

4-1-2014

Performances of Free-Space Optical Communication System Over Strong Turbulence

Ucuk Darusalam

Study Program of Opto-Electrotechnique & Laser Application, Department of Electrical Engineering, Faculty of Engineering, Universitas Indonesia, Depok 16425, Indonesia

Purnomo Sidi Priambodo

Study Program of Opto-Electrotechnique & Laser Application, Department of Electrical Engineering, Faculty of Engineering, Universitas Indonesia, Depok 16425, Indonesia, pspriambodo@ee.ui.ac.id

Harry Sudibyoy

Study Program of Opto-Electrotechnique & Laser Application, Department of Electrical Engineering, Faculty of Engineering, Universitas Indonesia, Depok 16425, Indonesia

Eko Tjipto Rahardjo

Study Program of Opto-Electrotechnique & Laser Application, Department of Electrical Engineering, Faculty of Engineering, Universitas Indonesia, Depok 16425, Indonesia

Follow this and additional works at: <https://scholarhub.ui.ac.id/mjt>



Part of the [Chemical Engineering Commons](#), [Civil Engineering Commons](#), [Computer Engineering Commons](#), [Electrical and Electronics Commons](#), [Metallurgy Commons](#), [Ocean Engineering Commons](#), and the [Structural Engineering Commons](#)

Recommended Citation

Darusalam, Ucuk; Priambodo, Purnomo Sidi; Sudibyoy, Harry; and Rahardjo, Eko Tjipto (2014)

"Performances of Free-Space Optical Communication System Over Strong Turbulence," *Makara Journal of Technology*. Vol. 18 : No. 1 , Article 3.

DOI: 10.7454/mst.v18i1.2934

Available at: <https://scholarhub.ui.ac.id/mjt/vol18/iss1/3>

This Article is brought to you for free and open access by the Universitas Indonesia at UI Scholars Hub. It has been accepted for inclusion in Makara Journal of Technology by an authorized editor of UI Scholars Hub.

Performances of Free-Space Optical Communication System Over Strong Turbulence

Ucuk Darusalam, Purnomo Sidi Priambodo*, Harry Sudiby, and Eko Tjipto Rahardjo

Study Program of Opto-Electrotechnique & Laser Application, Department of Electrical Engineering,
Faculty of Engineering, Universitas Indonesia, Depok 16425, Indonesia

*e-mail: pspriambodo@ee.ui.ac.id

Abstract

We report an experimental of free-space optical communication (FSOC) system that use tube propagation simulator (TPS) as the turbulence medium. The FSOC system use wavelength of 1550 nm at the rate transmission of 1000 Mbps and amplified with EDFA at the output of +23 dBm. Index structure of 10^{-15} – 10^{-13} as the representation of atmosphere index turbulences are used for simulation of intensity distribution model or scintillation. The simulation use gamma-gamma and K model as well. The beam wave propagation models used in simulation are plane wave, spherical wave and Gaussian wave. Spherical wave achieves highest performance via gamma-gamma in strong turbulence. While Gaussian wave achieves highest performance also via K model. We also found, characteristic FSOC system performance is calculated more accurately with gamma-gamma method for strong turbulence than K model. The performances from gamma-gamma for strong turbulence are $\langle SNR \rangle$ at 22.55 dB, $\langle Prfade \rangle$ at 5.33×10^{-4} , and $\langle BER \rangle$ at 9.41×10^{-6} .

Abstrak

Performansi Sistem Komunikasi Optik Media Atmosfir (*Free-Space Optical Communication*) dalam Kondisi Turbulensi Kuat. Kami melaporkan eksperimen sistem komunikasi optik media atmosfer (FSOC) menggunakan *tube propagation simulator* (TPS) sebagai kanal media turbulen. Sistem FSOC menggunakan panjang gelombang 1550 nm pada tingkat transmisi 1000 Mbps dan penguatan sinyal dengan EDFA pada luaran +23 dBm. Struktur indeks atmosfer pada kisaran 10^{-15} – 10^{-13} digunakan sebagai parameter skala turbulensi untuk menghitung distribusi model intensitas atau sintilasi. Simulasi perhitungan menggunakan model statistik gamma-gamma dan K. Model propagasi gelombang yang digunakan dalam simulasi adalah gelombang datar (*plane wave*), gelombang sirkular (*spherical wave*), gelombang Gaussian (*Gaussian wave*). Gelombang sirkular menghasilkan performansi tertinggi menggunakan model gamma-gamma pada turbulensi kuat. Sedangkan gelombang Gaussian menghasilkan performansi tertinggi menggunakan model K. Kami juga menemukan bahwa karakteristik performansi sistem FSOC dapat terukur lebih akurat menggunakan metode gamma-gamma untuk turbulensi kuat daripada model K. Hal tersebut mengacu pada hasil simulasi dan eksperimen. Hasil tersebut adalah dalam kondisi turbulensi kuat performansi $\langle SNR \rangle$ berada pada rentang 22,55 dB, $\langle Prfade \rangle$ dalam rentang $5,33 \times 10^{-4}$, dan $\langle BER \rangle$ pada rentang $9,41 \times 10^{-6}$.

