Turkish Online Journal of Qualitative Inquiry (TOJQI)
Volume 12, Issue 6, June 2021: 1370-1377

Scintillation Effect And ASK Modulation In FSO

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Abstract

Optical communication (Free space channel) has wider bandwidth and portability over radio frequency communication. When an optical wave propagates through the atmosphere its phase, amplitude and propagation direction changes causing turbulence. Scintillation is the major factor of turbulence. It is measured by scintillation index (σ_1^2). In this paper we will discuss about the effect of scintillation and it's parameters. The effect due to Scintillation is estimated with help of SLC model and Rytov variance model. A Free Space Optics (FSO) link with a bit rate of 1.25 Gb/s with ASK modulation for a link of 4km is designed.
Keywords: Atmospheric turbulence, FSO-link, Scintillation, Eye diagram.

1. Introduction

The FSO has changed the transmission of data wirelessly due to many advantages over Radio frequency communication systems like larger bandwidth, fast deployment, data rates and reduced size, reducing in fiber deployment cost and civil works. The light beam is modulated with carrier data to transmit from transmitter to receiver. The information is generally superimposed by modulation onto an electromagnetic wave called a carrier. After transmission at the receiver the signal is recovered by process of demodulation.

The transmitting laser beam is corrupted by the atmospheric conditions resulting in degradation of spot size at receiver. Atmospheric turbulence is caused by random temporal and spatial variations of refractive index of air due to factors like temperature, air pressure, humidity and wind conditions in the path between the source and object, which reduces the irradiance (power per surface area) at receiver.

Scintillation is one of the major atmospheric effect which effects the transmission of optical wave compared to other atmospheric conditions like haze, fog, turbulence. Attenuation of optical received signal is more compared to radio waves due to these parameters. Scattering and Refraction are main parameters effecting the optical wave front. Scintillation index (σ_1^2) which depends on atmospheric turbulence explains the amount of scintillation in optical wave. The medium through which the light transmits (free space) consists of various gases of different molecular size, possess different physical properties based on time, pressure, height and temperature. Despite these parameters fog, cloud, snow, and rain also effects the transmission of optical wave.

The attenuation causes the reduction of amplitude, power, phase change which leads to change of transfer data properties. This paper presents estimated scintillation loss in FSO link at different conditions.

The modulation is a very useful technique in the communication engineering. There are several modulation techniques, among them the ASK, BPSK are reliable for the better communication. In ASK, we generate the electrical pulses which is equivalent to the binary input and then transmitted. This paper presents the FSO communication link using Amplitude Shift Keying (ASK) modulation.

2. Scintillation Index

The loss due to scintillation is estimated with the help of many mathematical models. This paper considers two models, which are SLC model and Rytov variance model. These models help us to observe and analyse the effect of scintillation in FSO. The effect of scintillation is calculated by a factor Scintillation index (σ_1^2). It depends on atmospheric turbulence, which can be calculated based on height, temperature and other parameters. It is calculated for 3 different paths in transmission. They are horizontal path, Uplink path and Downlink path. Uplink is the communication going from ground to satellite. whereas Downlink is going from satellite to ground. For uplink and downlink paths the turbulence varies as function of height which is described through altitude model. Here we use SLC day and night model for finding the turbulence strength, which changes with respect to altitude.

3. Scintillation Index in horizontal path

Under Weak fluctuations, scintillation index for a plane wave propagating along a terrestrial link by the Rytov variance.

$$\sigma_1^2 = \beta^2 = 1.23 C_n^2 K^{7/6} L^{11/6}$$

σ_1^2 is scintillation index, β^2 is rytov variance, $K=2\pi/\lambda$ is optical wave number, L is path length.[5]

Under strong irradiance fluctuation conditions, effect of scintillation and turbulence strength is calculated with rytov variance ($l_o=0$, $L_o=\infty$)

$$\sigma_1^2 = \exp\left[\frac{0.49\,\beta^2}{\left(1+0.56\beta^{\frac{12}{5}}\right)^{\frac{7}{6}}} + \frac{0.51\beta^2}{\left(1+0.69\beta^{\frac{12}{5}}\right)^{\frac{7}{6}}}\right] -$$

$\beta^2 = 0.5 C_n^2 K^{7/6} L^{11/6}$

β is rytov variance, L = Path length, $K=2\pi/\lambda$ C_n^2 =turbulence strength

For horizontal path,

For weak turbulence $C_n^2 = 10^{-17}\, m^{-2/3}$

For strong turbulence $C_n^2 = 10^{-13}\, m^{-2/3}$

For a horizontal path, these parameters can be applied. But when the transmission of horizontal path occurs at a height lower than 50m, it differs the parameter values with practical values [5]. Hence the turbulence strength is approximated based on atmosphere conditions during the daytime is

