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# Analyzing the Effect of Scintillation on Free Space Optics

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*Abstract*— Owing to the unique features of free space optics such as high data rate, large bandwidth, easy installation and license free spectrum, this wireless technology is gaining a lot of momentum nowadays. Since the medium through which the signal travels is atmosphere, the performance of the system primarily depends upon the weather. Scintillation is one of the major concerns which is caused by variation in refractive index of air due to change in temperature. In this paper, the effect of scintillation on the performance of FSO system is analyzed in terms of eye diagrams, BER and Q-factor.

*Keywords-* *atmospheric channel; free space optics; refractive index;  scintillation*

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## I. INTRODUCTION

Currently, there has been a tremendous advancement and increasing growth in the field of wireless communication technology. Demand of high data rates, bandwidth and capacity requirement increases drastically as the usage of fast speed internet, live streaming and video-conferencing etc. increases. Since this demand is ever increasing, there is overwhelming rise in data and multimedia services that has led to congestion in conventionally used radio frequency (RF) spectrum. Thus a need was felt to shift from RF carrier to optical carrier. In optical carrier, the information travels in air in form of light which does not require any licensing of spectrum whereas in RF carrier, the spectrum usage is restricted. Therefore, optical communication is a striking prospect for high bandwidth and capacity applications. In urban areas, the current last mile access networks are largely based on RF technologies which offer far lesser capacity than the backbone network. Nevertheless, with exponentially increasing data traffic, it is inevitable that an alternative technology which is FSO is one of the most promising technologies for such application[1]. Owing to the narrow transmit beam width, the FSO system for short distance communication provides line-of-sight communication. This wireless technology operates in visible region and infrared region of the spectrum. In optical communication the information signal is transmitted via fiber that comprise of core and cladding but in case of free space optics, as the name suggests, the information signal is transmitted through the unguided medium i.e. the atmospheric channel.

## II. THEORY

FSO communication is a wireless technology in which the information signal propagates in atmospheric channel. The properties of the atmospheric medium are random function of space and time. Thus, FSO communication system becomes a random phenomenon that primarily depends upon weather and geographical location. There are various environmental elements like storm, snow, fog, clouds, rain, haze, etc., that is unpredictable in nature, causes strong deterioration in the optical signal. The various atmospheric factors have a great impact on propagation distance also and thus limit the link distance at which FSO could be deployed. When there is a variation in pressure and temperature of the atmosphere, a random phenomenon which is called atmospheric turbulence is created along the propagation distance. Turbulent cells are created which are also called eddies of different refractive indices and of different sizes. The beam that is propagating will feel constructive or destructive interference which is caused by the eddies that act like a lens. Random fluctuations will occur in the intensity and phase of the signal received at the receiver section which leads to redistribution of signal energy. When heat of sun or heat emissions from various man made sources occurs in the atmosphere, there is a change in the medium of refractive index which leads to deformation or deterioration of laser beam. This effect of scintillation affects the laser beam propagation and causes fluctuation at the receiver signal. Pockets of heat developed in the atmosphere are at times destroyed or created since the fluctuations caused due to turbulence is random in nature[2]. There are many techniques such aperture averaging[3], adaptive optics, diversity technique can help in overcoming the losses incurred

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by atmosphere. One more method to improve system performance is using OFDM in FSO system[4].

The signal that is received by the receiver will consist of random fluctuation and disturbance in the intensity of the signal. These fluctuations are called scintillation and is measured in terms of scintillation index which is also known as normalized variance of intensity fluctuations, expressed by equation (1)

$$\sigma_n^2 = \frac{\langle (I-\langle I \rangle)^2 \rangle}{\langle I \rangle^2} = \frac{\langle I^2 \rangle}{\langle I \rangle^2} - 1 \qquad (1)$$

Where: I = | E |²: is the signal irradiance (or intensity)[5].
Refractive index structure parameter is denoted by $C_n^2$ which determines the strength of turbulence in the atmosphere. And, scintillation index is the function of $C_n^2$ which expressed as (2)

$$\sigma_R^2 = 1.23 C_n^2 \, k^{\frac{7}{6}} \, L^{\frac{11}{6}} \qquad (2)$$

where the atmospheric structure constant $C_n^2$ is a measure of the strength of the scintillation, $k = 2\pi/\lambda$, and $L$ is the link length.