Keywords: free-space optical communication (FSOC) system, scintillation, turbulence media, $\langle SNR \rangle$, $\langle BER \rangle$, $\langle Prfade \rangle$

1. Introduction

Atmospherical turbulence is the major problem for implementation of free-space optical communication (FSOC) system as terrestrial platform. It caused the media propagation of beam wave behaves random distribution of refraction index spatially and temporally. This is caused by fluctuation of wind speed, temperature and medium density in randomly fashion. It leads beam

wave propagation deterioration such as diffraction, scattering, and attenuation that behaves randomly as well. Those leads to random beam irradiance into the receiver lens. Hence it cause the scintillation phenomena to receiver. By all means the characteristic performance of FSOC system is decreasing [1-3].

Scintillation is fluctuation of signal intensity which is received by photodetector. It also exhibits noise. It is

represented as intensity distribution of received beam wave that is induced by atmospheric turbulence. Higher degree of scintillation represents the scale of turbulence. The intensity distribution has characteristics for each turbulence scale. This causes SNR no longer constant but also has the mean value for each turbulence scale. The mean value of SNR contributes major parameter to characteristic performance of FSO system. The mean value of SNR determines the rate of probability of fade (*Prfade*) of beam waves in atmospheric turbulence. Higher rate value of probability of fade means lower possibility of photodetector to detect beam wave intensities. It also contributes major factor for mean value of BER. The ideal characteristic performance of FSO system is the lowest of *Prfade*, lowest mean value of BER and higher mean value of SNR.

In order to mitigate the deteriorating beam waves by the presence of atmospheric turbulence many methods have been reported successfully overcoming those problems. Multiple beam wave transmission and multiple beam receiver or MIMO has been reported could enhance the performance of FSO system at significant value [3]. Saturated EDFA at transmitter beacon has been reported successfully overcoming high turbulence [4]. In order to shrink wide distribution of scintillation, the spatial diversity has been reported to mitigate high scale of turbulence successfully [5-6]. In order to overcome beam wander effect, the wide angle of lens receiver in array configuration has been reported in simulation to elevate the FSO system performance as well [7]. CMOS imaging receiver has been reported in mitigation of induced atmospheric turbulence in order to detect the lowest of signal intensity.

The accuracy and precision is also being studied widely in representing the distribution of irradiance or scintillation, in order to improve the characteristic performance. Common statistical methods are gamma-gamma, K, and lognormal [8-9]. Markov chain model in maximum-likelihood has been reported to reach improved significant results [10]. Radiative transfer theory also has been reported successfully in minimizing BER [11]. Wavelet signal processing also being used as optimization method on the receiver unit in reduction BER [12].

On this preliminary research we have designed the FSO system over turbulence media (TPS/tube propagation simulator). TPS is designed to induce beam wave propagation in the scale of weak to strong turbulence. The goal of research is investigation of the effect of strong turbulence medium in order to seek the high characteristic performance of FSO system when it already to be implemented in real atmosphere environment or turbulence. The characteristic performance of system is analyzed with gamma-gamma and K model. Beam

wave propagation models are used plane wave, spherical wave and Gaussian wave for simulation.

We compare the results of simulation with analytical measurement of experiment. We also make an analysis comparison with previous work of others that implement gamma-gamma and K model distribution. We have great intention to develop FSO system that have robust characteristic performance in real atmospheric turbulence.

2. Experiment

Model of FSO System. Atmospheric turbulence affects the signal intensity which is received by photodetector. Signal intensity which propagates from transmitter and reaches the receiver lens behaves fluctuation randomly, as can be seen in Eq. 1 [13]:

$$I^o(r, L + L_f) = \frac{W_0^2}{W^2 \left(1 + \frac{\Omega_G}{\Lambda_1}\right)} \exp\left(-\frac{2r^2}{W^2}\right)$$

$$I\langle 0, L + L_f \rangle = \frac{W_G^2}{W_0^2} \frac{I^o(0, L)}{SR} \exp\left(-\frac{2r^2}{W^2 SR}\right) \quad (1)$$

W is focus spot behind single finite lens. r is radius of focus spot.