$C_n^2 = r^{-4/3}$

4. Scintillation Index In Uplink Path

In uplink path, we transmit the wave through spherical plane wave propagation. scintillation index and strength of turbulence for an spherical wave propagating along a uplink link by the Rytov variance. ($l_o=0$, $L_o=\infty$)

$$\sigma_1^2 = \exp\left[\frac{0.49\,\beta^2}{\left(1+0.56\beta^{\frac{12}{5}}\right)^{\frac{7}{6}}} + \frac{0.51\beta^2}{\left(1+0.69\beta^{\frac{12}{5}}\right)^{\frac{5}{6}}}\right] - 1$$

based on Rytov variance,

$$\beta = 2.25\, K^{7/6} (H-h_0)^{5/6} \sec^{11/6}(\zeta)\mu_{sp}$$

$$\mu_{sp} = \int_{h0}^{H} C_n^2(h)\left(\frac{h-ho}{H-ho}\right)^{5/6}\left(1-\frac{h-ho}{H-ho}\right)^{5/6} dh$$

β is rytov variance,

ζ=zenith angle (angle between path of wave and line vertical to ground ,<= 45°)

H is height of receiver h_o is height of transmitter

$C_n^2(h)$ is turbulence strength. It is dependent on SLC day and night model based on height, until 20km.

After 20km, μ_{sp}=2.6*$10^{-16}m^{1/3}$
For an uplink spherical wave under weak fluctuations the effect of Scintillation (Scintillation index) is equal to the effect of scintillation in downlink plane wave. For a regime (β <1) influences outer scale, but it will tend to decrease scintillation (β >4).[4]

5. Scintillation Index In Downlink Path

In downlink path we transmit the wave through plane wave propagation. In downlink propagation there will be minute effect of beam spreading compared to diffraction effects as atmosphere is only closer to receiver aperture.

Scintillation index and strength of turbulence for a plane wave propagating along a downlink by the Rytov variance for general irradiance fluctuation. (l_o=0, L_o=∞)[2]. The scintillation index is

$$\sigma_1^2 = \exp\left[\frac{0.49\,\beta^2}{\left(1+1.11\beta^{\frac{12}{5}}\right)^{\frac{7}{6}}} + \frac{0.51\beta^2}{\left(1+0.69\beta^{\frac{12}{5}}\right)^{\frac{5}{6}}}\right] - 1$$

$$\beta = 2.25\, K^{7/6}\,(H-h_0)^{5/6}\sec^{11/6}(\zeta)\mu_{pl}$$

$$\mu_{pl} = \int_{h0}^{H} C_n^2(h)\left(\frac{h-ho}{H-ho}\right)^{5/6}dh$$

β is rytov variance,
ζ=zenith angle (angle between path of wave and line vertical to ground ,<= 45°5°
H is height of receiver h_o is height of transmitter
C_n^2 (h) is turbulence strength. It is dependent on SLC day and night model based on height, until 20km.
After 20km, μ_{pl}=2.6*$10^{-16}m^{1/3}$

6. SLC Day and Night Model

The turbulence strength varies according with height of transmitter or receiver from ground. The turbulence strength is classified based on height and weather condition (day or night). we can measure the turbulence strength until a height of 20km, further an approximated value is taken based on typed of transmission band of wave.[2]
For day, the turbulence strength varies as following,

C_n^2 (h)=1.7*10^{-14}	0 < h < 18.5m
=3.13 *$10^{-13}/h^{1.05}$	18.5 < h < 240m
=1.3 *10^{-15}	240 < h < 880m
=8.87 *$10^{-7}/h^3$	880 < h < 7200m
=2.0*$10^{-16}/h^{1/2}$	7200< h < 20,000

For night, the turbulence strength varies as following,

C_n^2 (h) = 8.4*10^{-15}	0 < h < 18.5m
=2.87*$10^{-12}/h^2$	18.5 < h < 240m
=2.5 *10^{-16}	240 < h < 880m
=8.87 *$10^{-7}/h^3$	880 < h < 7200m
=2.0*$10^{-16}/h^{1/2}$	7200< h < 20,000m

7. Transmission Of Power In FSO Channel

Power received after the transmission of wave can be calculated by,
$P_{rec} = P_{tran}\,.d_r^2/(d_t + \Theta R)^2\ 10^{\alpha R/10}$
d_r=receiver aperture

d_t=transmitter aperture
θ=beam divergence
for narrow beam it is 1milliradians
for normal beam it is 1milliradians to 8 milliradians
R=range α=attenuation
An optical wave transmitting in earth's atmosphere will have reduction in signal properties due to presence of various gases of different molecular sizes in channel.[6]. The volume mixing ratio (VMR) of gaseous components differ with altitude. These are shown in the following figure

