver loss (dB) and *AD* is additional loss.

Visibility, representing the viewing distance or size at which an object or light can be seen clearly [4], establishes a link with attenuation. To estimate optical attenuation data from visibility statistics to estimate the scope of FSO system, specific attenuation for the unit of length is calculated using the formula below [1].

$$\beta(\lambda) = \frac{1}{R} 10 log\left(\frac{P_0}{P_r}\right) = \frac{1}{R} 10 log\left(e^{\gamma(\lambda)R}\right) \tag{10}$$

Table 1: *Visibility based on weather conditions.*

Weather Conditions	*Visibility (km)*	*Attenuation (dB/km)*
Dense Fog	0.05	315
Thick fog	0.2	75
Moderate Fog	0.5	28.9
Light Fog	0.770 - 1	19.3
Thin fog/heavy rain	1.9-2	13.8
Haze/medium rain	2.8-4	6.6
Light haze/light rain	5.9-10	3.1
Clear/drizzle	18-20	0.54
Very clear	23-50	0.19

where:
R = length of the transmission link.
P_0 = the optical power emitted by the transmitter.
P_r = optical power at distance R .
γ = Atmospheric attenuation coefficient.

Empirical models are commonly used to predict attenuation due to fog based on visibility range information. The wavelength widely used as the reference visibility range is 550 nm. The following equation describes the specific attenuation of fog [13] [14][15].

$$\gamma(\lambda) = \frac{3.91}{\upsilon}\left(\frac{\lambda}{550}\right)^{-p} \tag{11}$$

where:
υ = range of sight (km).
λ = operating wavelength (nm).
p = coefficient of scattering size distribution.

Based on Kim's model, the p-value is determined by the following formula [1] [14] [16]:

$$p = \begin{cases} 1.6, & \upsilon > 50 \\ 1.3, & 6 < \upsilon < 50 \\ 0.16\upsilon + 0.34, & 1 < \upsilon < 6 \\ \upsilon - 0.5, & 0.5 < \upsilon < 1 \\ 0, & \upsilon < 0.5 \end{cases} \tag{12}$$

and the p-value in the Kruse model can be calculated by the following equation [1]:

$$p = \begin{cases} 1.6, & \upsilon > 50 \\ 1.3, & 6 < \upsilon < 50 \\ 0.585, & \upsilon < 6 \end{cases} \tag{13}$$

The value of visibility can be used to discriminate between various weather conditions. The visibility values for different weather conditions are summarized in Table 1.

On the receiving side, the PIN photodetector receives the information signal, converts it into an electrical signal, and undergoes filtering to eliminate unwanted signals so that the receiving side can capture the desired signal. In this research, FSO simulations are carried out with a focus on differences in distance, atmospheric conditions, and aperture diameter. The outcomes of this research are assessed by analyzing the Bit Error Rate (BER), Optical Signal-to-Noise Ratio (OSNR), electrical Optical Signal-to-Noise (SNR), and Q factor. The global parameters in this research can be seen in Table 2.

Table 2: *Global Parameter of FSO Model.*

No	Parameter	Value	Unit
1	*Bit Rate*	2.5	Gbps
2	*Sequence Length*	1024	Bits
3	*Wavelength*	1310; 1550	nm
4	*Distance*	0.2 up to 1.4	km
5	*Aperture Diameter*	5 up to 30	cm
6	*Extinction Ratio*	30	dB
7	*CW Laser Power*	10	dBm
8	*PIN Responsivity*	0.1	A/W

SNR compares the amount of transmitted power and noise to determine the signal quality. To evaluate the quality and reliability of the FSO network, a useful approach is to compare the power received on the photodetector side. Noise in wireless optical systems is divided into two main parts: shot noise and thermal noise [16]. SNR can be represented as follows:

$$\mathrm{SNR}_{\mathrm{FSO(dB)}} = \mathrm{S\ (dB)} - \mathrm{N\ (dB)} \tag{14}$$

where S is received signal power, and N is signal noise. BER represents the ratio of the error bits to the bits sent in a single transmission on the transmission system. The error function can be denoted as erfc; in standard optical communication systems, the BER value is 10-9. This research employs 4-PPM and OOK NRZ modulation, where calculations are obtained using the following equation (14) and equation (15) [4] [7].