$\Omega_G = \frac{2L}{kW_G^2 W_G}$ is radius of receiver lens. W_0 is the radius of transmitted beam wave from the source or TX. $I^o(0, L)$ is the signal intensity in the absence of atmospheric turbulence. SR is the Sthrel ratio of

$1 + 1,63\sigma_R^{\frac{12}{5}} \Lambda_1$

which is the function of Rytov factor $D_{\downarrow G}, \Lambda_{\downarrow 1} \gg \Omega_{\downarrow G}$

$$I^o(0, L + L_f) \cong \frac{W_G^2}{W^2} I^o(0, L) \exp\left(-\frac{2r^2}{W^2}\right).$$

The signal power is in Eq. 2.

$$I^o(0, L) \cong \frac{W_G^2}{W^2} I(0, L)$$

is the instantaneous irradiance.

$$P_s \cong \int_0^{2\pi} \int_0^{00} I(r, L + L_f) r dr d\theta \cong \frac{1}{8} \pi D_G^2 I(0, L) \quad (2)$$

The output current of photodetector is the mean value as stated in Eq. 3,

$$\langle I_s \rangle = \frac{\eta e \langle P_s \rangle}{h\nu} \quad (3)$$

Integrating Eq. 2, the mean of signal power is given in Eq. 4,

$$P_s \langle P_s \rangle = \frac{1}{8} \pi D_G^2 I(0, L) \cong \frac{\pi D_G^2 I^0(0, L)}{8 \left(1 + 1,63 \sigma_R^5 \Lambda_1 \right)} \quad (4)$$

The variance of signal noise shall behave,

$$\begin{aligned} \sigma_{SN}^2 &= \langle I_S^2 \rangle - \langle I_S \rangle^2 + \langle I_N^2 \rangle \\ &= \left(\frac{\eta e}{h\nu} \right)^2 \langle \Delta P_S^2 \rangle + \frac{\eta e^2 B \langle P \rangle_S}{h\nu} \end{aligned} \quad (5)$$

$\langle \Delta P_S^2 \rangle = \langle P_S^2 \rangle - \langle P_S \rangle^2$ is the fluctuation of input signal power that contributes to signal noise at photodetector. If $\langle I_S \rangle$ and σ_{SN}^2 is larger then the mean of SNR is given in Eq. 6 [13],

$$\langle SNR \rangle SNR = \frac{\langle I_S \rangle}{\sigma_{SN}^2} = \frac{\langle P_S \rangle}{\sqrt{\langle \Delta P_S^2 \rangle + \frac{2h\nu B \langle P_S \rangle}{\eta}}} \quad (6)$$

$\langle SNR \rangle$ in Eq. 6 can be simplified as stated in Eq. 7,

$$\langle SNR \rangle = \frac{SNR_0}{\sqrt{\left(\frac{P_{S0}}{\langle P_S \rangle} \right) + \sigma_I^2(D_G) SNR_0^2}} \quad (7)$$

SNR_0 is value of SNR when the turbulence does not induce beam wave propagation. Hence P_{S0} represents the output signal power from photodetector at the absence of turbulence. $\sigma_I^2(D_G)$ is scintillation index within range value of 0-1 [13]. The ratio of output power by the induced of turbulence is

$$\frac{P_{S0}}{\langle P_S \rangle} \cong 1 + 1,63 \sigma_R^5 \Lambda_1$$

Those ratio is deterioration effect of atmospherical turbulence. $\frac{P_{S0}}{\langle P_S \rangle}$ is the Strehl ratio, which is the

characteristical of imaging system. It can be approximated as given in Eq. 8,

$$\frac{P_{S0}}{\langle P_S \rangle} \cong 1 \quad (8)$$

Hence the $\langle SNR \rangle$ is the function of SNR_0 and σ_I^2 as can be seen in Eq. 9,

$$\langle SNR \rangle = \frac{SNR_0}{\sqrt{1 + \sigma_I^2(D_G) SNR_0^2}} \quad (9)$$

Rate detection related with $\langle SNR \rangle$ is given in Eq. 11,

$$\begin{aligned} Pr_d &\cong \int_0^{00} \int_{i\tau}^{00} pi(s) pi + n (i I s) di ds \\ &= \frac{1}{2} \int_0^{00} pi(s) erfc \left(\frac{i\tau - s}{\sqrt{2\sigma_N}} \right) ds \end{aligned} \quad (10)$$

or

$$Pr_d = \frac{1}{2} \int_0^{00} p_I(U) erfc \left(\frac{TNR - \langle SNR \rangle u}{\sqrt{2}} \right) du \quad (11)$$

Rate detection is $\langle SNR \rangle$ when the P_S which represented as $p_{\downarrow} I(U) p_{\downarrow} I$ achieves threshold level of photodetector (TNR/threshold to noise ratio). By all means the probability of false alarm rate also exhibits on the photodetector as can be seen in Eq. 12,

$$Pr_{fade} = \frac{1}{2} erfc \left(\frac{TNR}{\sqrt{2}} \right) \quad (12)$$

Also FAR (false alarm rate) has relation with the probability of false alarm rate as stated in Eq. 13,

$$FAR = \frac{B}{2\sqrt{3}} \exp \left(-\frac{TNR^2}{\sqrt{2}} \right) \quad (13)$$