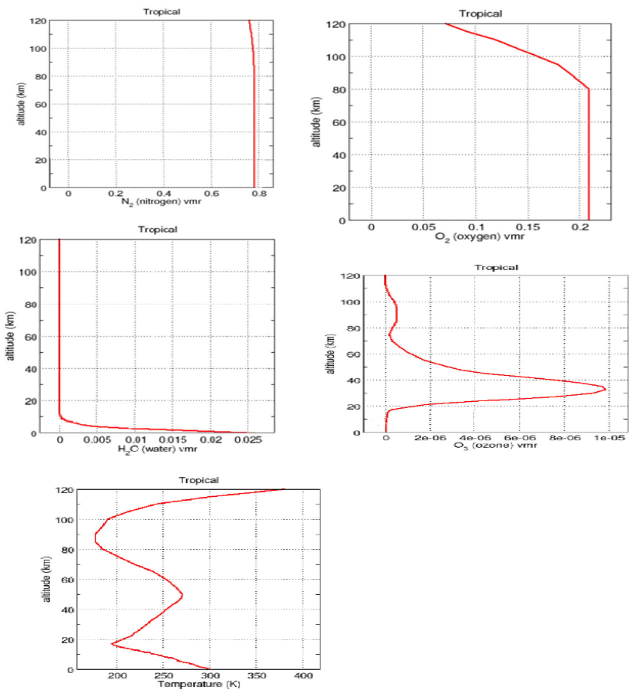

Fig.1. Volume mixing ratio(VMR) of gaseous components differ with amplitude

The loss in power produced by oxygen and water vapor is described by attenuation. At a specific temperature 20°C, the attenuation for oxygen is observed as (For f < 57Ghz)

$$\gamma_o(\text{dB/km}) = \left[\frac{6.6}{f^2 + 0.33} + \frac{9}{(f - 57)^2 + 1.96}\right] f^2\, 10^{-3}$$

For 57Ghz < f < 63Ghz

$$\gamma_o(\text{dB/km}) = 14.9$$

For 63Ghz < f <350Ghz,

$$\gamma_o(\text{dB/km}) = \left[\frac{4.13}{(f - 63)^2 + 1.1} + \frac{0.19}{(f - 118.7)^2 + 2}\right] f^2\, 10^{-3}$$

At 20°C surface temperature the specific attenuation for water vapor is(f < 350Ghz)

$$\gamma_w(\text{dB/km}) = \left[0.067 + \frac{2.4}{(f - 22.3)^2 + 6.6} + \frac{7.33}{(f - 183.5)^2 + 5} + \frac{4.4}{(f - 323.8)^2 + 10}\right] f^2 \rho\, 10^{-4}$$

where f is the frequency in GHz and ρ is the water vapor concentration in g/m3.

8. ASK Simulation

FSO communication link using the ASK modulation is studied for 3km transmission range quantitatively. The optical transmitter of the simulation link consists of the Pseudo Random Binary Sequence with a bit rate of 1.25Gb/s. The transmission protocol Non-Return-to-Zero (NRZ) pulse generator which converts the input binary to the electrical signal as low(0) and high(1) . A Continuous Wave (CW)laser with a frequency of 193.1THz (1.552um wavelength) and a low power of 1mW is used. An optical modulator Mach-Zehnder modulator converts the CW optical beam into modulated beam to transmit the generated NRZ signal. The modulated signal is amplified through a Erbium Doped Fiber Amplifier with a power gain of 60dB and collimated using external secondary optics to have low divergence in propagation.

The modulated signal is then transmitted through a free space optical propagation channel to the receiver. The FSO channel attenuation is assumed to be 15dB/km due to atmosphere and humidity. The receiver optics is considered to have an aperture of (10-20) cm diameter.

The optical receiver consists of a PIN photodiode to convert the received optical signal to electrical pulses. The responsivity of the PIN photodiode is 1A/W. Then the signal is passed through the low pass Bessel filter of cut-off frequency of 0.95*symbol rate to reduce electrical noise in the channel. The output is digitized, and performance studied. The simulation layout is shown in Fig no.2.

