Engineering and Technology Journal 42 (02) (2024) 276 - 287

Engineering and Technology Journal
Journal homepage: https://etj.uotechnology.edu.iq

Performances study of Psk and Ask modulation technique under atmospheric turbulence in Fso communication system

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HIGHLIGHTS

- A design model with different modification types was simulated using Optisystem 7.0 software to evaluate its performance under different weather conditions to determine the best modification method.
- Attenuation was calculated for each type of atmospheric turbulence.
- The result of PSK and ASK modulation-based FSO systems used coupler-based delay line filters under various climatic conditions described.

ARTICLE INFO

Handling editor: Makram A. Fakhri

Keywords:
FSO
Optisystem 7.0
Digital modulation
wireless communication
Amplitude Shift Keying (ASK)
Phase Shift Keying (PSK)
Atmospheric turbulence

ABSTRACT

The performance and reliability of a free-space optical (FSO) communication system can be greatly increased using various methods. The primary goal of each technique is to reduce the effect of disturbances that lead to intensity or phase fluctuations in the system's receiver. Recent issues include increased data consumption and a crowded radio frequency spectrum, where free-space optical communication (FSOC) has changed the way people share information in a big way. In place of wired communication systems, it is possible to transport voice, video, and data effectively through air. High speed, cost savings, small buildings, low power consumption, energy economy, maximum transfer capacity, and adaptability are some of the main advantages of FSOC. Repair downtime can be reduced because of the quick advancement of high-speed connection technology. It is also now possible to quickly establish a backup network in an emergency or crisis. The design of FSO systems for two types of digital modulation techniques is the primary focus of this work. An examination of the FSO link's performance in various channel conditions using various modulation techniques is conducted. This analytical mechanism can aid a modulation strategy for various channel conditions. The results indicated that PSK modification is stronger against atmospheric turbulence than ASK modification in terms of quality factor and signal-to-noise ratio (SNR). In addition, the values of received power, quality factor, and signal-to-noise ratio were higher in the case of atmospheric turbulence during rain than in the case of fog, followed by dust conditions. The systems can operate using adaptive optics and evaluate the system's performance in the presence of atmospheric turbulence in terms of signal quality, received power, and signal-to-noise ratio.

1. Introduction

Free-space optical communication (FSOC) is a significant approach in the evolution of wireless communications that has seen massive interest and development in the past decade [1]. FSOC technologies are becoming increasingly appealing and significant as the demand for high-speed communication grows. FSOC lines are critical for meeting the demand for future terrestrial and ground-space communication applications [2]. The modulated light is used in FSO communications, a line-of-sight (LOS) technique, to convey information across stations in constant or mobile instances. FSO has also been used in military applications demanding high security. In 1970, Nippon Electric Company (NEC, Japan) built the first full-duplex FSO link between Yokohama and Tamagawa over a distance of 14 km, utilizing a He-Ne laser operating at 632 nm [3]. The advanced time of internal FSO communication began by suggesting diffused infrared emanations for internal interchanges.

Since then, researchers have focused on characterizing interior channels and structuring the recipients and transmitter optics. In its Mars Laser Communication Demonstration (MLCD) program, the National Aeronautics and Space Administration (NASA) demonstrated using FSO for advanced space applications. FSO communications technology has recently received much attention because it offers broadcasts at extremely high data rates involving two endpoints hundreds of kilometers apart [3,4].

http://doi.org/10.30684/etj.2023.143196.1567
Received 07 September 2023; Received in revised form 22 November 2023; Accepted 04 December 2023; Available online 20 December 2023
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Recent advancements in FSO communications have established it as a viable alternative to radio frequency (RF) systems. An FSO system consists of a transmitting and receiving terminal. Information is encoded onto electromagnetic waves through modulation and delivered to the receiving system, much like an RF system. FSO links operate at significantly higher frequencies than RF links, typically in the infrared or visible regions. Faster frequencies produce broader bandwidths, which produce higher data rates [5]. The amplitude of the downlink signal traveling across the FSO connection is distorted because of various atmospheric interferences, such as scattering, refraction, and absorption, as well as unfavorable weather conditions like light, moderate, and severe fog.

The gamma-gamma channel model is taken into account for atmospheric turbulence since it holds for all three turbulence conditions, namely weak turbulence (WT), moderate turbulence (MT), and strong turbulence (ST) conditions [6]. Due to its many benefits, such as its low cost, license-free operation, immunity to electromagnetic interference, and high level of security, free-space optical communication (FSO) has become a popular area of study. The FSO link relies on sending data via the atmosphere and using a telescope to receive optical light. However, certain difficulties, like scintillations, atmospheric turbulence, and fog, eventually diminish the transmission distance and lower the signal-to-noise ratio (SNR). Among all the difficulties, atmospheric turbulence and fog negatively impact FSO [7]. Based on variations in refractive index and inhomogeneity, atmospheric turbulence is divided into weak, medium, strong, and saturated routines. Different mathematical models, such as log-normal, negative exponential, and gamma-gamma, to illustrate weak, strong, weak-to-strong, and generalized turbulences, correspondingly, are established to symbolize the turbulence routines [8]. This aims to offer useful insights into how PSK and ASK modulation techniques perform in FSO communication systems operating in the presence of atmospheric turbulence and provide recommendations for choosing the most appropriate modulation scheme for a given set of environmental factors and communication needs. To compare the current study and previous studies, the results we reached were the same as those of previous studies that used the same digital modification methods, as the study [6] indicated the emergence of the same behavior with changes in wavelength and distance.

