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# Improvement in Performance of Free Space Optical Communication

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## ABSTRACT
Free Space Optics is the technology that uses line-of-sight path for the communication between two points. The FSO uses beam of light to provide optical connection that can send and receive video, voice, and data information. The performance of modulation techniques such as Binary Phase Shift Keying (BPSK) and Quadrature Phase Shift Keying (QPSK) are studied in the AWGN channel and the Rayleigh Channel. There are certain impairments associated with the FSO system. The effect of scintillation index and Free Space Path Loss (FSPL) are also considered in this work.

**Keywords**
FSO, Bit error rate (BER), Atmospheric turbulence, Scintillation, Channels, BPSK, QPSK.

## 1. INTRODUCTION
Free space optics (FSO) communications provides an enormous and unregulated bandwidth where a data rate in excess of 100 Gbit/s is achievable over a distance of 1-4 km. The free space optical communication is based on the optical communication with only difference that here the light signal which carries the information is not confined into a physical channel such as Optical Fiber. In the Free Space Optical communication the optical signal is transmitted into the free space and the air or vacuum space acts as the channel for signal transmission. The beam of light rays carrying the data travels in this channel. The local area network (LAN) based FSO system has the potential to solve the "last-mile" problem for the foreseeable future as a bandwidth in excess of 2THz is readily available in optical wavelengths. Along with high data transfer rate, a direct line-of-sight FSO link offer numerous advantages compared to the conventional wired and radio frequency (RF) wireless communications [1]. The FSO link consumes relatively low power and they also provide greater security to the data as the data carrying light rays are confined to very narrow area as the light beam is of small diameter. The FSO signals are also less sensitive to the electromagnetic interferences.

The performance of the FSO link is hampered by some atmospheric conditions such as- fog, smoke, rain, snow etc. There are few other circumstances when the performance of the FSO system may get affected which include building sway during earthquake or some temporary blockage between line-of-sight connections required for data transmission. The major issue related to this FSO system is the atmospheric turbulence which depends upon the temperature and pressure of the atmospheric region through which the signal has to pass [1][2]. The main components of an FSO transmitter and receiver are modulator, optical source, optical detector and a demodulator. The basic block diagram of a Free Space Optical system is given in the Figure 1.

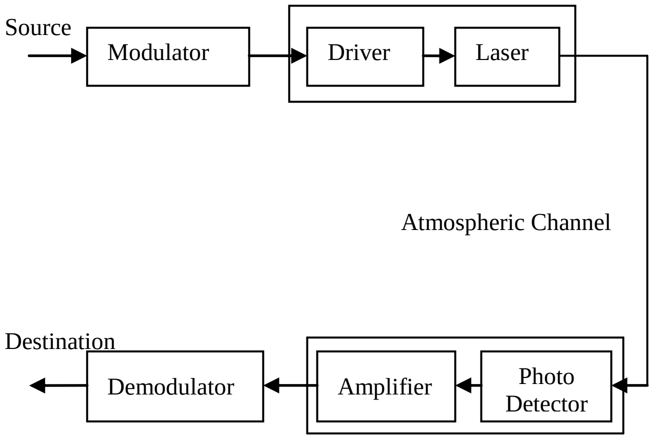


**Figure 1: Basic block diagram of the FSO system**

The modulation and the demodulation both are done in the electrical domain as the commonly used modulation technique in this system is Pulse Position Modulation (PPM) and On-Off Keying (OOK) [3]. Apart from these modulation techniques, the research is going on to implement other modulation techniques along with some coding techniques to get the optimum performance of the system. Free-space point-to-point optical links can be implemented using infrared laser light, although low-data-rate communication over short distances is possible using LEDs. Infrared Data Association technology is a very simple form of free-space optical communications [4][5].