In order to evaluate Pr_{fade} in Eq. 12 as function of $\langle SNR \rangle$ it can be acquired by assumption that the Probability Density Function of irradiance is gamma-gamma as can be seen in Eq. 14,

$$pi(u) = \frac{2(\alpha\beta)^{\frac{\alpha+\beta}{2}}}{\Gamma(\alpha)\Gamma(\beta)} u^{\frac{\alpha+\beta}{2}-1} K_{\alpha-\beta} \left(2\sqrt{\alpha\beta}u \right), u > 0 \quad (14)$$

While for K model is,

$$pi(u) = \frac{2\alpha}{\Gamma(\alpha)} (\alpha u)^{\frac{\alpha-1}{2}-1} K_{\alpha-1} \left(2\sqrt{\alpha}u \right), u > 0 \quad (15)$$

If the beam wave propagation is modelled as spherical wave, the paramaters of scintillation index of α_{sw} dan

β_{sw} in Eq. 16-17, are [13],

$$\alpha_{sw} = \frac{1}{\exp \left[\frac{0,49\beta_0^2}{\left(1 + 0,18d^2 + 0,56\beta_0^5 \right)^{\frac{7}{6}}} \right]} \exp \left[\frac{0,49\beta_0^2}{\left(1 + 0,18d^2 + 0,56\beta_0^5 \right)^{\frac{7}{6}}} \right]^{-1} \quad (16)$$

$$\beta_{sw} = \frac{1}{\exp \left[\frac{0,51\beta_0^2 \left(1 + 0,69\beta_0^{\frac{12}{5}} \right)^{-\frac{5}{6}}}{\left(1 + 0,9d^2 + 0,62d^2\beta_0^{\frac{12}{5}} \right)^{\frac{7}{6}}} \right]} - 1 \quad (17)$$

$\beta_0^2 = 0,5C_n^2 k^{\frac{7}{6}} L^{\frac{11}{6}}$ is Rytov variances of beam wave which propagates through distance L meter.

$d = \sqrt{\frac{kD^2}{4L}}$ For the case of plane wave, the index scintillation (α_{pw} dan $\beta_{\downarrow pw}$) of Eq.18-19 are [13],

$$\alpha_{pw} = \frac{1}{\exp \left[\frac{0,49\beta_0^2}{\left(1 + 0,65d^2 + 1,11\beta_0^{\frac{12}{5}} \right)^{\frac{7}{6}}} \right]} - 1 \quad (18)$$

$$\beta_{pw} = \frac{1}{\exp \left[\frac{0,51\beta_0^2 \left(1 + 0,69\beta_0^{\frac{12}{5}} \right)^{-\frac{5}{6}}}{\left(1 + 0,9d^2 + 0,62d^2\beta_0^{\frac{12}{5}} \right)^{\frac{7}{6}}} \right]} - 1 \quad (19)$$

Also for the case of Gaussian wave model is given in Eq. 20-21 [13],

$$\alpha_{gw} = \frac{1}{\exp \left[\frac{0,49 \left(\frac{\Omega_G - \Lambda_1}{\Omega_G + \Lambda_1} \right)^2 \beta_0^2}{\left(1 + 0, \frac{4(2 - \Theta_i) \left(\frac{\beta_0^2}{\beta_5^2} \right)}{\left(\Omega_G + \Lambda_1 \right) \left(\frac{1}{3} - \frac{1}{2} \Theta_i^2 \right)^{\frac{6}{7}}} + 0,56(1 + \Theta_i) \beta_0^{\frac{12}{5}} \right)^{\frac{7}{6}}} \right]} - 1 \quad (20)$$

$$\beta_{gw} = \frac{1}{\exp \left[\frac{0,51\beta_0^2 \left(\frac{\square}{1 + 0,69\beta_0^{\frac{12}{5}}} \right)^{\frac{5}{6}}}{\left(1 + \frac{\left[1,2 \left(\frac{\beta_0^2}{\beta_B^2} \right) \right]^{\frac{12}{5}} + 0,83\beta_0^{\frac{12}{5}}}{\Omega_G} + \Lambda_1 \right)^{\frac{7}{6}}} \right]} - 1 \quad (21)$$

The Rytov variance ($\beta_{\downarrow} \beta^{\uparrow} 2$) of Eq. 20-21, for Gaussian wave is given in Eq. 22 [13],

$$\beta_B^2 \cong 3,86\beta_0^2 \left\{ 0,4 \left[(1 + 2\Theta_1)^2 + 4\Lambda_1^2 \right]^{\frac{5}{12}} \times \cos \left[\frac{5}{6} \tan^{-1} \left(\frac{1 + 2\Theta_1}{2\Lambda_1} \right) \right] - \frac{11}{16} \Lambda_1^{\frac{5}{6}} \right\} \quad (22)$$