2. FSO link challenges

2.1 Atmospheric turbulence

Clear air turbulence can have a considerable influence on the transmitted optic beam. Wind and sun heat can both contribute to homogeneous air pressure and temperature. These fluctuations cause irregular distinctions in the refractive index of the atmosphere, resulting in air cells (eddies) of varying sizes and refractive indices. Distinctions in the optical beam's transmission path and refractive index in the air may cause random changes in the received signal phase and amplitude. The schematic representation of an FSO communications infrastructure is shown in Figure 1. An optical transmitter conveys data signals, whether analog or digital, through the environment. At the receiver end, the optical beam targets the photodetector, whose output is electronically manipulated to receive the information signal. The size of the turbulence cell, which can be described as follows, determines the impact of atmospheric turbulence on the optical signal:

1) When the dimensions of the turbulence cells are smaller than the laser beam diameter, the laser beam bends and deforms. The laser beam strength at the receiver fluctuates with time due to minute variations in the arrival time of the wave front's element portions. This interference has both positive and negative effects. The scintillation effect is seen in Figure 1(a).
2) The optical path can be twisted if the air turbulence cell size exceeds the beam width. Figure 1(b) shows how the laser source's beams (solid rays) are twisted as they pass through the huge air cell, arriving off-axis rather than on-axis as predicted in the absence of turbulence [9].

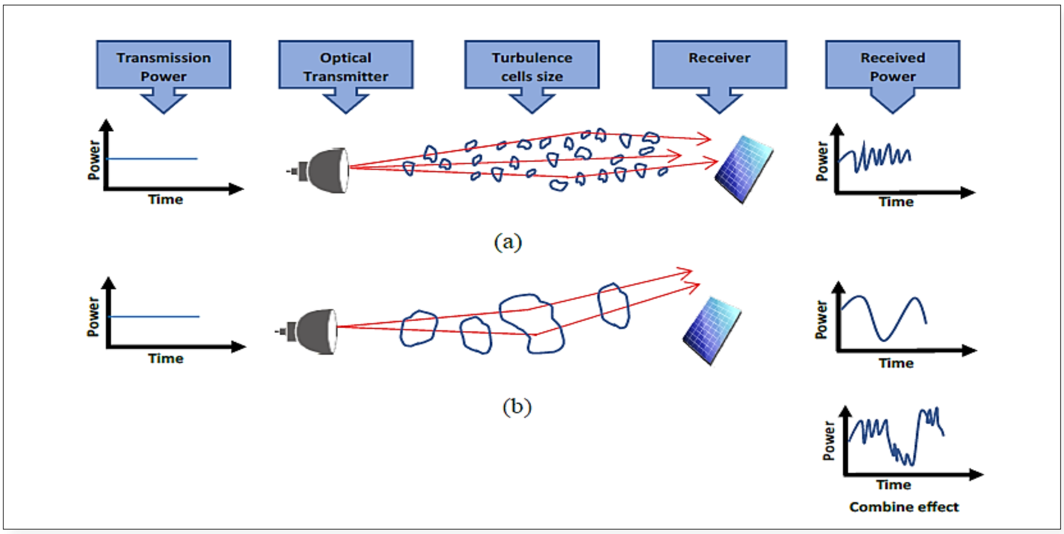


Figure 1: Turbulent Cell Size Comparison with (a) Scintillation and (b) Beam Wander"[9]

An FSO communication system with modulation and demodulation algorithms is shown in Figure 2. After the electrical signal has been modified using the modulation algorithm, a laser driver transforms it into an optical signal, which is then transmitted to the receiver by atmospheric turbulence. The term "scintillation" refers to variations in phase and amplitude brought on by refraction, reflection, scattering, and other effects brought on by shifts in the refractive index of the turbulent environment. The received signal is then converted into an electrical signal through a PIN photodetector, which is demodulated using the proper demodulation model. After demodulation, the signal can be expressed as [10] :

$$y = IRA\zeta m(t) + n(t) \tag{1}$$

where ***R*** is the photo detector's responsiveness, ***I*** denotes the light intensity's half peak, and ζ denotes the modulation index. In addition, ***A*** denotes the subcarrier's amplitude, and ***m(t)*** and ***n(t)*** denote the electrical signal and the additive white Gaussian noise.

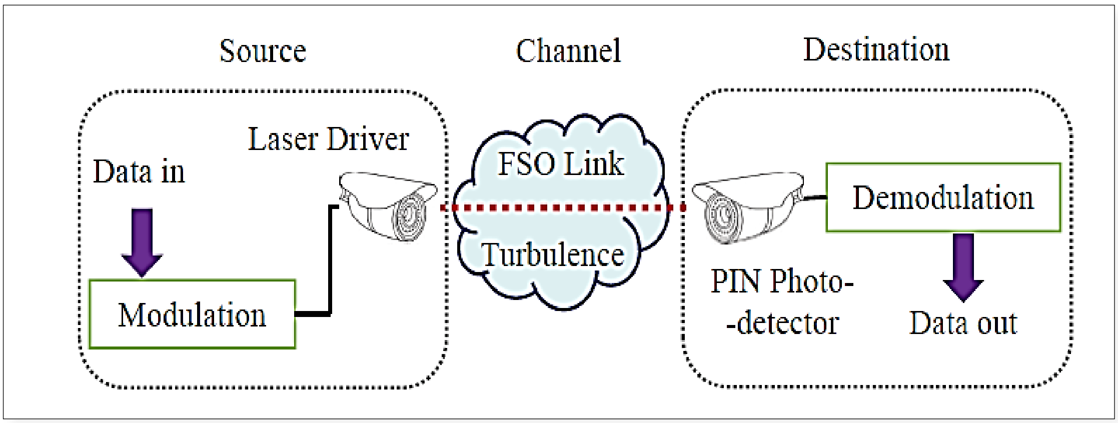


Figure 2: The Model of the Atmospheric Turbulence System's Optical Wave Propagation [10]

2.2 Weather attenuation effects

The collimated beam of light is transmitted via an optical transmitter. With increasing link distance, the transmitted beam's breadth widens. By reducing the link margin at the receiver side, the increased beam width leads to signal loss, a decline in SNR, and an increase in bit error rate (BER). The diameter of the receiver aperture on the receiving side should be greater to receive all the information transmitted by the optical carrier, but doing so also increases noise from ambient light. Atmospheric attenuation and geometric loss combine to provide the overall attenuation. In Equation, the total attenuation is given [11] :

$$Attenuation\left[{}^{dB}/_{Km}\right] = \frac{d_r^2}{(d_t+(L\theta))^2}\tau \tag{2}$$

Here ***dt*** represents the diameter of the transmitter (in mm), ***dr*** is the diameter of the receiver (in mm), ***θ*** is the divergence angle of the beam (in rad), and ***L*** is the length of the communication link (in m). Geometrical losses are considered constant losses because all internal design parameters remain constant [11].