$$\boldsymbol{BER_{4-PPM} = \frac{1}{2}.erfc\left(\frac{\sqrt{SNR}}{2\sqrt{2}}\right)} \tag{15}$$

$$\boldsymbol{BER_{NRZ-OOK} = \frac{1}{2}.erfc\left(\frac{1}{2\sqrt{2}}\sqrt{SNR}\right)} \tag{16}$$

3. RESULT AND ANALYSIS

The performance of the FSO system using PPM and OOK modulation was observed based on three scenarios, including the influence of increasing transmission distance, differences in atmospheric conditions (weather conditions), and variations in the aperture value of the optical lens diameter. Additionally, observations were also carried out to determine the reliability of the laser input system using wavelengths of 1330 nm and 1550 nm.

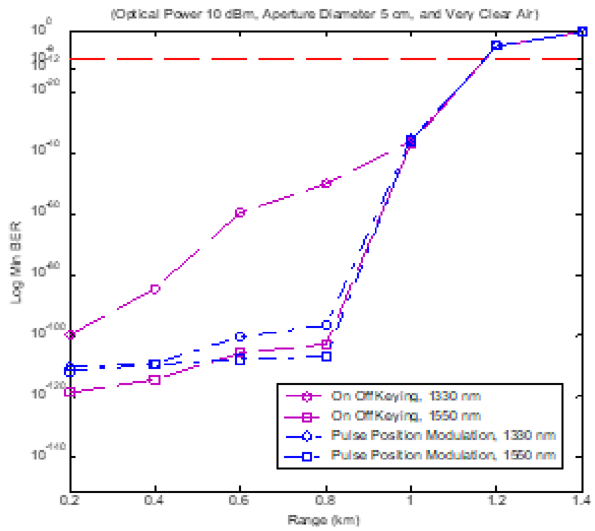

Fig. 4: Minimum BER Result for Range Variation.

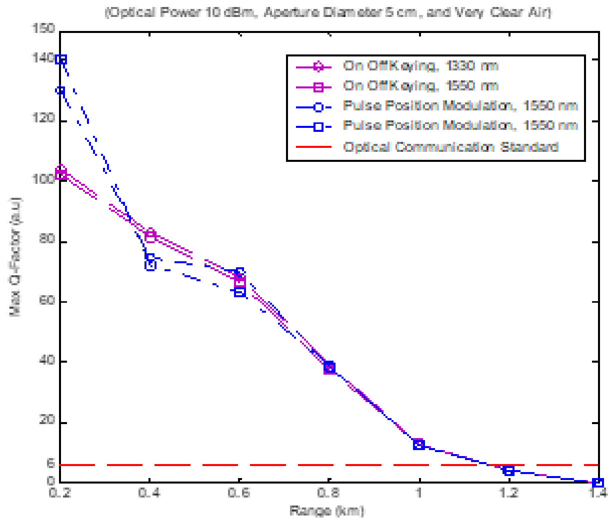

Fig. 5: Maximum Q- Factor Result for Range Variation.

3.1 Scenario 1 (Range Variation for Optical Power 10 dBm, Aperture Diamete 5 cm, and Very Clear Condition)

The first scenario observed the performance of the FSO system based on the visibility of the transmission distance in very clear water conditions ranging from 0.2 km to 1.4 km. The laser input power in this test was limited to 10 dBm with an optical lens aperture diameter of 5 cm. The test results included minimum BER, maximum Q factor, and Optical and electrical SNR values, as shown in Figure 4 to Figure 7.

Based on Figure 4, in general, the BER value of the FSO system obtained, employing both PPM modulation and OOK modulation, meets optical communication standards ($<10^{-9}$) for distances up to 1 km. When using PPM modulation, there is no significant difference in BER values obtained across varying wavelengths. However, in OOK modulation, the BER value for the 1550 nm wavelength tends to increase significantly with an increase in transmission distance from 0.2 to 1 km compared to the 1330 nm wavelength.