Finally $\langle BER \rangle$ is given in Eq. 23 [13],

$$\langle BER \rangle = \frac{1}{2} \int_0^{\infty} p_I(U) \operatorname{erfc} \left(\frac{\langle SNR \rangle u}{2\sqrt{2}} \right) du \quad (23)$$

Proposed experiment. As shown on the Fig. 2-3, FSOC system is fiber detection. Optical modem of full-duplex TX/RX at λ of 1550 nm and rate transmission of 1000 Mbps. For each unit of TX and RX is connected to UTP of PC's in order to perform point-to-point connection. On TX, output of laser transceiver of -2.4 dBm is amplified by EDFA at the output of +23 dBm. The output from EDFA is collimated by beam collimator and transmitted into TPS. Beam wave propagates through turbulence medium of TPS. TPS is designed with various scale of turbulence. It reaches lens focuser (RX). The focus spot is coupled into MMF and detected by Optical Power Meter.

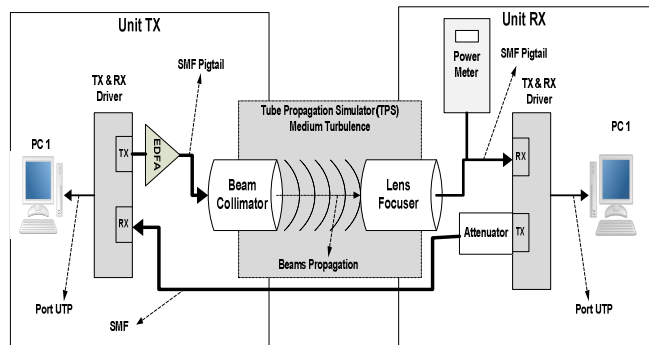


Figure 2. Experiment Diagram of FSOC Fiber Detection Method

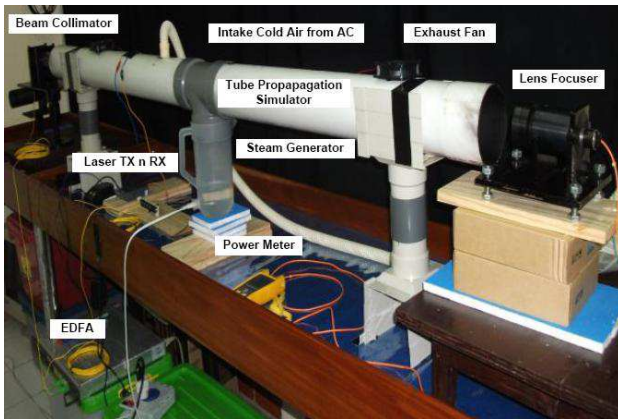


Figure 3. Set-up Diagram of Turbulence Medium as the Optical Beam Wave Propagation (Tube Propagation Simulator/TPS)

TPS diagram is shown in Fig. 3. It is composed of main tube of 3.5 inch diameter with the length of 2.2 m. The tube is designed to be localized turbulence medium which are performed by configuration of exhaust fan, steam generator (SG) and intake cold air (air conditioner, AC). Hence turbulence medium induces beam wave propagation optimally. The scale of turbulence is determined by configurations of those main equipment. Strong turbulence is designed extremely by the collision of cold air from AC ($T_{AC} = 16\text{ }^\circ\text{C}$) and steam ($T_{SG} > 50\text{ }^\circ\text{C}$) then air is expanded rapidly by exhaust fan. Through those, the index refraction distribution on TPS is the same conditions as real atmospheric turbulence.

Fig. 2-3 are the proposed experiment set-up for FSO system that implement full-duplex communication scheme with different wavelength for TX-forward and -backward. In this work we use experiment set-up of Fig. 3 to perform analytical measurement. The analytical measurement is calculated $\langle SNR \rangle$ from data of transmitted and received of signal power. Hence we can compare the characteristic performance of FSO system between results of simulation and analytical measurement. We equipped Fig. 3 with OSA (Optical Spectrum Analyzer) and BER-T (BER tester) in order to measure SNR , BER , and spectral analysis.

3. Results and Discussion

The results of simulation for gamma-gamma model (Eq.14) with the means of probability of fade $\langle Prfade \rangle$ and means of bit error rate $\langle BER \rangle$ as functioned of means of SNR ($\langle SNR \rangle$) are shown in Fig 4.a-b. The models of beam wave propagation are using plane wave, spherical wave, and gaussian wave for strong turbulence and the wavelength is 1550 nm. The index of structure for gamma-gamma and K models is using 10^{-13} for strong turbulence [13]. While the distance of

propagation is 1000 m. $\langle SNR \rangle$ is in the range of 0-20 dB. The scintillation index parameter use Eq. 16-21 for each beam waves propagation model.