Various attenuation issues that cause power loss cause the link's quality to degrade. The link margin must be used more precisely to offset the power loss. The link margin (***Pl***) is defined as the ratio of the receiving power (***Pr***) and receiver threshold or sensitivity (***S***), which is often stated in *dB* [12]:

$$p_l = \frac{10 log p_r}{S} \tag{3}$$

For effective recovery at the receiver side, the average power of the signal must be greater than the receiver sensitivity. The manufacturer will often state the sensitivity, which ranges from 20 to 40 *dBm.* The receiver's power is represented as [12]:

$$p_r = \frac{p_t e^{-\alpha t} A_{rx}}{(\theta l)^2} \tag{4}$$

where A_{rx} is the area of receiver aperture, is ***θ*** the divergence angle, ***α*** is atmospheric attenuation, and ***l*** is the distance between the source and receiver, P_r and P_t represent the power at the receiver and source, respectively. One of the key players impacting the system's overall performance is the atmospheric attenuation coefficient. Atmospheric attenuation is the word used to describe the type of attenuation that results from the presence of aerosols.

This attenuation is caused by the combined action of infrared light being absorbed and scattered by airborne gas molecules. The atmospheric loss is stated as follows in dB [13]:

$$Loss_{propagation} = -10log_{10}T_a \tag{5}$$

where: T_a = The atmospheric transmittance is the ratio of power received to power transmitted into the optical link.

2.2.1 Rain Attenuation

Rainfall models rely heavily on multiple distribution models based on raindrop size.

Rain-induced signal attenuation is highly dependent on different patterns of rain distribution. The most well-known study about raindrop size distribution is from Marshall and Palmer. The Marshall-Palmer distributions are based on their data and the law of Parsons. Rain attenuates when droplets are large enough to reflect and refract optical signals. The attenuation is calculated as follows and represented in dB/km [14,15]:

$$Att_{rain} = k_1R^{k_2} \tag{7}$$

where:R = Represents rain rate in mm/hr, K1 and K2 = Are model parameters that depend upon raindrop size and rain temperature. The rain attenuation prediction model's values for FSO are k1= 1.074 and k2= 0.67, respectively."The value of R according to different rain conditions is shown in the Table 1 below [14,15].

Table 1: R Values for Rain Conditions

Rainfall	**R Standards (*mm/hr*)**
Light rain	2.5
Medium rain	12.5
Heavy rain	25
Cloud burst & heavy rain	100

2.2.2 Fog attenuation

Fog is the primary factor in atmospheric attenuation since it contributes to scattering and absorption. A relationship must be built to anticipate the optical attenuation statistics from the visibility statistics. The attenuation increases to more than 350 dB/km when the visibility is less than 50 m. Strong lasers with specialized procedures are required to improve communication [16]. Based on an empirical model and a theoretical strategy that depends on the visibility range, various models are employed to calculate the attenuation brought on by fog, smoke, and dust. According to the Kim model, the atmospheric attenuation coefficient can be expressed [17]:

$$\alpha = \frac{17.35}{V}\left(\frac{550}{\lambda}\right)^{q} \tag{8}$$

V is the visible range in kilometers, and λ is the wavelength in nanometers. The particle size distribution is given by q, α, which represents the overall attenuation coefficient. The Kruse model can be used to illustrate how the particle size distribution relates to the visibility range [17]:

$$q = \begin{cases} 1.6 & if\ V > 50km \\ 1.3 & if\ 6\ km < V < 50\ km \\ 0.585V^{1/3} & if\ V < 6\ km \end{cases} \tag{9}$$

According to Equation (8), greater wavelengths will experience less attenuation in any weather. Kim modified Equation (9) to account for low visibility. Hence, the Kim model's particle size can be expressed as [17] :

$$q = \begin{cases} 1.6 & if\ V > 50km \\ 1.3 & if\ 6\ km < V < 50\ km \\ 0.16V + 0.34 & if\ 1\ km < V < 6\ km \\ V - 0.5 & if 0.5\ km < V < 1\ km \end{cases} \quad \text{Dust Attenuation} \tag{10}$$

2.2.3 Dust attenuation

There are four categories of dust events based on visibility range, namely, dust haze (light dust), blowing dust (light dust), dust storm (moderate dust), and severe dust storm (dense dust). As a result, Table 2 represents categories of dust storms into four kinds depending on visibility range, and visibility range V is calculated using the following Equation [18]:

$$V = -\frac{10logT_{th}}{\alpha}(Km) \tag{11}$$

where T_{th}: contrast threshold= ***0.02*** according to Koschmieder law. The signal attenuation coefficient α is calculated as follows [18]:

$$\alpha = -\frac{10logT}{4.343L}(dB/Km) \tag{12}$$

L is the link length in kilometers, and ***T*** is the optical signal's transmittance at 550 nanometers.

Table 2: Classification of a dust storm based on the range of visibility [19]

Dust type	Description	Visibility (km)
Severe dust storm	Dense	< 0.2
Dust storm	Moderate	0.2-1
Blowing dust	Light	1-10
Dust haze	Light	≤ 10

Dust attenuation affects the signal transmission in FSO in addition to geometrical losses. Can say the received optical power is as follows [19]:

$$P_r = P_t(\frac{D_2}{(D_1+\theta L)})^2\tau_t\tau_r \times 10^{-\left(\frac{\alpha L}{10}\right)} \tag{13}$$

where τ_r is the receiver optical efficiency, τ_t is the transmitter optical efficiency, θ_t is the divergence angle of the beam, ***L*** is the optical link, D_1&D_2 are the transmitter and receiver aperture diameter', P_t is the transmitter optical power, and α is the attenuation coefficient. A pin photodiode is used on the receiver side to convert the receiver signal to electrical signal power.