## 2. GAMMA-GAMMA MODELING
The gamma-gamma model of turbulence is based upon such modulation process which assumes that the small scale and large scale effects are responsible for the changes occurring in the path of radiated light signal travelling through turbulent atmosphere. This channel model also considers a region between transmitter and receiver which is known as Fresnel zone. The Fresnel zone is an elliptical area between transmitter and receiver around the line-of-sight path between them. The Fresnel zone helps in carrying the strongest signal to the receiver. The eddies cells which are smaller than the Fresnel zone result in small signal effect i.e. scattering and the eddied cells larger than the Fresnel zone result in large scale effect known as refraction [6].

The small scale eddies are represented by $\alpha$ and the large scale eddies are represented by$\beta$. Both these parameters can be related to the atmospheric turbulence as

$$\alpha = \frac{1}{\exp\left[\frac{0.49\beta_0^2}{\left(1+1.11\beta_0^{12/5}\right)^{7/6}}\right]-1}$$
(1)

$$\beta = \frac{1}{\exp\left[\frac{0.51\beta_0^2}{\left(1+1.11\beta_0^{12/5}\right)^{5/6}}\right]-1}$$
(2)

Where, $\beta_0^2$ is the Rytov variance which depends upon the refractive index, $c_n^2$.

## 3. ISSUES RELATED TO FSO

The various issues related to the free space optic system are-atmospheric turbulence, scintillation, fog, smoke, building sway etc. These are the parameters which affect the performance of the system. The research is going on to make the FSO system more efficient and accurate.

### 3.1 Atmospheric Turbulence

The atmospheric turbulence is caused by the random fluctuations in the temperature and the pressure of the atmospheric region through which the FSO signal has to pass. This is one those problems which we cannot overcome completely as this depends upon the time of the day as the temperature is majorly controlled by the Sun but still we can improve up to an extent. Due to the temperature changes in the atmosphere the refractive index of the air changes which causes the light beam to deviate from its intended path towards receiver [1][7].

### 3.2 Scintillation

Atmospheric scintillation can be defined as the changes occurring in the light intensities in time and space at the plane of a receiver detecting the optical signal. The received signal at the detector fluctuates because of changes in the refractive index which arise due to change in the temperature of the air along the transmit path. These index changes make the atmosphere to function like a series of small lenses that deflect portions of the light beam into and out of the intended transmit path [7]. The time scale of these fluctuations is in milliseconds, which is approximately equal to the time that it takes a volume of air the size of the beam to move across the path, and therefore is related to the speed of wind to move those lenses like air regions [1]. The effect of scintillation on the optical signal will be highest when the temperature of the day is at the maximum level, this occurs usually during midday. FSO systems operate horizontally in the atmosphere near the surface (in case of terrestrial links), experiencing the maximum scintillation possible.

Scintillation effects for small fluctuations follow a log-normal distribution, characterized by the variance, $\beta_0^2$ for a plane wave given by the following:

$$\beta_0^2 = 1.23.\, c_n^2.\, k^{\frac{7}{6}}.\, L^{\frac{11}{6}}$$
(3)

Where $k = 2\pi/\lambda$

$c_n^2$ is the refractive index of the atmosphere which depends upon the temperature and varies throughout the day.

Now the equation for scintillation index is as follows

$$\sigma_p^2 = \exp\left\{\frac{0.49\beta_0^2}{(1+0.65d^2+1.11\beta_0^{\frac{12}{5}})^{\frac{7}{6}}} + \frac{0.51\beta_0^2(1+0.69\beta_0^{\frac{12}{5}})^{\frac{-5}{6}}}{(1+0.9d^2+0.62d^2\beta_0^{\frac{12}{5}})^{\frac{7}{6}}}\right\} - 1$$
(4)

Here,

$$d = \sqrt{\frac{KD^2}{4L}}$$

D is receiver aperture diameter. From the above equation, scintillation index is calculated and then fading loss can be calculated from the following equation [8]:

$$\alpha_{scin} = 4.343\{1\,\{\mathrm{erf}^{-1}(2P_{thr} - 1).\,[2\ln(\sigma_p^2 + 1)]^{\frac{1}{2}} -$$
$$12\ln(\sigma p2+1)$$
(5)

From the above equation, fading loss can be calculated by putting values of scintillation index which we can calculate from the value of receiver aperture and by putting the link range equal to 2 km. The figure 2 given below shows the effect of scintillation index on the fading loss which plays an important role in determining the performance of the FSO system.