The results of simulation using K model for $\langle Prfade \rangle$ and $\langle BER \rangle$ are shown in Fig 5.a-b. The index scintillation or decomposition of α and β (gamma-gamma parameters) for each beam waves is resulted from Eq. 16-21.

From gamma-gamma and K distribution model for plane wave, spherical wave, and Gaussian wave, it can be seen that (Fig. 4 and Fig. 5): (a) In strong turbulence, spherical wave achieve highest performance, $\langle Prfade \rangle$ is in range value of 0.001–0.015 and $\langle BER \rangle$ is in range order of 0.09×10^{-4} – 0.82×10^{-4} . (b) Gaussian wave also achieves highest performance, $\langle Prfade \rangle$ is in range value of 0.01–0.02 and $\langle BER \rangle$ is in range order of 0.2×10^{-4} – 1.5×10^{-4} .

FSOC system performances measurement using gamma-gamma and K distribution for $\langle Prfade \rangle$ and $\langle BER \rangle$ are shown in Fig 6-7. $\langle SNR \rangle$ is the actual values resulted from analytical measurement by comparing signal power at the absence and the present of turbulence on TPS.

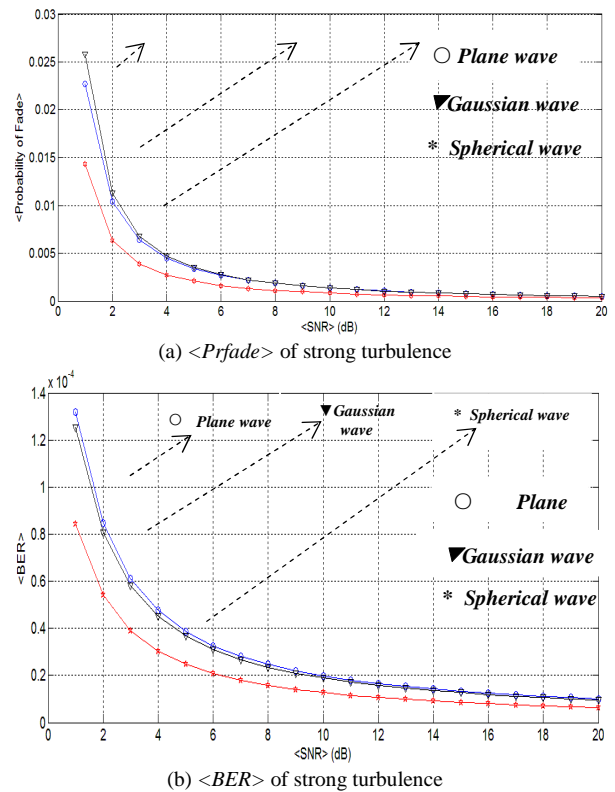
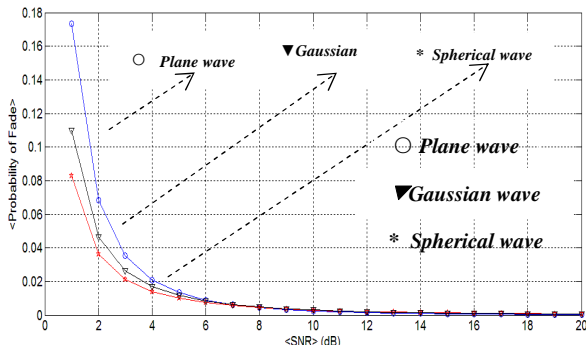
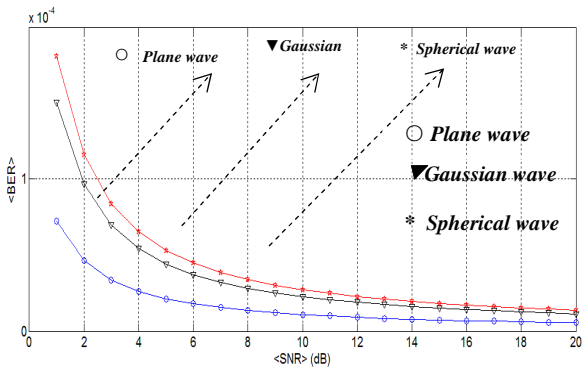


Figure 4(a-b). Simulation of Means of Probability of Fade ($\langle Prfade \rangle$) and Means of BER ($\langle BER \rangle$) Over Strong Turbulence Using Gamma-Gamma Distribution