3. System design and configuration

There are four stages that the signal goes through during modulation: The transmission stage is the initial stage. The pulse generator of the PSK digitally encodes the digital data of the bit sequationuence generator. The phase shift modulator modulates the optical carrier signal using the encoded data. The delay line filter, used in the second stage, is designed to account for dispersion effects and reduce the fading and jitter they cause. The atmosphere acts as a channel at the FSO channel's third point. The final step is the receiving stage, which senses the optical signal and converts it into an electrical signal.

Figure 3 describes the suggested PSK modulation technology. Typically, the system comprises a transmitter, an FSO channel, and a receiver. The transmitter portion has a built-in PRBS that generates a pulse fed into the PSK pulse generator with a dark current of 10 *nA*. Thermal noise is set $1x10^{-22}$ W/Hz at a response of 1A/W. The FSOC PSK modulation system's global parameter settings are displayed in Table 3.

Table 3: Key Subjects of the Proposed PSK Modulation System

Considerations	Rate	Statement
Bit Rate	10 Gbps	High data rate
Modulation	PSK	compensate dispersion effects, reduce the turbulence effect
Wavelength	632 nm	Low scattering
Channel	Free space	Rain, fog, and dust
Optical Amplifier	20dB	
Optical Output from the Transmitter	5 mw	Power (Pt)
Aperture of Transmitter-Receiver	50 mm-75 mm	Divergence of Beam 2 mrad
Photo Detector	APD	Responsively 1A/W
Dark Current Thermal	10nA	Thermal noise $1/10^{22}$ W/Hz

The modulator, laser source, coder, channel, and receiver unit are all included in The Simulation Shape for ASK Modulated, as seen in Figure 4. The coder generates a data signal by encoding the data bits, and the laser source is the carrier signal. Accordingly to the input signal, the amplitude modulator adjusts the carrier signal's amplitude. The modulated signal is transmitted into the atmosphere via the FSO channel. The signal is picked up via the receiver portion, and the photodetector locates the optical signal to convert it to the electrical signal.

Optisystem software was used to simulate and model a simple FSO system employing the ASK modulation technique for performance characterization. In this simulation, one part of the optical transmitter is the PRBS generator, which represents the data or information that needs to be conveyed and has a bit rate of 10 Gbit/sec. The output of the PRBS generator is the non-return-to-zero (NRZ), a bit flow of binary pulses made up of a series of known and repeating "0s" (OFF) or "1s" (ON) in a pattern. The used laser has a 632 nm wavelength and 5 mw of power. The AM modulator takes two inputs: the carrier signal from the continuous-wave laser and the electrical signal from the NRZ pulse generator. The main purpose is for the system to use free space optics. Therefore, the modulator changes the electrical signal into the optical signal. A free-space optical channel has been considered the medium in the free-space between receivers and transmitters. The beam divergence is set at while this happens to (2 *mrad*). The FSOC ASK modulation system's global parameter settings are displayed in Table 4.