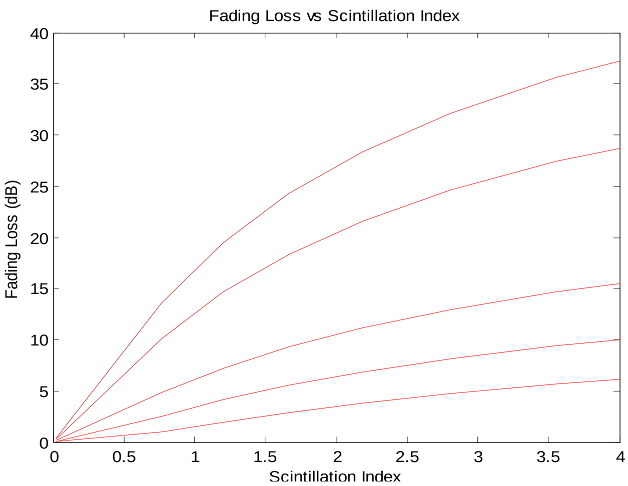


**Figure 2: Effect of scintillation index on fading loss**

The figure 2 indicates that fading loss increases with increase in scintillation index with different values of $Pthr = 0.5, 0.3, 0.1, 0.001$ *and* $0.00001$.With increase in outage probability, fading loss decreases. The values of the scintillation index are used to calculate the signal-to-noise ratio (SNR) values which are used later to calculate the bit-error-rate (BER).

### 3.3 Window attenuation

The FSO gives an advantage that it provides service through the windows for those customers who do not have the access to the terrace of their building or the apartment. But along with this advantage a limitation comes, the glass of windows add some amount of the attenuation to the signal. The uncoated glass windows usually attenuate 4% per surface, due to reflection. The perfectly clear double-pane window attenuates all optical signals at least 15% as there are four surfaces, each with 4% reflection. The glasses which are tinted or coated with some semi-transparent papers can attenuate the signal to a much higher value [1].

### 3.4 Rain and Snow attenuation

The rain and the snow are one of the components of the atmospheric weather which hamper the line-of-sight link between the transmitter and the receiver. The snow is divided into two types-wet snow and dry snow. The amount of attenuation due to wet snow is higher than the attenuation occurring due to dry snow [9][10]. The dry snow effects at the low snow rate whereas wet snow effects at high snow rate. The amount of attenuation decreases as the visibility increases during the snowfall.

## 3.5 Free Space Path Loss

In the field of communication, free-space path loss (FSPL) is the loss in signal strength that would occur in a line-of-sight path through free space (usually air), with no obstacles nearby to cause reflection or diffraction. It does not include factors such as the gain of the antennas used at the transmitter and receiver, nor any loss associated with hardware imperfections [9][10]. The equation for free space path loss (FSPL) and the effect of link length are given below:

$$\mathrm{FSPL} = \left(\frac{4\pi d}{\lambda}\right)^2 \quad (6)$$

Where:
d= distance between transmitter and receiver
$\lambda$ = wavelength.