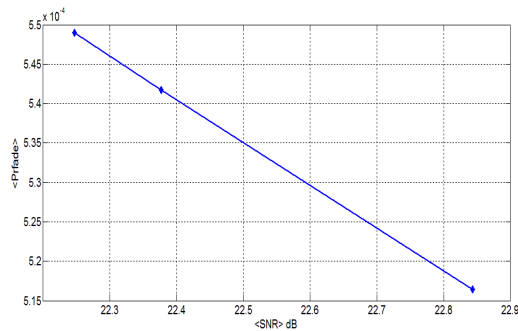


(a) $\langle Pr_{fade} \rangle$ of strong turbulence

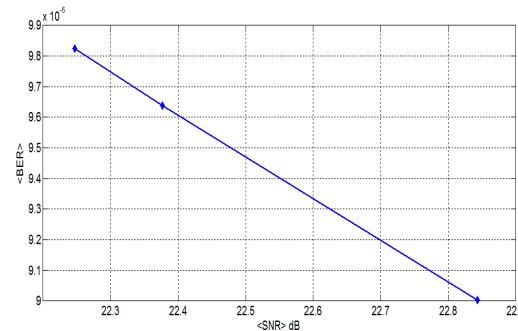


(b) $\langle BER \rangle$ of strong turbulence

Figure 5(a-b). Simulation of Means of Probability of Fade ($\langle Pr_{fade} \rangle$) and Means of BER ($\langle BER \rangle$) Over Strong Turbulence Using K Distribution Model

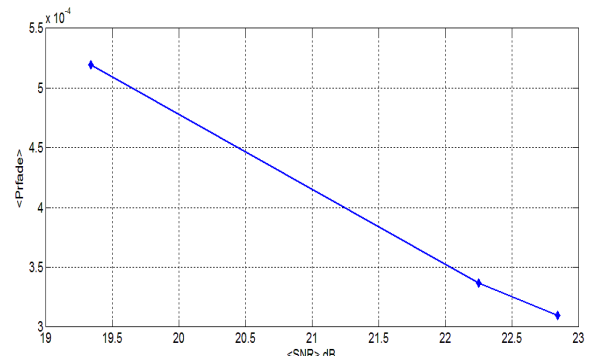


(a) $\langle Pr_{fade} \rangle$ of strong turbulence

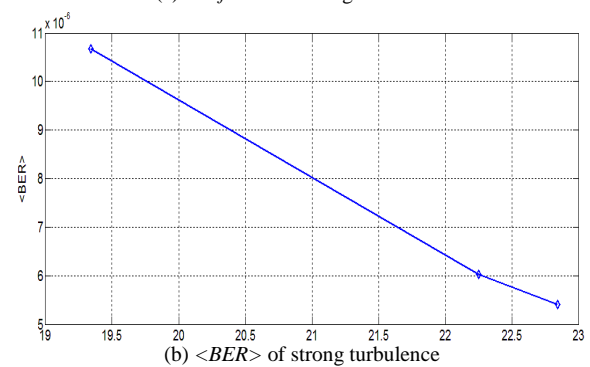


(b) $\langle BER \rangle$ of strong turbulence

Figure 6(a-b). Measurements of $\langle Pr_{fade} \rangle$ and $\langle BER \rangle$ Over Strong Turbulence Using Gamma-Gamma Distribution Model



(a) $\langle Pr_{fade} \rangle$ of strong turbulence



(b) $\langle BER \rangle$ of strong turbulence

Figure 7(a-b). Measurements of $\langle Pr_{fade} \rangle$ and $\langle BER \rangle$ Over Strong Turbulence Using K Distribution Model

From Fig. 6 and Fig. 7, it is shown that gamma-gamma and K measurement method for various scale of turbulence are: (a) In strong turbulence $\langle SNR \rangle$ is 22.25–22.85 dB, $\langle Pr_{fade} \rangle$ is 5.17×10^{-4} – 5.49×10^{-4} , while $\langle BER \rangle$ is 9.0×10^{-6} – 9.83×10^{-6} . (b) $\langle SNR \rangle$ is 19.3–22.75 dB, $\langle Pr_{fade} \rangle$ is 3.15×10^{-4} – 5.25×10^{-4} , and $\langle BER \rangle$ is 5.4×10^{-4} – 10.75×10^{-4} .

From the simulation via gamma-gamma and K model, it can be seen that $\langle Pr_{fade} \rangle$ and $\langle BER \rangle$ get lower order as $\langle SNR \rangle$ increase from 0–20 dB. Higher $\langle SNR \rangle$ in strong turbulence has great impact to increasing those parameter. For gamma-gamma spherical wave achieves high characteristic performance for all scale of turbulence. This is caused by characteristic beam wave propagation which the divergence from the transmitter is minimum to be induced by turbulence media, compared to plane wave and Gaussian wave that have constant beam dimension from beam collimator to lens receiver. The characteristic of spherical wave can be said has lower probability to be induced by turbulence medium. From gamma-gamma model the index scintillation is decomposed into two parameter which are α and β . For the constant beam wave dimension along propagation distance, it shall contribute to accumulation of wider distribution of scintillation. For that reason plane wave and Gaussian have great probabilities to be induced by turbulence

relatively. However the results via gamma-gamma show the same trend as the results from the work of reff. [8].