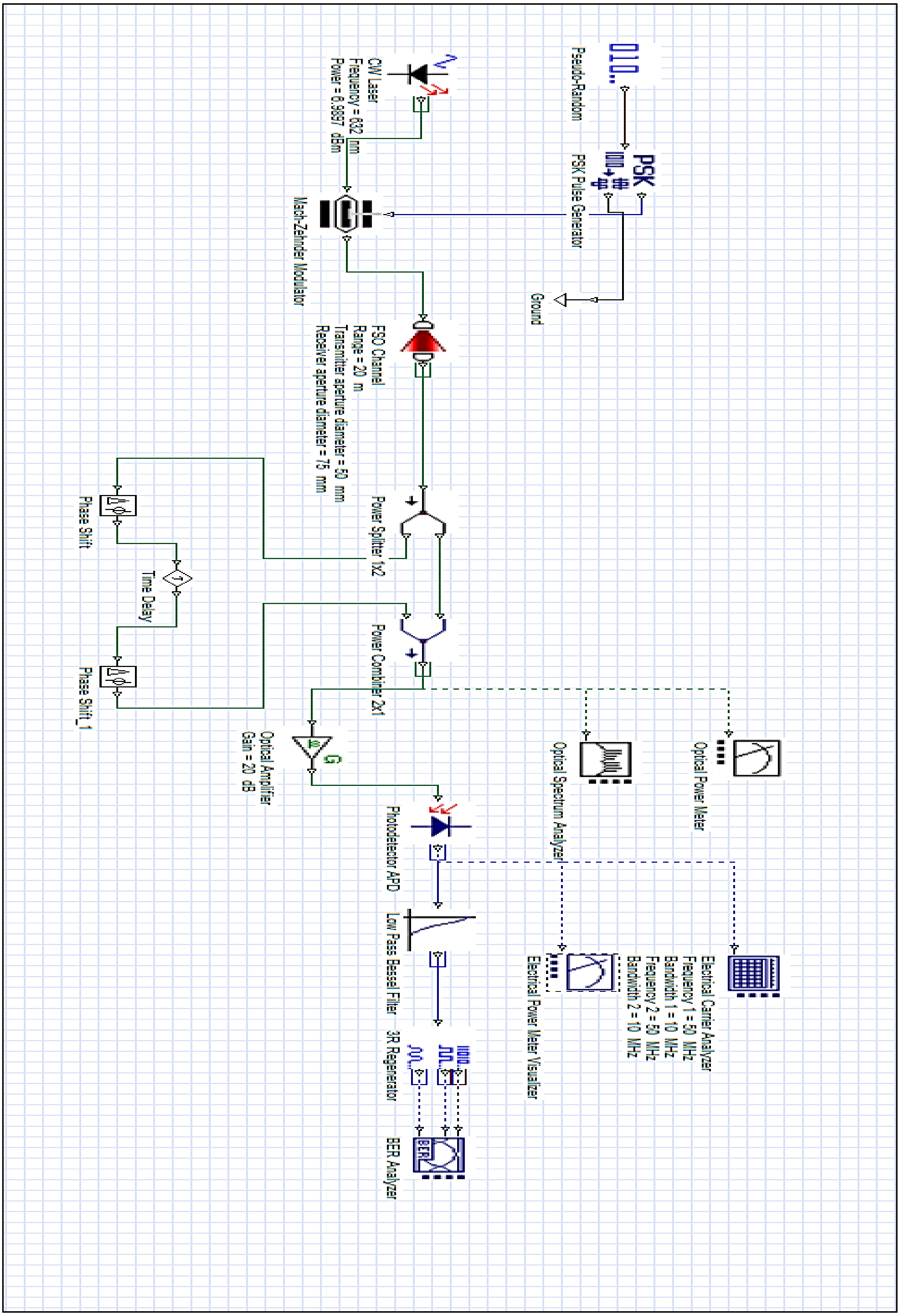


Figure 3: The Simulation Shape for PSK Modulated FSO System

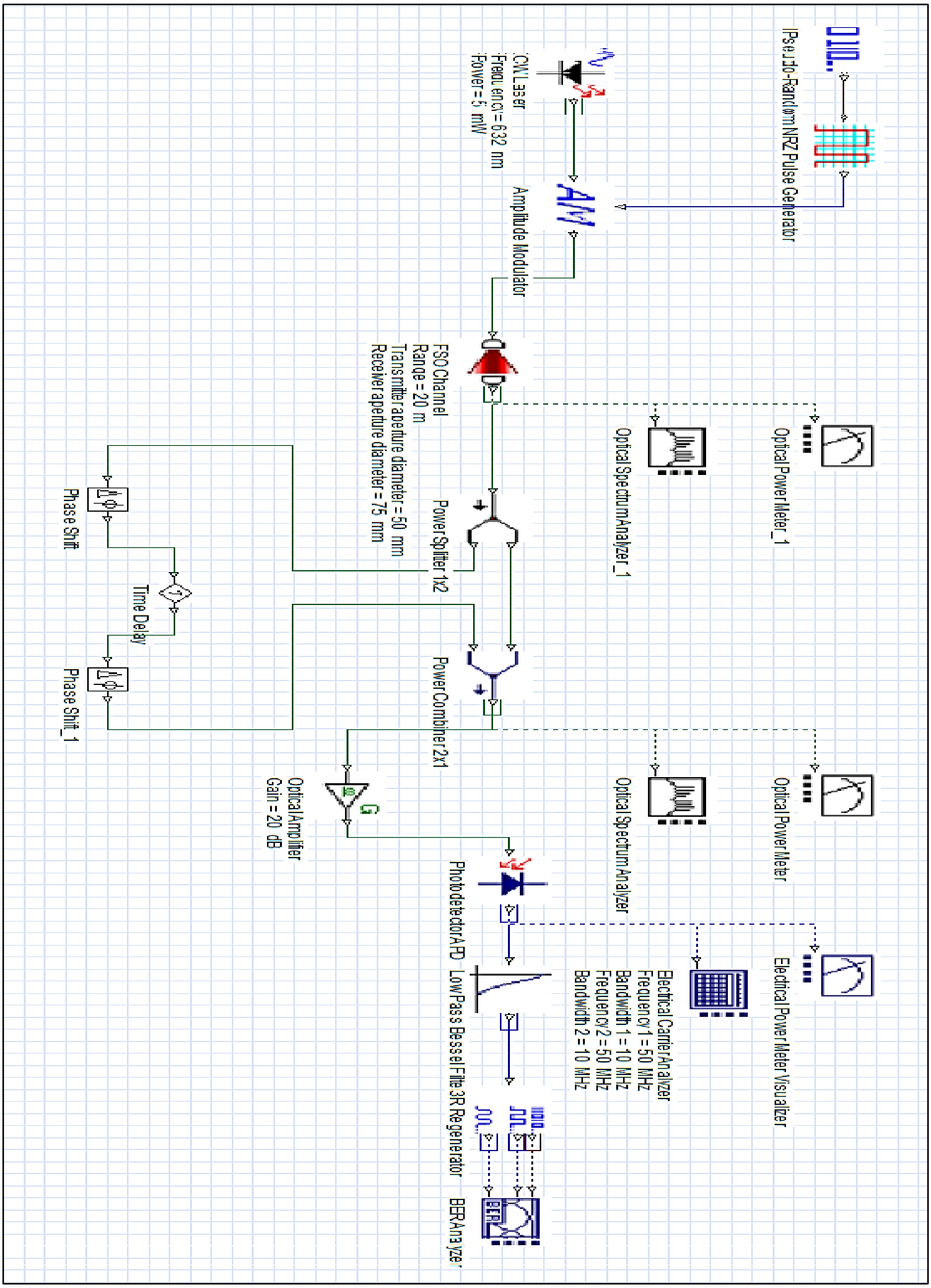


Figure 4: The Simulation Shape for ASK Modulated FSO System

Table 4: Key Subjects of the Proposed ASK Modulation System

Considerations	Rate	Statement
Bit Rate	10 Gbps	High data rate
Modulation	ASK	compensate dispersion effects, reduce the turbulence effect
Wavelength	632 nm	Low scattering
Optical Amplifier	20 dB	
Channel	Free space	Rain, fog, and dust
Optical Output from the Transmitter	5 mw	Power (Pt)
Transmitter/Receiver aperture	50 mm/75 mm	2mrad Beam Divergence
Photo Detector	APD	Responsivity =1A/W
Dark Current Thermal	10 nA	Thermal noise = 1x10^{-22} W/Hz

Using the Optisystem program, a PSK and ASK modulated FSO system design was simulated and modeled to test how well it worked in different weather conditions. The simulation construction of the above-proposed modulated systems is shown in Figures 3 and 4. A 10 Gbit/s data bit is created by a PRBS generator and encoded using PSK and ASK pulse generators in the optical transmitter. PSK's optical carrier signal output was created using a CW laser with a 5 mw and a 632 nm wavelength, and the ASK pulse generator modified the optical carrier signal phase to create the modulated signals. The modulated signal is passed via a delay line filter to enhance the functionality of the FSO system. The FSO channel receives and transmits the adjusted signal. The performance is examined using the FSO channel's various ranges and attenuation levels corresponding to weather conditions. The optical receiver has an APD photodiode, a low-pass filter, and a 3R-regenerator to convert the authentic bit sequationuence into an electrical signal. Together with optical power meters and spectrum analyzers, it also has an electrical carrier analyzer. Lastly, the performance is assessed using a BER analyzer and oscilloscope visualizers.