The refractive index structure parameter ($C_n^2$) changes with day time, geographical position and elevation. The level or strength of scintillation increases as the temperature due to sun increases in a daytime. Scintillation is highest during mid day [6]. The value of strength of scintillation in case of weak turbulence is $7e^{-14}$ and for strong turbulence it can be up to $7e^{-12}$ or greater.

### III. RESULTS AND DISCUSSION

All the simulations are performed using VPI Transmission Maker version 9. Table1. shows various parameters used in simulating FSO system.

Table1. Parameters used in FSO system

| PARAMETER | VALUE |
|---|---|
| Time window | $64/10e^{-9}$ sec |
| Sample mode bandwidth | $1280e^{9}$ Hz |
| Sample rate | $160e^{-9}$ Hz |
| Bit rate | 20Gbps |
| Coding | NRZ |
| Average power of CW laser | $0.05e^{-3}$ Watt |
| Modulator | Mach-Zehnder |
| Propagating distance | 2Km |
| Launch waist | $2e^{-2}$ m |

| | |
|---|---|
| Receiver aperture diameter | $10e^{-2}$ m |
| Wavelength | 1550 nm |

Figure1. shows the eye diagram of received signal at different level of $C_n^2$ (strength of scintillation). It can be inferred from the diagrams that more the value of $C_n^2$, more the eye gets closed and more the signal gets distorted. For $C_n^2 = 7\,e^{-12}$, the atmospheric turbulence is very high, and the corresponding eye is completely closed which shows incorrect information is received. For $C_n^2 = 7e^{-15}$, the atmospheric turbulence is very low, and the corresponding eye is completely open which shows that the complete information has been received. So, it can be summarized by Table2.

Table2. Level of turbulence at different $C_n^2$ values

| $C_n^2$ (Strength of Scintillation) | Atmospheric turbulence |
|---|---|
| $7e^{-12}$ | High |
| $7e^{-13}$ | Moderate |
| $7e^{-14}$ | Low |



(a) $C_n^2 = 7e^{-12}$



(b) $C_n^2 = 7e^{-13}$

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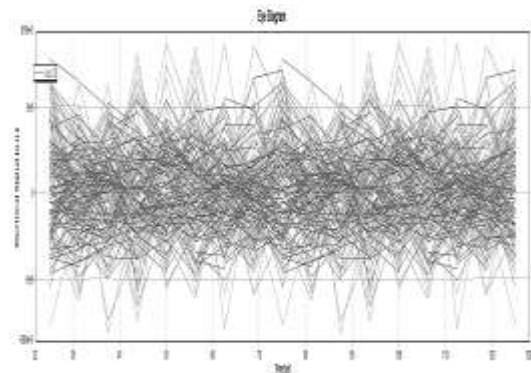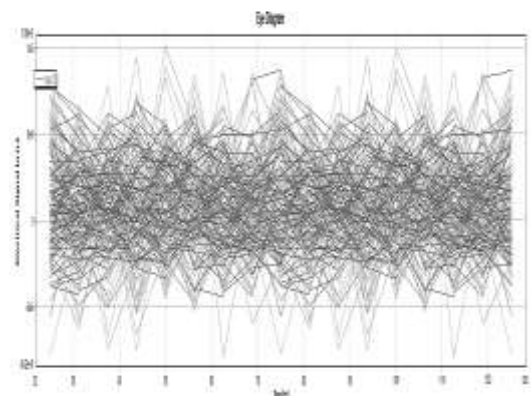
(c) $C_n^2 = 7e^{-14}$





(d) $C_n^2 = 7e^{-15}$
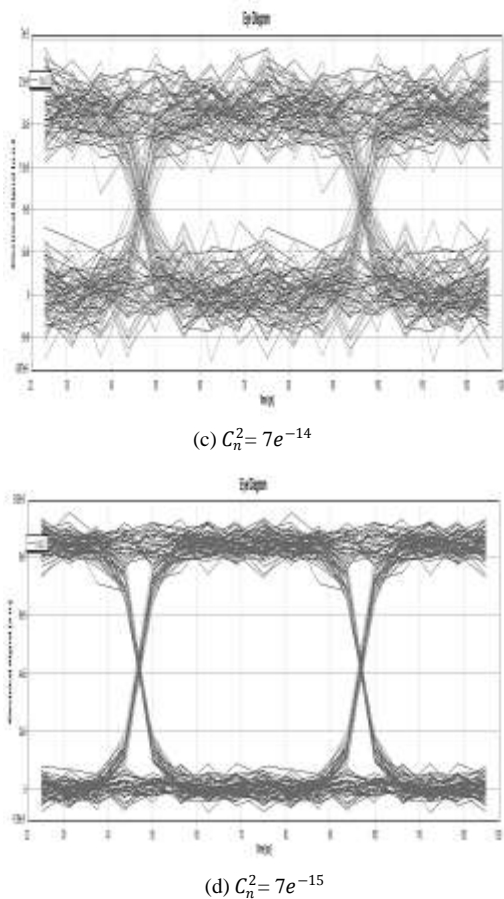
Figure 1. Eye diagrams at (a) $C_n^2 = 7e^{-12}$ (b) $C_n^2 = 7e^{-13}$ (c) $C_n^2 = 7e^{-14}$ (d) $C_n^2 = 7e^{-15}$