The results analytical measurement of characteristic FSOC system performance also show that $\langle BER \rangle$ gamma-gamma approximates the simulation results in strong turbulence. This results also has been shown by W. Gappmair et al. [14], gamma-gamma is appropriate in measurement of heavy turbulence. Jaedon Park et al. [14], also have achieved results that gamma-gamma was suitable in measuring the moderate-strong turbulence. J. Perez [16] also have reported that in controlled medium turbulence the results of strong turbulence at 10^{-6} . Ehsan Bayaki et al. [17], also had reported that in strong turbulence which were 10^{-2} – 10^{-3} for the range $\langle SNR \rangle$ of 20–25 dB.

From K model simulation it also has trend as the gamma-gamma simulation for $\langle Prfade \rangle$ and $\langle BER \rangle$ increase as $\langle SNR \rangle$ goes higher. But using K model, Gaussian wave is more robust from turbulent inducement. In K model the index scintillation does not being decomposed into α and β . the index scintillation is join value of α and β parameters. It means that in K model does not measure the distribution of scintillation in inner scale and outer scale of turbulence medium parameters. Hence for measuring the performance in strong turbulence, K model is not representative to acquisition the real condition of turbulence medium. Also by comparing the masurement and comparing to other research works using K also, It was stated that K is precise method for weak turbulence. Samimi et al. [18] have reported that K model is appropriate for weak turbulence condition. Mingbo Niu et al. [19], also have reported that with $\alpha < 2$ and the range $\langle SNR \rangle$ of 10–30 dB, $\langle BER \rangle$ sebesar 10^{-2} – 10^{-7} . Kamran Kiasaleh [20] have had strong justification that the $\langle BER \rangle$ via K model never achieved order at 10^{-9} .

4. Conclusions

From the simulation via gamma-gamma, spherical wave model achieves highest characteristic performance than other beam wave model. For K model, Gaussian wave achieves high characteristic performance than other ones. The comparison from simulation and analytical measurement results show that gamma-gamma model is more accurate and precise than K model. The accuration and precession are caused by the averaged values of α and β from all beam waves model

approximates at real condition of scintillation distribution for strong turbulence on TPS.

References

- [1] X. Zhu, J.M. Kahn, IEEE Trans. Commun. 50/8 (2002) 1293.
- [2] V.W.S. Chan, J. Lightwave Technol. 24/12 (2006) 4750.
- [3] Z. Hajjarian, J. Fadlullah, J. Commun. 4/8 (2009) 524.
- [4] M. Abtahi, P. Lemieux, W. Mathlouthi, L.A. Rusch, J. Lightwave Technol. 24/12 (2006) 4966.
- [5] H. Li-qiang, W. Qi, S. Katsunori, WASE International Conference on Information Engineering, China, 2010, p.127.
- [6] Y.-S. Hurh, K. Shin, S. Lee, J. Lee, J. Lightwave Technol. 23/12 (2005) 4022.
- [7] X. Ma, L. Liu, B. Tu, X. Zhang, J. Tang, J. Lightwave Technol. 28/24 (2010) 3582.
- [8] A. Bekkali, C.B. Naila, K. Kazaura, K. Wakamori, M. Matsumoto, IEEE Photonics J. 2/3 (2010) 510.
- [9] H.E. Niztazakis, T.A. Tsiftsis, G.S. Tombras, IET Comm. 3/8 (2009) 1402.
- [10] X. Zhu, J.M. Kahn, IEEE Trans. Commun. 51/3 (2003) 509.
- [11] C. Reindhart, Y. Kuga, S. Jaruwatanadilok, A. Ishimaru, IEEE J. Selected Areas in Comm. 27/9 (2009) 1591.
- [12] P. Latsa-Babu, B. Srinivasan, IEEE Trans. Comm. 58/6 (2010) 1.
- [13] L.C. Andrews, R.L. Philips, 2nd ed., SPIE Press, Washington, USA, 2005, p.820.
- [14] W. Gappmair, M. Flohberger, IEEE Trans. Wireless. Comm. 8/5 (2009) 2209.
- [15] Eunju Lee, Giwan Yoon, IEEE Photon. Tech. Lett. 23/4 (2011) 269.
- [16] J. Perez, Z. Ghassemlooy, S. Rajbhandari, M. Ijaz, H.L. Minh, IEEE Comm. Lett. 16/3 (2012) 408.
- [17] E. Bayaki, R. Schober, R.K. Mallik, IEEE Trans. 57/11 (2009) 3415.
- [18] H. Samimi, J. IET Optoelectron. 6/1 (2012) 1.
- [19] M. Niu, J. Cheng, J.F. Holzman, Proc. of WCNC, Sydney, NSW, 2010.
- [20] K. Kiasaleh, A.V. Bagrov, V.P. Lukin, C. Shen, F. Chen, X. Yu, IEEE Trans. Comm. 54/4 (2006) 604.