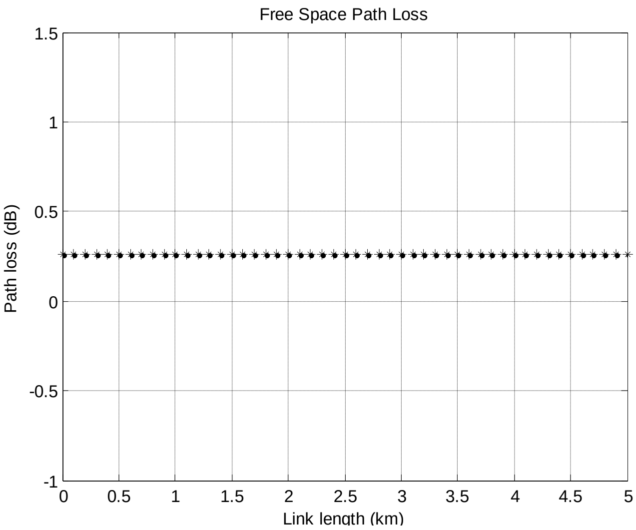


**Figure 3: Free space path loss suffered by FSO signal**

The graph given in figure 3 shows the FSPL offered by atmosphere to the FSO link which is about 0.3dB/km along the length of link which means that signal will be degraded by 0.3dB every km till the receiver.

## 4. MODULATION TECHNIQUES

There are different options available for the modulation techniques which can be used in the field of Free Space Optical communication such as On-Off Keying (OOK), Binary Phase Shift Keying (BPSK) and QPSK (i.e. Quadrature Phase Shift Keying). The OOK modulation provides good BER performance but data rate is low [5]. The need of the present time is to get high data rate along with good BER performance.

## 4.1 Binary Phase Shift Keying (BPSK)

Binary Phase-shift keying (BPSK) is a digital modulation scheme that conveys data by changing, or modulating, the phase of a reference signal (the carrier wave). BPSK is appropriate for low-cost passive transmitters and the BPSK is simplest form of phase shift keying (PSK). It uses two phases which are separated by 180° and so can also be termed 2-PSK. It does not matter exactly where the constellation points are positioned, and most of the times they are represented on the real axis, at 0° and 180°. This modulation is the most robust of all the PSKs since it takes the highest level of noise or distortion to make the demodulator reach an incorrect decision. The BPSK modulation performance is studied in the AWGN channel and Rayleigh Fading channel. This AWGN channel does not account for any other fading and interference. The AWGN channel only accounts for the Additive White Gaussian noise added in the original information signal while transmission. The AWGN channel does not consider the effects of multipath signal traveling, fading, frequency selective fading and interference of any other signal while the signal travels through the atmospheric channel [11]. The Rayleigh fading channel assumes that the signal goes through such a channel in which the magnitude of the information signal will vary randomly or the fading of signal will occur according to the Rayleigh distribution [12]. The performance of the BPSK modulation in the AWGN channel is given below in the figure 4. The BER equation of BPSK modulation is as given below:

$$\mathrm{BER} = \frac{1}{2}\mathrm{erfc}(\sqrt{\mathrm{SNR}}) \quad (7)$$

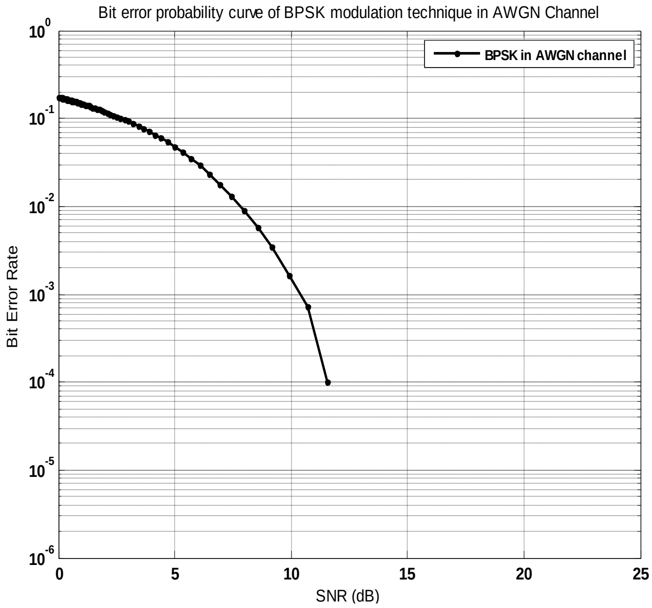


**Figure 4: BER performance of the BPSK modulation in the AWGN channel**

The graph represented in the figure 4 portrays the BER performance of the BPSK modulation in the AWGN channel. It is clear as the BER value of $10^{-4}$ is achieved at an SNR value of about 13dB. If SNR value is further increased then there are no errors occurring in the received signal which means the BER value becomes zero. The performance of BPSK modulation in the Rayleigh Fading channel is given in the figure 5.