Figure 2. BER vs strength of scintillation

Figure2. shows graph of BER for different Cn² values. It can be seen from fig.2, the bit error rate is higher at high scintillation level whereas it decreases for low values of scintillation. When the strength of scintillation is very high i.e., Cn² $= 7e^{-12}$, the BER is $4.45e^{-1}$ which is very high. And, when the strength of scintillation is low i.e., Cn² $= 7e^{-14}$, the BER is $1.87e^{-5}$ which is still acceptable. It should be noted that even at low scintillation, the FSO system performance gets deteriorated substantially. The exact values of BER for different strength of scintillation are shown in Table3.
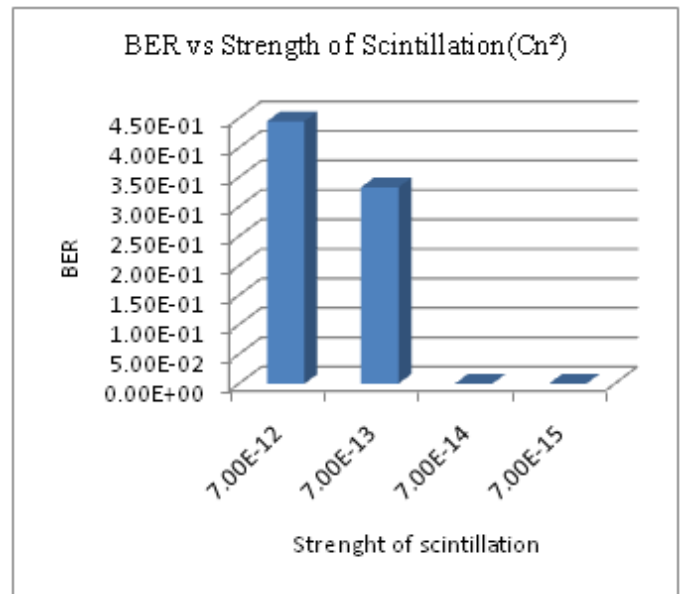
Also, the graph of Q-FACTOR for different Cn² values has been shown in figure 3. The Q-factor basically indicates the performance of the system. In the figure, it is shown that for low scintillation i.e., Cn² $= 7e^{-14}$, the Q-factor is high and the value is 4.12. For high scintillation i.e., Cn² $= 7e^{-12}$, the Q-factor is very low and the value is 0.127. The exact values of Q-factor for different strength of scintillation are shown in table 4.

Table4. Q-factor value for different strength of scintillation

| STRENGTH OF SCINTILLATION(Cn²) | Q-FACTOR |
|---|---|
| 7.00E-15 | 13.52 |
| 7.00E-14 | 4.12 |
| 7.00E-13 | 0.428 |
| 7.00E-12 | 0.127 |

Table3. BER value for different strength of scintillation

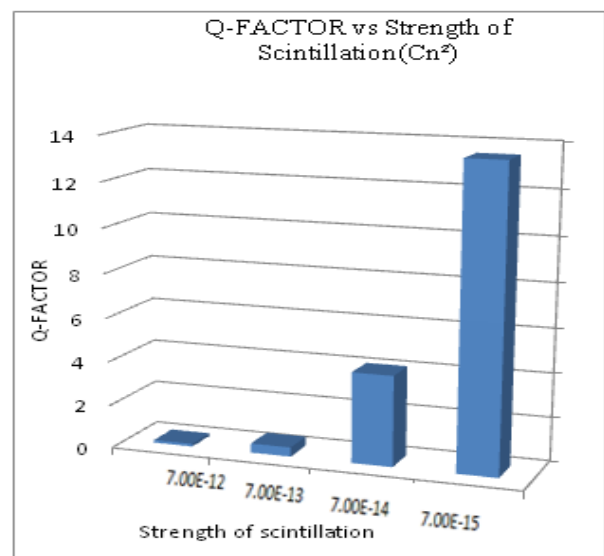| STRENGTH OF SCINTILLATION(Cn²) | BER |
|---|---|
| 7.00E-12 | 4.45E-01 |
| 7.00E-13 | 3.33E-01 |
| 7.00E-14 | 1.87E-05 |
| 7.00E-15 | 5.82E-42 |