4. Results and discussion

The signal-to-noise ratio (SNR) and optical link performance are considered for different transmission lengths and disturbance types. Figure 5 shows the signal-to-noise ratio (SNR) curves for Pt = 5mW (6.9897dBm) for different types of attenuation. The results for the Q factor, power at the receiver (dBm), and signal-to-noise ratio (SNR) with different attenuation and range settings are shown in Tables 5, 6, and 7 below for each type of modulation.

Table 5: Results for Q-Factor, SNR, and Power at the Receiver (dBm), with Rain Weather at PSK and ASK Modulation

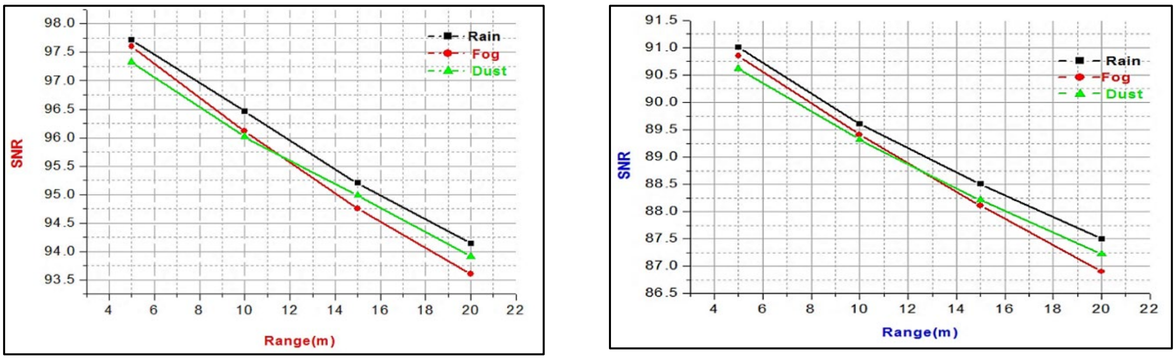
α dB/km 39.10	Range (m)	Q-factor	Received power (dBm) Before optical amplifier	Received power (dBm) after optical amplifier	SNR
PSK	5	3597.50	4.910	28.332	97.602
	10	3455.30	3.375	25.303	96.111
	15	3303.10	2.020	22.603	94.751
	20	3146.50	0.801	20.120	93.610
ASK	5	2045.41	4.411	31.470	91.00
	10	1997.60	3.025	28.710	89.60
	15	1947.86	1.818	26.300	88.50
	20	1897.60	0.750	24.140	87.50

Table 6: Results for Q-Factor, SNR, and Power at the Receiver (dBm), with Fog Weather at PSK and ASK Modulation

α dB/km 39.10	Range (m)	Q-factor	Received power (dBm) before optical amplifier	Received power(dBm) after optical amplifier	SNR
PSK	5	3597.50	4.910	28.332	97.602
	10	3455.30	3.375	25.303	96.111
	15	3303.10	2.020	22.603	94.751
	20	3146.50	0.801	20.120	93.610
ASK	5	2040.70	4.261	31.210	90.85
	10	1985.80	2.727	28.110	89.41
	15	1927.60	1.372	25.410	88.11
	20	1866.90	0.153	22.950	86.90

Table 7: Results for Q-Factor, SNR, and Power at the Receiver (dBm), with Dust Weather at PSK and ASK Modulation

α dB/km	Range (m)	Q-factor	Received power (dBm) before optical amplifier	Received power(dBm) after optical amplifier	SNR
PSK 89.20	5	3597.50	4.910	28.332	97.602
44.63	10	3455.30	3.375	25.303	96.111
29.75	15	3303.10	2.020	22.603	94.751
22.31	20	3146.50	0.801	20.120	93.610
ASK 89.20	5	2040.70	4.261	31.210	90.85
44.63	10	1985.80	2.727	28.110	89.41
29.75	15	1927.60	1.372	25.410	88.11
22.31	20	1866.90	0.153	22.950	86.90



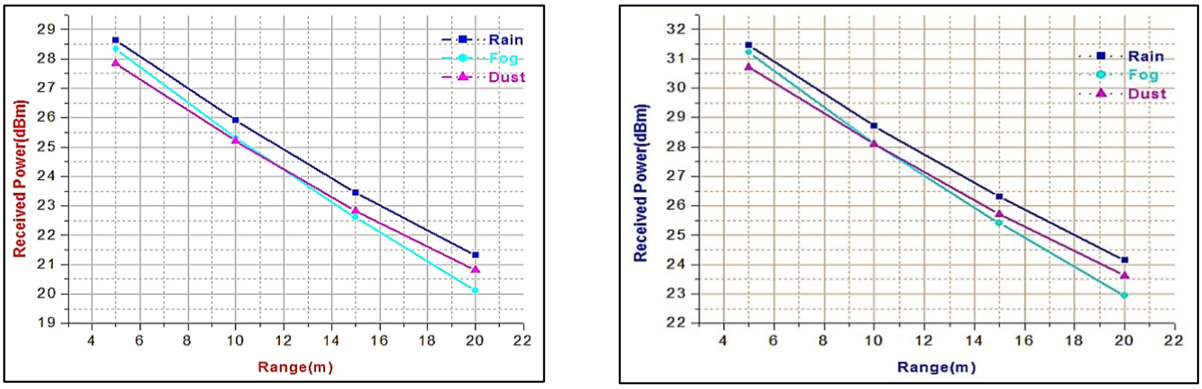
PSK
(a)

ASK
(b)

Figure 5: SNR vs. Range for PSK and ASK Modulation System for Various Types of Atmospheric Turbulence

SNR is the relationship between the received signal and the noise in the background. Its noise is powerful. Due to the additional noise that the turbulence introduces, the SNR reduces air turbulence for both the PSK and ASK modulation techniques. Due to its phase modulation, which is less susceptible to the amplitude changes brought on by turbulence, PSK modulation is, once more, more resistant to air turbulence than ASK modulation. Figure 5 (a and b) indicates the SNR vs. Range for PSK and ASK Modulation Systems for Various Types of Atmospheric Turbulence.