Figure 4 shows that up to a distance of 0.8 km, the BER values obtained range from 10^{-120} to 10^{-100} and experience a significant increase to 10^{-40} at a distance of 1 km. Beyond 1 km, the BER value converges to the range of 10^{-9} at 1.2 km and approaches closer to 0 at 1.4 km. Considering the use of bit rate of 2.5 Gbps and the remarkably low BER value up to a distance of 0.8 km, these findings present an opportunity to enhance system reliability. This improvement could be achieved by exploring higher bit rates, particularly 5 Gbps or 10 Gbps, especially in conditions of very clear air.

Similar results were obtained for the Q factor value, as shown in Figure 5, indicating no significant difference between PPM and OOK modulation. Although at a distance of 0.2 km, PPM modulation exhibit a Q factor value exceeding 100 a.u. A decrease in the Q factor

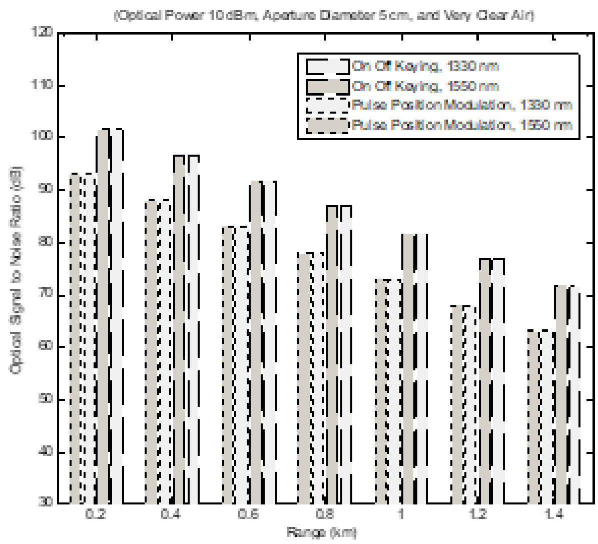

Fig. 6: OSNR Result for Range Variation.

value occurs as the distance increases to a range of 12 a.u. at 1 km. Meanwhile, at a distance of 1.2 km to 1.4 km, the Q factor value for all PPM and OOK modulation and wavelength variations fall below the optical communication standard (Q factor threshold is 6 a.u.). Thus, based on this value, system visibility is limited to a distance of 1 km.

Furthermore, performance observations were based on the Optical Signal-to-Noise Ratio (OSNR) value obtained on the photodetector side, as shown in Figure 6. According to the OOK characteristics, the test results show that the OOK OSNR is higher than that of PPM for both the 1330 nm and 1550 nm variations. Figure 6 shows that up to a distance of 1 km, the OSNR for PPM modulation remains above 70 dB, but at a distance of 1.2 km to 1.4 km, it falls within the range of 60 dB.