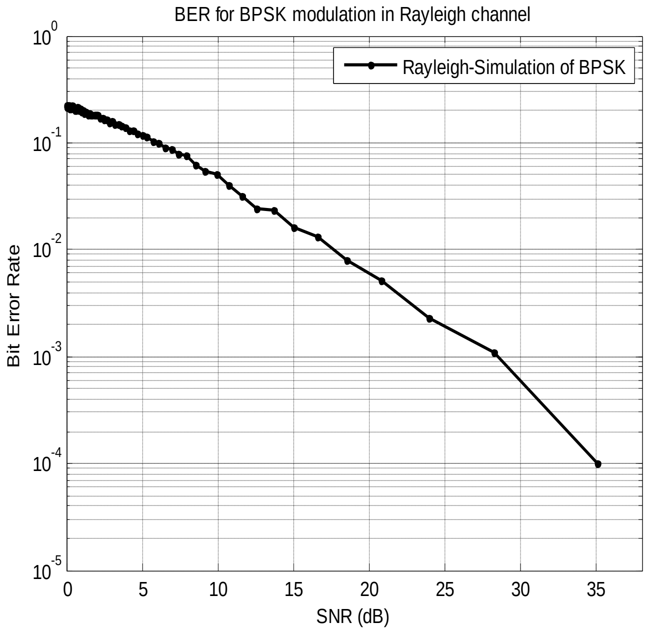


**Figure 5: BER performance of BPSK in Rayleigh Fading Channel**

The graph represented in the figure 5 portrays the BER performance of the BPSK modulation. It is clear as the BER value of $10^{-4}$ is achieved at an SNR value of 35dB. After the SNR value is further increased then there are no errors occurring in the received signal which means the signal gets immunity from the errors. But apart from these performances, the BPSK modulation has a disadvantage of wastage of the bandwidth as one symbol getting transmitted carries only one bit (i.e. 1Bit/symbol).

## 4.2 Quadrature Phase Shift Keying (QPSK)

The Quadrature Phase Shift Keying is one of the variants of PSK modulation which uses four different points on the constellation diagram, equally spaced around a circle to represent the data bits. These four phases help the QPSK to encode two bits per symbol while representing the data [13]. The QPSK is can be used to double the data rate compared with a BPSK system while it maintains the same bandwidth of the signal. The QPSK can also work in a manner, in which it maintains the data-rate of BPSK but make the bandwidth requirement half as compared to BPSK [14]. The bit error rate equation of QPSK modulation is given below:

$$BER = \operatorname{erfc}(\sqrt{SNR}) \quad (8)$$

The performance of the QPSK modulation in the AWGN channel is given in the figure 6. This AWGN channel does not account for any other fading and interference. The AWGN channel only accounts for the Additive White Gaussian noise added in the original information signal while transmission. The AWGN channel does not consider the effects of multipath signal traveling, fading, frequency selective fading and interference of any other signal while the signal travels through the atmospheric channel. This wideband Gaussian noise is generated by most of the natural resources, such as by the thermal vibrations of the atoms in the conductors, Short noise, Johnson noise and celestial source Sun [10].