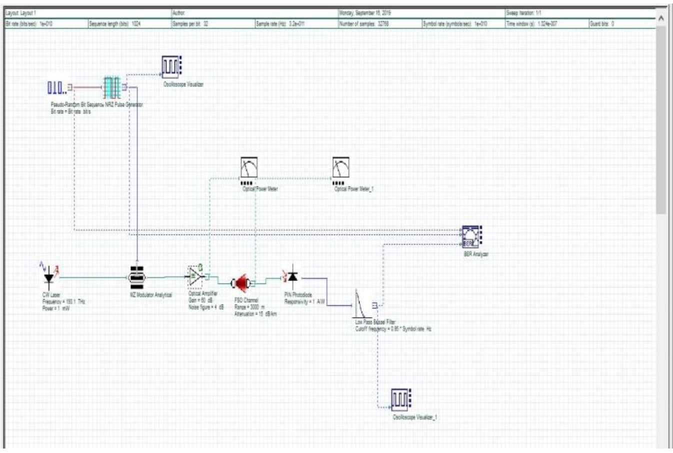

Figure: 2 Simulation layout for ASK modulation

Table: 1 parameters of simulation for ASK

DEVICE	PARAMETER	VALUE
Pseudo Random Binary Sequence	**Bit rate**	1.25Gb/s
CW laser	**Frequency** **power**	193.1THz 1mW
FSO channel	**Range** **Attenuation** **Beam divergence** **Transmitter divergence**	**3km** **15dB/km** **2 mrad** **10cm**

9.Results

The main aim of this simulation is to understand the characteristics of the ASK modulation in FSO communication. The received power, modulation depth extinction ratio, Bit Error Rate are studied and evaluated. The results are as shown

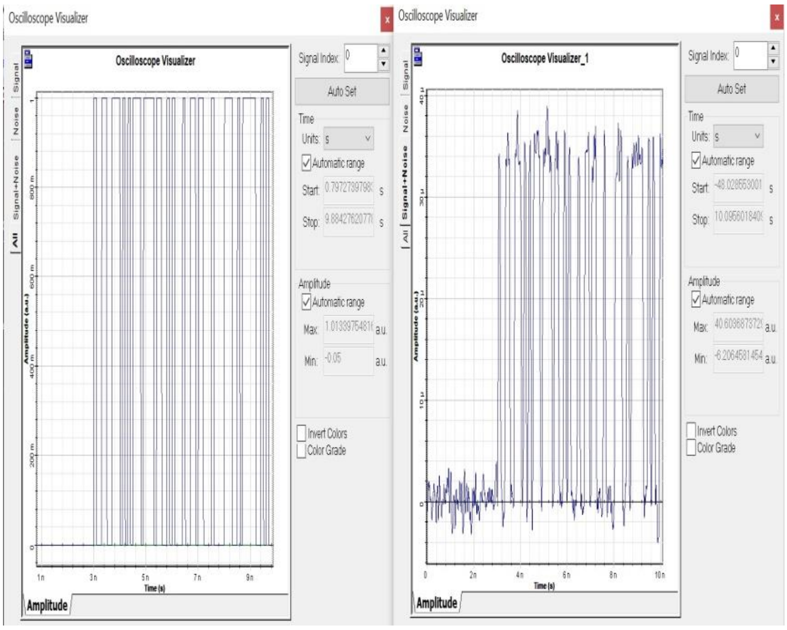

Figure: 3. Transmitted and received signals for ASK

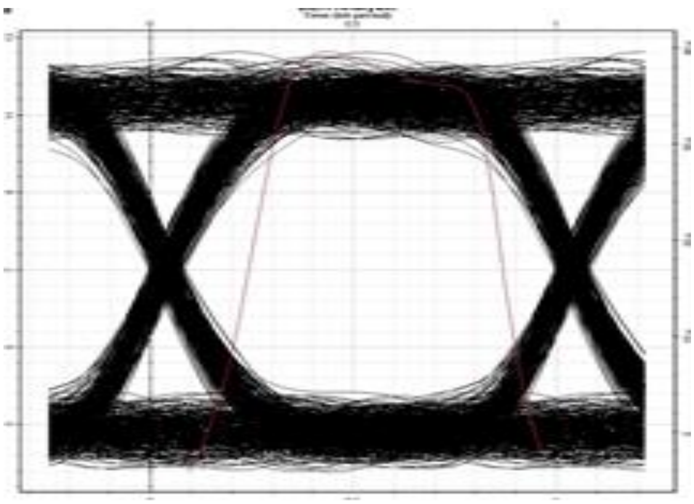

Figure: 4.BER analyser

Table:2.parameters of simulation for ASK

Modulation schemes	value
Max Q-factor	**12.6361**
Min. BER	**6.65144e-037**
Eye Height	**2.64959e-005**
Threshold	**1.69517e-005**
Decision Inst	**0.4375**

10. Conclusion

In this paper, the Scintillation loss is calculated based on Rytov variance model and SLC model in horizontal path, uplink and downlink path. Scintillation index is calculated according with turbulence strength. Here turbulence strength is varied by change in height of transmitter or receiver and atmospheric parameters. Turbulence strength is approximated in uplink and downlink after certain height (20km). The FSO communication link is designed by using ASK modulation and the results are observed for a channel range of 4kms.

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