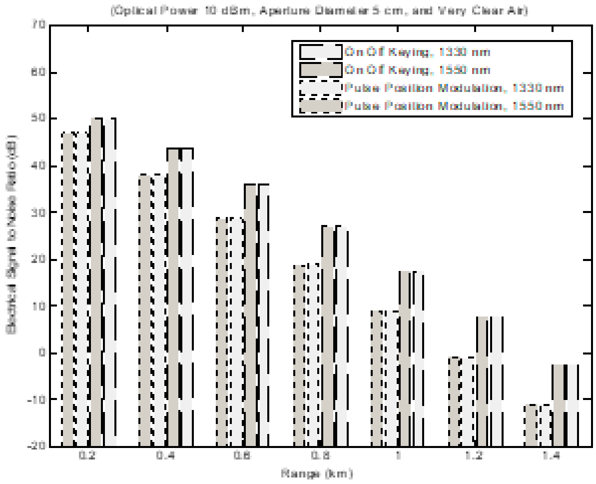

Fig. 7: *ESNR Result for Range Variation.*

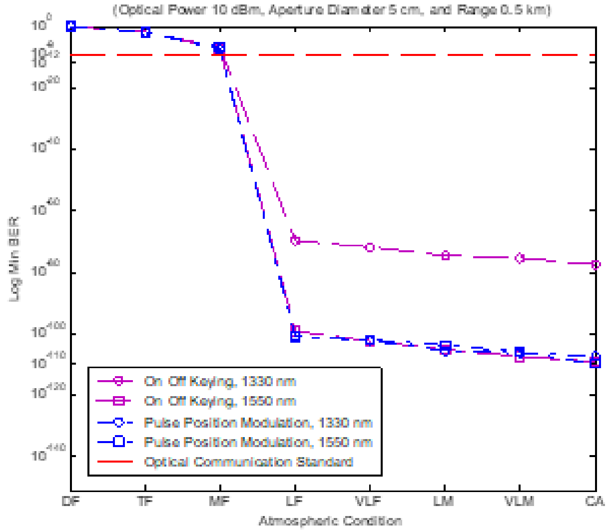

Fig. 8: *Minimum BER Result for Atmospheric Condition Variation.*

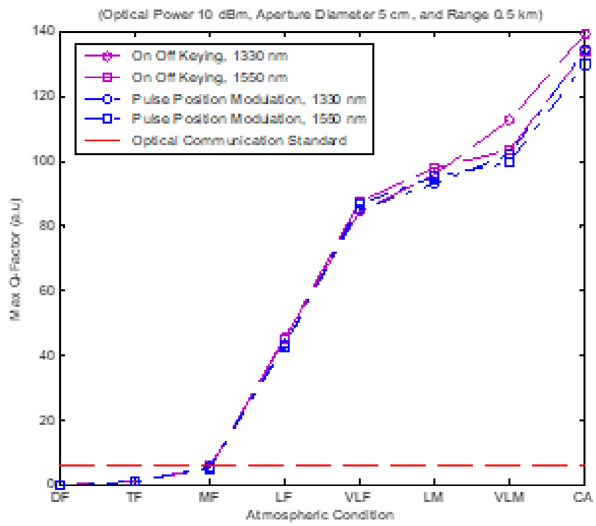

Fig. 9: *Maximum Q Factor Result for Atmospheric Condition Variation.*

In contrast, OOK modulation maintains an OSNR of up to 70 dB even at a distance of 1.4 km. By considering a fairly high OSNR, OOK modulation has the potential to improve signal quality by increasing the responsiveness of the photodetector.

Subsequently, measurements were made on the Electrical Signal-to-Noise Ratio (ESNR) value after passing through the low-pass Bessel filter, as shown in Figure 7. The ESNR results indicate that the ESNR of OOK modulation surpasses that of PPM modulation, with no significant difference in value between long uses at the wavelength of 1330 nm and 1550 nm. Figure 7 shows that up to a distance of 1 km, OOK modulation still has an ESNR value within the range of 18 dB, while PPM modulation falls within the range of 10 dB. A decrease in the ESNR value to below 0 dB occurs at a distance of 1.2 km to 1.4 km, indicating a significant impact of noise on the system. Therefore, based on the OSNR and ESNR values as shown in Figure 6 and Figure 7, besides employing appropriate filters, it is necessary to increase the laser transmit power and increase the responsiveness of the photodetector in order to achieve maximum visibility distance and BER values that meet standards in very clear water conditions.

3.2 Scenario 2 (Atmospheric Condition Variation for Optical Power 10 dBm, Aperture Diameter 5 cm, and Range 0.5 km)

Scenario 2 focuses on observing the performance of the FSO system based on the influence of variations in atmospheric or weather conditions, including dense fog (DF), thick fog (TF), moderate fog (MF), light fog (LF), very light fog (VLF), light mist (LM), very light mist (VLM), and clear air (CA) at a distance of 0.5 km. This distance was determined by considering the projected use of FSO communications in urban areas, with visibility and attenuation values for the FSO system based on Equation 10, Equation 11, and specific conditions outlined in Table 1.