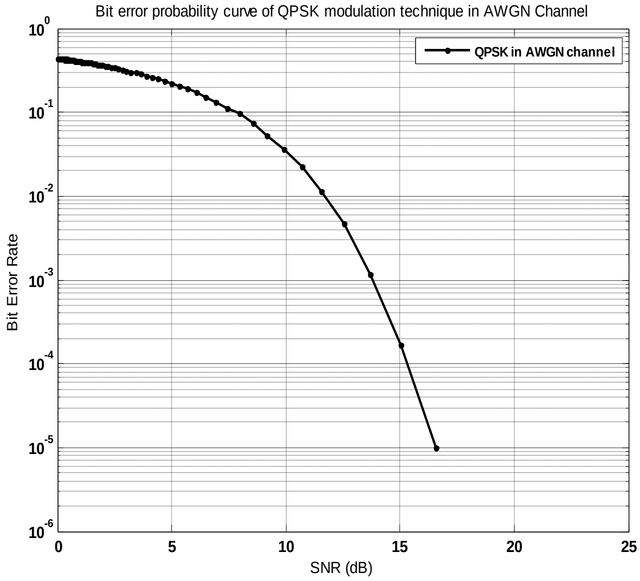


**Figure 6: BER performance of QPSK in the AWGN channel**

The graph given in the figure 6 portrays the performance of QPSK modulation in the AWGN channel. The BER value of $10^{-5}$ is achieved with an SNR of 18dB level and if the SNR value is further increased then there is no error received in the signal at the receiver end.

The performance of the QPSK in the Rayleigh channel is given in the figure 7. This Rayleigh channel considers the effect of Rayleigh distribution and plots the BER performance of the QPSK modulation technique accordingly.

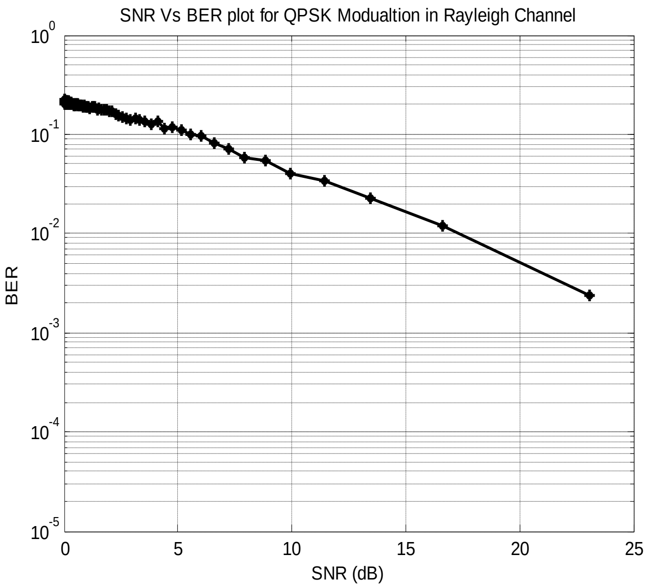


**Figure 7: BER performance of QPSK modulation in the Rayleigh Channel**

The graph in the figure 7 above portrays the performance of the QPSK modulation as the BER value of $10^{-2}$ is achieved at the SNR value of about 17dB and the performance gets further improved as the value of SNR is increased. When the SNR value is increased above ~23dB the BER value becomes zero.

## 5. CONCLUSION

The Free Space Optics System (FSO) is becoming the solution to the problem of last-mile service providing. The performance of the FSO system utilizing the BPSK and QPSK modulation are studied in the AWGN channel and Rayleigh channel. The values of the signal to noise ratio (SNR) are calculated from the varying value of scintillation index. The BER value of $10^{-4}$ is can be achieved by the BPSK modulation in the AWGN channel with an SNR value of 13dB and above this value of SNR the BER value becomes zero. In Rayleigh channel the SNR value of 35dB is required for achieving similar performance. The BPSK modulation provides lower data rate as compared to QPSK modulation. In the QPSK modulation if the SNR value is 18dB then we can achieve $10^{-5}$ value of BER and if the SNR is increased above then BER value becomes zero. In the case of Rayleigh channel if the SNR is 23dB, the BER value of $10^{-2}$ is achieved and if this SNR value is further increased then the BER value becomes zero. The QPSK modulation provides better performance than the BPSK modulation in terms of data rate. The choice of modulation technique in a particular application will depend on the achieved value of SNR i.e. if the SNR value is more than 25dB then the QPSK modulation can be used as it will provide higher data rate for signal transmission.

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