In Figure 6 (a and b), the received signal power decreases with an increasing distance range under this three atmospheric turbulence. The receiver signal power is also higher under rain than in fog and dust. Also, the receiver signal power curves have very close behavior for middle values under conditions of fog and dust.



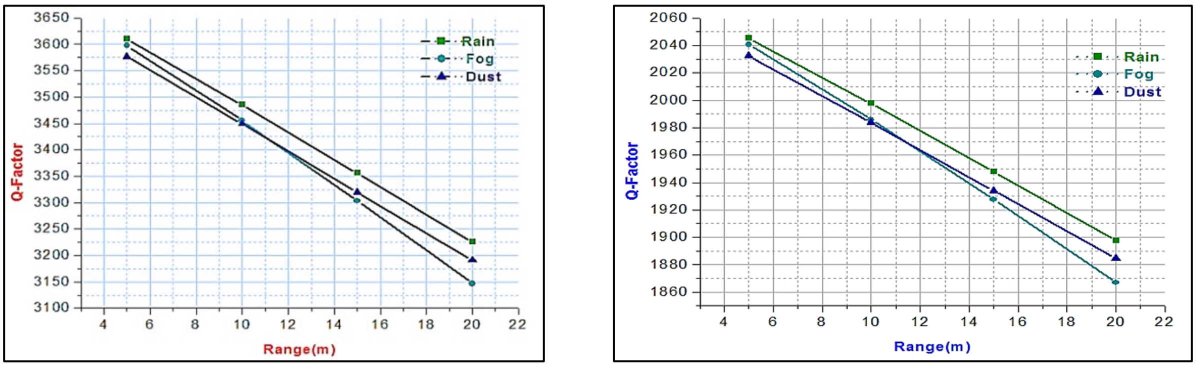
PSK
(a)

ASK
(b)

Figure 6: The Received Power vs. Range for PSK and ASK Modulation System for Various Types of Atmospheric Turbulence

P_r is the overall power that a receiver receives after traveling through a channel, known as the received power. Due to the atmosphere's scattering and absorption of the signal, atmospheric turbulence reduces the received power for both PSK and ASK modulation systems. However, because ASK modulation depends on the signal's amplitude, it is more susceptible to air turbulence than PSK modulation.

In Figure 7(a and b), the Q-factor falls under these three atmospheric turbulences as the distance range increases. In addition to the Q-factor, rain has a higher value than dust and fog. Moreover, under fog and dust, the Q-factor curves exhibit extremely similar behavior for the middle and near-end values.



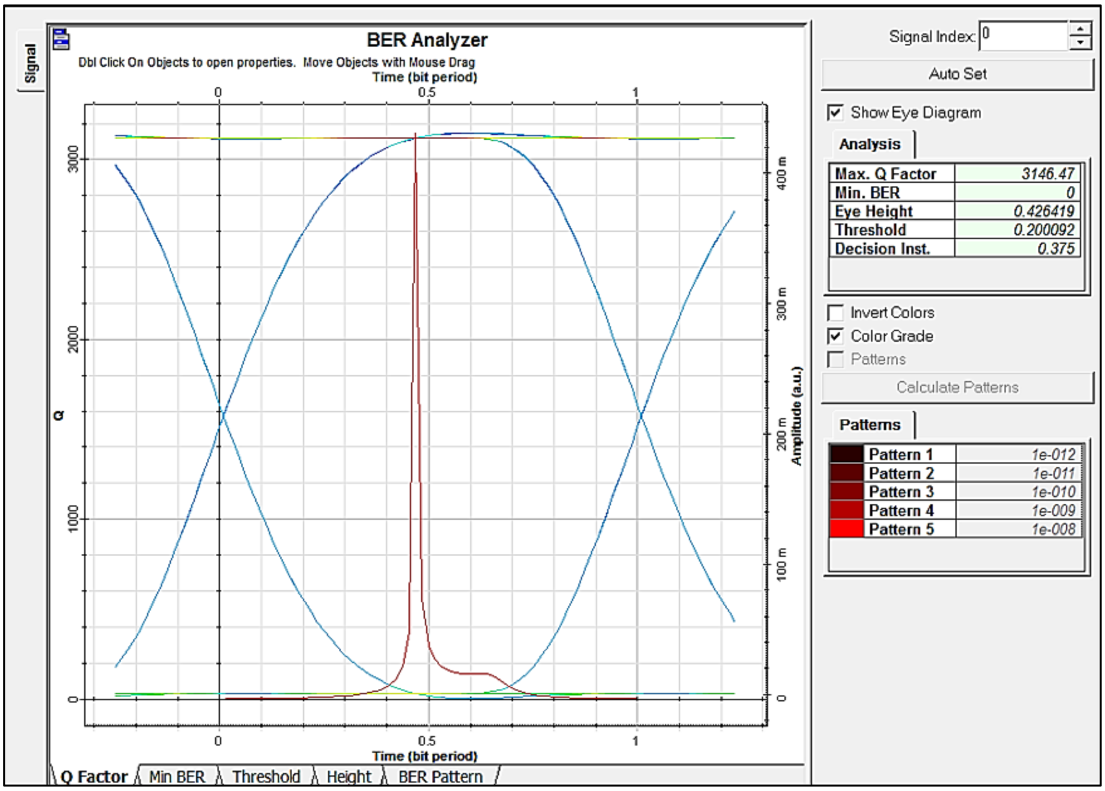
PSK
(a)

ASK
(b)

Figure 7: Q- Factor vs. Range for PSK and ASK Modulation System for Various Types of Atmospheric Turbulence

Q-factor Signal quality is measured by the quality factor (Q-factor), which is the difference between the signal and noise powers of the received signal. The Q-factor for both PSK and ASK modulation methods decreases with air turbulence due to the additional noise that the turbulence introduces. However, compared to ASK modulation, PSK modulation is more robust to amplitude variations brought on by turbulence due to its phase modulation, which is less vulnerable. As a result, in terms of received power, quality factor, and SNR, PSK modulation is more resistant to atmospheric turbulence than ASK modulation. This is because PSK modulation's phase modulation makes it less susceptible to the amplitude changes brought on by turbulence.