Figure 8 indicates the performance differences of the FSO system based on atmospheric conditions including fog and mist conditions. For this test scenario, the conditions of DF, TF, and MF failed to meet optical communication standards due to BER values exceeding 10^{-9}. Even in DF conditions, the BER value obtained can reach 1. The results obtained aligned with the attenuation and visibility values in Table 1, where DF visibility is limited to a distance of 0.05 km, TF is limited to a distance of 0.2 km, and MF is limited to a distance of 0.5 km.

The FSO system performed optimally, whether using PPM modulation or OOK modulation for all wavelength variations in LF, VLF, LM, VLM, and CA conditions. The obtained BER values are below 10^{-60} to 10^{-100} in CA

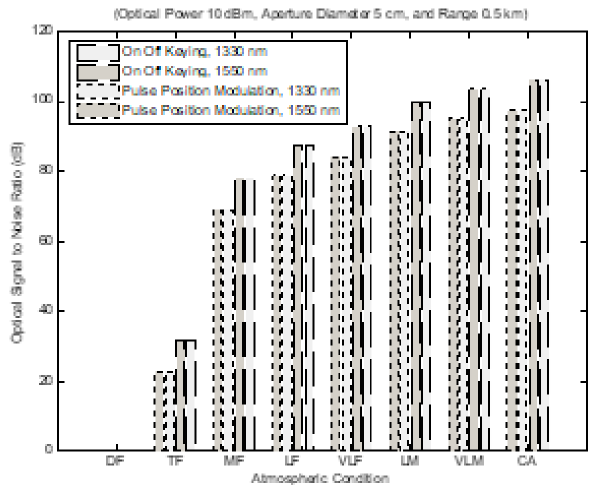

***Fig. 10**: OSNR Result for Atmospheric Condition Variation.*

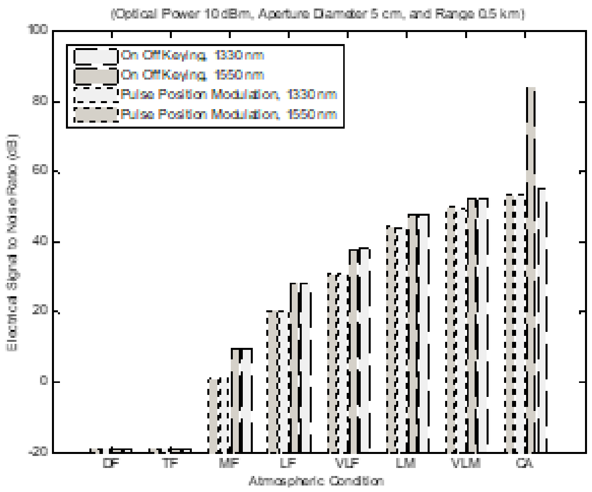

***Fig. 11**: ESNR Result for Atmospheric Condition Variation.*

conditions. Therefore, using a 10 dBm laser power, an aperture diameter of 5 cm, and a distance of 0.5 km, both PPM and OOK modulation are highly suitable for use. These results also indicate opportunities for increasing transmission distance or bit rate, especially in LF to CA conditions. However, further investigation is needed regarding the performance of the FSO system, especially in other fog conditions (TF and MF), as discussed in scenario 3.

The Q factor results in Figure 9 also show similar results to the BER values, with DF, TF, and MF having Q Factor values below 6 a.u. A significant increase in the Q factor value occurred for conditions LF to CA. The system's performance using wavelengths of 1330 nm and 1550 nm also shows consistent results, with VLF, LM, VLM, and CA conditions exhibiting Q factor values above 80 a.u.