Figure 3. Q-factor vs strength of scintillation

Figure4. shows the curve of BER vs distance. It is very natural that when the distance of propagation increases the losses incurred by atmosphere will eventually increase. Therefore, the effect of scintillation will aggravate with the distance and the signal will get more distorted. It can be seen from the figure that as the distance is increased from 2km to 10 km, the BER value increases significantly from $3.32e^{-1}$ to $4.38e^{-1}$. Table5. shows the value of BER for various propagating distances.

Table5. BER for various propagating distances

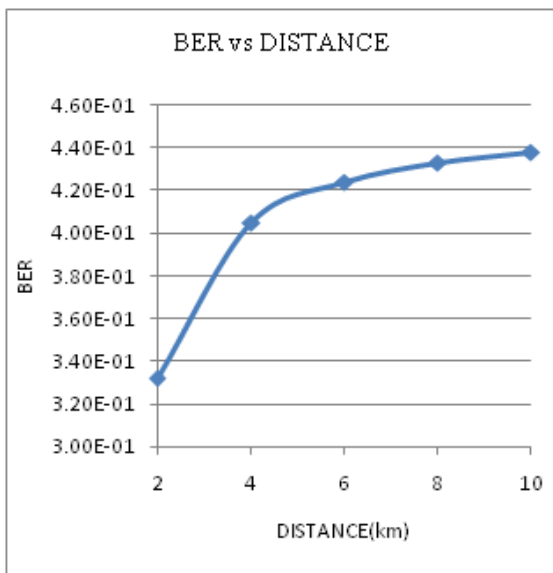| DISTANCE(km) | BER |
|---|---|
| 2 | $3.32e^{-1}$ |
| 4 | $4.05e^{-1}$ |
| 6 | $4.24e^{-1}$ |
| 8 | $4.33e^{-1}$ |
| 10 | $4.38e^{-1}$ |



Figure 4. BER vs Distance

Figure5. shows the curve of Q-factor vs distance. The Q-factor decreases with the increase in propagation distance. It can be seen from the figure that as the distance is increased from 2km to 10 km, the Q-factor value increases significantly from 0.42 to 0.14. Table6. shows the value of Q-factor for various propagating distances.

Table6. Q-factor for various propagating distances

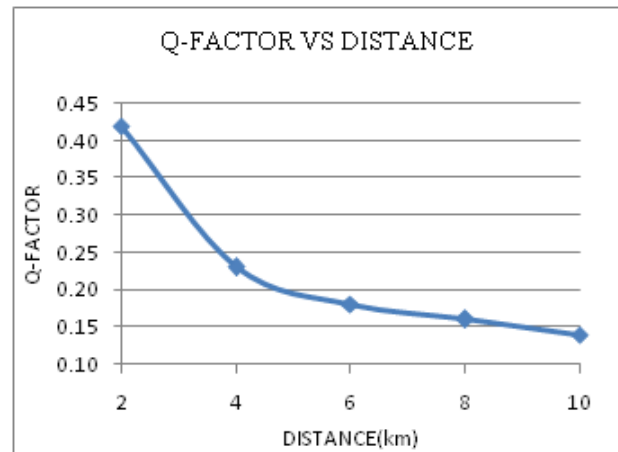| DISTANCE(km) | Q-FACTOR |
|---|---|
| 2 | 0.42 |
| 4 | 0.23 |
| 6 | 0.18 |
| 8 | 0.16 |
| 10 | 0.14 |



Figure 5. Q-factor vs Distance

## IV. CONCLUSION

Nowadays, FSO is highly demanded because of its numerous advantages such as high data rates, large bandwidth, easy installation and license free spectrum. Though the system inherits so many advantages, the performance gets deteriorated by the weather phenomenon. Scintillation is one such phenomenon considered in this paper. It is causes intensity fluctuation of the signal at receiver side. It is measured in terms of scintillation index. In this paper, the effect of different level of scintillation is analyzed on free space optic system.

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