Figures 8 and 9 show an eye diagram of PSK and ASK modulation in rain conditions with a range of 20 meters between transmitter and receiver. The readings show zero value for BER in both cases of modulation.



Signal Index: 0

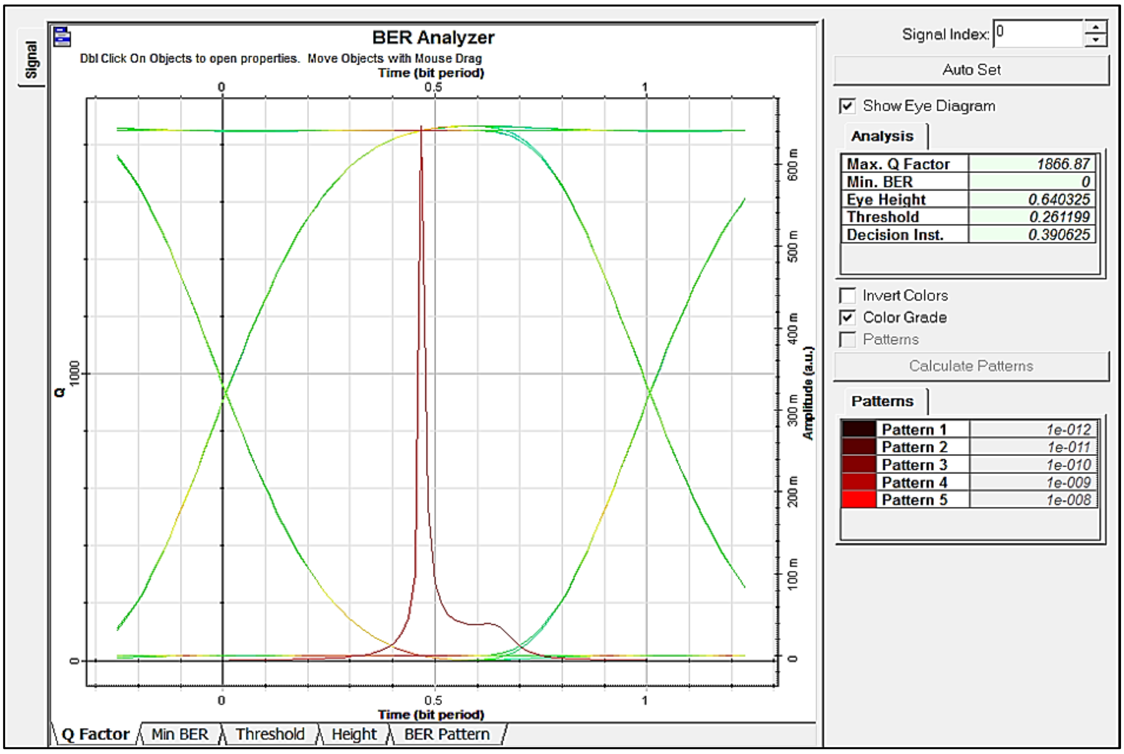
☑ Show Eye Diagram

Max. Q Factor	3146.47
Min. BER	0
Eye Height	0.426419
Threshold	0.200092
Decision Inst.	0.375

☐ Invert Colors
☑ Color Grade
☐ Patterns

Pattern 1	1e-012
Pattern 2	1e-011
Pattern 3	1e-010
Pattern 4	1e-009
Pattern 5	1e-008

Figure 8: PSK modulation results



Signal Index: 0

☑ Show Eye Diagram

Max. Q Factor	1866.87
Min. BER	0
Eye Height	0.640325
Threshold	0.261199
Decision Inst.	0.390625

☐ Invert Colors
☑ Color Grade
☐ Patterns

Pattern 1	1e-012
Pattern 2	1e-011
Pattern 3	1e-010
Pattern 4	1e-009
Pattern 5	1e-008

Figure 9: ASK modulation

5. Conclusion

The atmospheric turbulence in FSO communication systems affects PSK and ASK modulation techniques. Turbulence causes random variations in the refractive index of the atmosphere, leading to fluctuations in the received optical signal. PSK modulation generally outperforms ASK modulation in FSO communication systems under atmospheric turbulence. PSK is more robust against amplitude variations caused by turbulence because it encodes information in the phase of the carrier wave. ASK modulation is more susceptible to amplitude fluctuations due to turbulence, leading to a higher bit error rate (BER) and reduced data transmission reliability. Various mitigation techniques can be employed to improve PSK and ASK modulation performance in FSO systems under atmospheric turbulence. Both PSK and ASK modulation techniques have their place in FSO communication systems, and the choice should be made after a thorough analysis of the specific environmental conditions and application requationuirements. The performance analysis of the FSO link under different channel conditions with different modulation schemes is analyzed. This analysis mechanism can help to adopt a modulation technique for different channel conditions. With a high Q-factor and a BER that is extremely close to zero, this is a new technique for the study. The result of PSK and ASK modulation-based FSO systems using coupler-based delay line filters under varied weather circumstances has been described. However, the choice of modulation technique should be made based on a careful assessment of the specific conditions and trade-offs of the FSO communication system in question. Mitigation techniques can be crucial in enhancing system performance in atmospheric turbulence.

Author contributions

Conceptualization, E. Al–Gazzi, E. Ali and A. Mohammed; Methodology, E. Al–Gazzi and E. Ali; software, E. Al–Gazzi and A. Mohammed; validation, E. Al-–Gazzi; formal analysis, E. Al–Gazzi; Investigation, E. Al–Gazzi and A. Mohammed; resources, E. Al–Gazzi; data curation, E. Al–Gazzi; Writing—original draft preparation, E. Al–Gazzi; Writing—review and editing, E. Al-–Gazzi; Visualization, E. Al–Gazzi; Supervision, Esraa K. Al–Gazzi; project administration, Esraa K. Al–Gazzi and Assel J. Mohammed. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data availability statement

The data that support the findings of this study are available on requationuest from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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