The OSNR value in Figure 10 can be used as a reference for system performance analysis, where OOK modulation

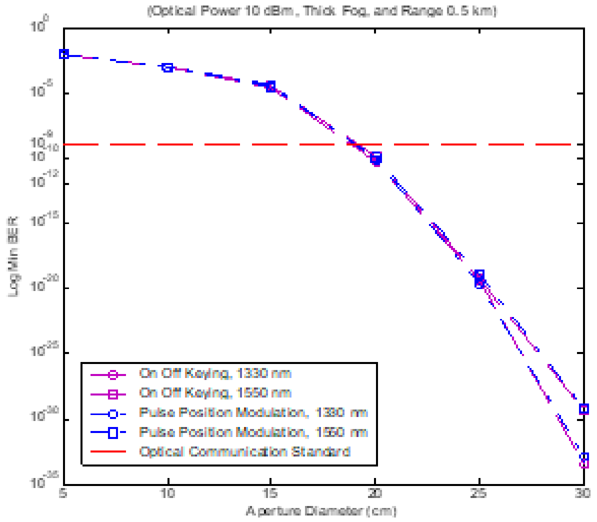

***Fig. 12**: Minimum BER Result for Aperture Diameter Variation.*

has a higher value than PPM modulation. LF, VLF, LM, VLM, and CA have OSNR values above 80 dB. The variation in the BER value of DF, TF, and MF are caused by the OSNR values falling below 80 dB; even in DF, the OSNR value is 0 dB. In TF conditions, particularly OOK modulation, the OSNR is at 40 dB.

These results certainly provide an opportunity for further investigation, specifically in terms of adjusting transmit power and increasing the aperture diameter to align with the established standards. Similar to the preceding OSNR outcomes, the ESNR value obtained shows values exceeding 20 dB for LF to CA conditions, within the range of 60 dB, as shown in Figure 11. These results show the effectiveness and importance of filtering after the optical detection mechanism.

3.3 Scenario 3 (Aperture Diameter Variation for Optical Power 10 dBm, Thick Fog, and Range 0.5 km)

Scenario 3 involved a comprehension examination of the quality of the FSO system using PPM and OOK modulation based on the influence of varying optical lens aperture diameters. The observation focused on Thick Fog conditions with a signal quality below standard. This test aimed to assess the potential performance improvement by increasing the aperture diameter of the optical lens, employing a transmit power of 10 dBm, and restricting the distance to 0.5 km with a bit rate of 2.5 Gbps.

Figure 12 shows that increasing the aperture diameter value results in a drastic decrease in the BER value. Notably, the aperture diameter ranging from 20 cm to 30 cm is shown to meet BER standards in thick fog conditions. These results have proven that the proposed FSO system model using a larger aperture has the potential to be recommended for foggy conditions,

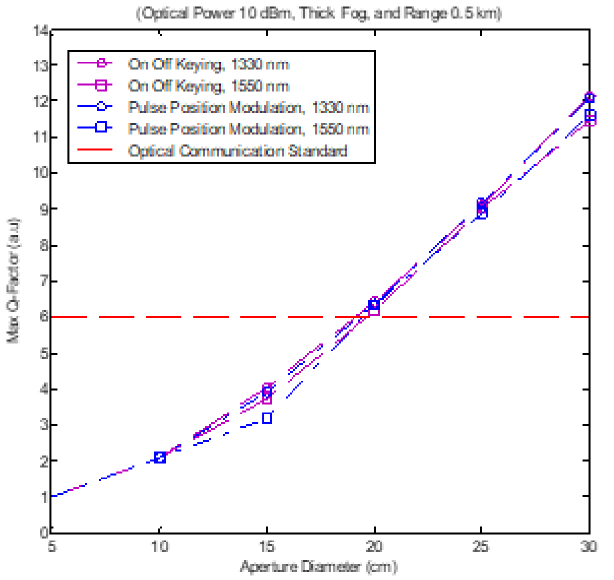

Fig. 13*: Maximum Q Factor Result for Aperture Diameter Variation.*

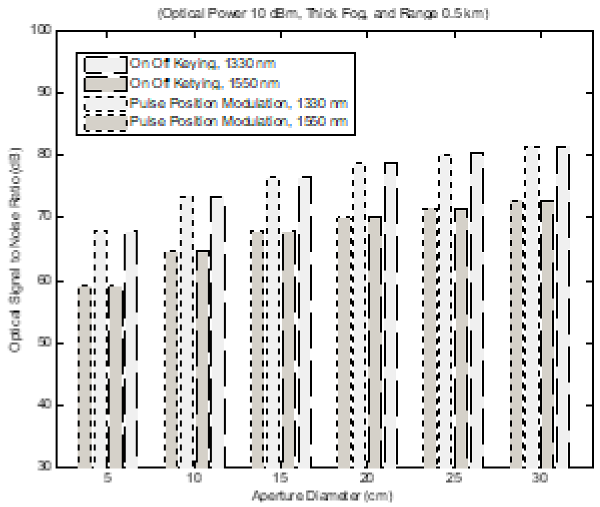

Fig. 14*: OSNR Result for Aperture Diameter Variation.*

despite its limitation to a distance of 0.5 km and bit rate of 2.5 Gbps. This result can be analyzed according to equation (9), where increasing the aperture diameter increases the received power. The Q Factor values in Figure 13 confirm these findings, with diameters ranging from 20 cm to 30 cm, the Q factor value reaches more than 6 a.u. Even with an aperture value of 30 cm diameter, it has a value of up to 12 a.u. Figure 12 and Figure 13 also show the system's reliability for using wavelengths of 1330 nm and 1550 nm for OOK and PPM modulation, with no significant difference in the results obtained.

Regarding the received power, which correlates with OSNR and ESNR, Figures 14 and 15 show that using an aperture diameter of 20 cm to 30 cm for a wavelength of

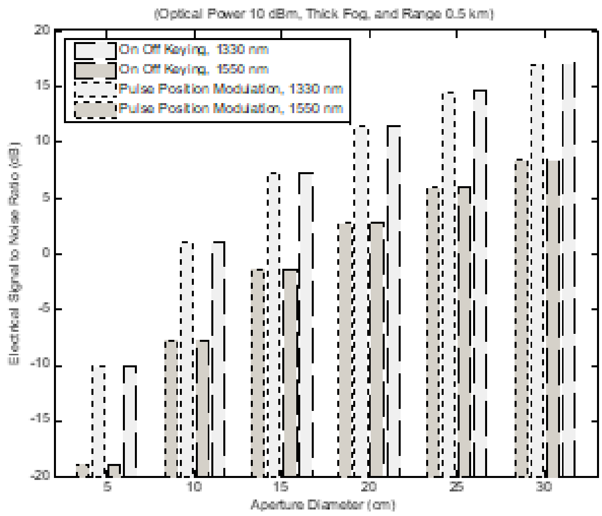

Fig. 15*: ESNR Result for Aperture Diameter Variation.*

1330 nm yield an OSNR exceeding 75 dB and an ESNR surpassing 10 dB. In contrast, the 1550 nm wavelength has an OSNR value of more than 67 dB and an ESNR of more than 3 dB. Thus, observing the wavelength used, 1330 nm is recommended for PPM and OOK modulation.

4. CONCLUSION

Based on observations of the FSO system reliability using PPM and OOK modulation at a bit rate of 2.5 Gbps and an optical lens diameter of 5 cm, the proposed system model is capable of meeting optical communication standards up to a transmission distance of 1 km. Meanwhile, in testing various atmospheric conditions with an optical lens diameter of 5 cm to a distance of 0.5 km, the system model is suitable for use in light fog, very light fog, and light mist to clear air conditions. However, in this test scenario, the system is not feasible for dense, thick, and moderate fog conditions. Furthermore, observations at a distance of 0.5 km show that by increasing the optical lens aperture diameter from 20 cm to 30 cm, the proposed system model can achieve BER values of less than 10-30 to 10-12 in thick fog conditions. In general, there is no significant difference between system performance, including BER, Q factor, and OSNR and ESNR values, whether using PPM modulation or OOK modulation, where the use of a wavelength of 1330 nm is more recommended than 1550 judging from the selected signal to noise ratio value. These results certainly provide an opportunity for further investigation in terms of transmit power and increasing the aperture diameter to meet standards.

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