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The Performance in FSO Communication Due to Atmospheric Turbulence Via Utilizing New Dual Diffuser Modulation Approach

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Abstract

A new transmission and detection technique namely Dual Diffuser Modulation (DDM) for free space optical (FSO) communication systems is proposed. FSO communication systems can provide the line-of-sight optical transmission with low cost and good security. However, the distance dependent atmospheric turbulence and path-loss affect widespread use of FSO systems and limit their application to short-range links. This paper analyzes the capacity performance in term of power received for FSO communication between the conventional on off keying (OOK) and DDM technique under the influence of the atmospheric turbulence. Capacity of distance performance also analyzes in this paper. As the result, the distance of FSO can increased when the power transmitted increased with considering at standard acceptance BER 10^{-9}. Meanwhile at the effective power received for the comparison between both techniques, the performance of power received approximately about -50 dB increased. This indicate that the DDM technique improved the performance if compare to conventional OOK technique.

Keywords: Dual Diffuser Modulation (DDM); Free Space Optic; Bit Error Rate; Power Received;

INTRODUCTION

Free space optical communication is an attractive alternative over fiber optical communication where provides high bandwidth, fast-installation and high security [1]. Nevertheless, atmospheric turbulence often interfere FSO communication system. The atmospheric turbulence which can lead the laser beam such as beam wanders, beam spreading and scintillation. The beam wanders is refer to the condition beam deflected randomly through the changing refractive index oddities. Meanwhile beam spreading refers to conditions where the beam spread more than diffraction estimated predict. Lastly, for scintillation it affected the phase front of the beam can vary and resulting fluctuation irradiance or well known as intensity signal. The combination of all these effect will cause both the spatial and temporal experience random fluctuations in refractive index of the variability of element factor such as temperature, pressure and wind variations along the optical propagation path through the channel [2-9]. The conventional technique that is OOK uses an injected voltage level as a threshold into a decision circuit, which decides whether the incoming bit is a 0 or a 1. When the data input voltage is higher than the threshold, a 1 bit is regenerated, and vice versa. However, this technique has two inherent problems; the instability of the injected threshold voltage, and the complexity of a dynamic threshold processing. As the threshold voltage has its own noise and fluctuation, it adds to the deterioration of the signal, thus limits the systems performance. Meanwhile, due to the random nature of the incoming bits, coupled with the masking noises and jitters, the threshold voltage level cannot be set a fixed value, and therefore a dynamic voltage threshold adjustment is required [2]. In this paper we make the comparison performance dual-detection approach with the conventional approach in term of turbulence strength. In section II we outline the model dual-detection approach with assume using OOK modulation. In section III we derive the theoretical analysis for SNR and BER. Meanwhile section IV and V discuss the result and summary of paper.

DUAL DIFFUSER MODULATION DESIGN

The system employs two transmitters and On-Off Shift Keying (OOK) modulation as reference for conventional system. When the first transmitter sends binary '1', the second transmitter which is set in compliment condition will send the binary '0' in simultaneously and vice versa. Meanwhile at the receiver part, the signal will go through the subtractor for the differential detection process. Here we assume the ideal subtractor condition where no losses signal occurs during subtraction. Therefore, the signal output will become bit '1' for sending binary '1' and bit '-1' for sending binary '0'. This condition leads to modification on conventional OOK modulation particularly in improving signal threshold detection and reduce power loss. This modification is called dual diffuser modulation (DDM) technique.

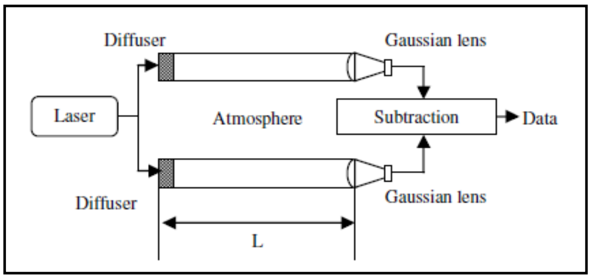


Figure 1: Dual Diffuser Modulation setup in FSO communication

THEORY OF ANALYSIS

Based on the Rytov theory, the field of the plane wave in random media is given [10].

$$E_o(\vec{r}) = A_o(\vec{r}) \exp\,(i\varphi_o(\vec{r})) \tag{1}$$

Where $A_o(\vec{r})$ is amplitude of the laser beam in the atmosphere without the presence of turbulence. φ_o and $E_o(\vec{r})$are the phase and laser beam profile, respectively. However in the presence of turbulence, the scintillation effect is more dominant which change the refractive index and as a consequence lead to intensity fluctuations. Therefore this condition directly change the laser beam profile [10,11].

$$E_o(\vec{r}) = A_o(\vec{r}) \exp\big(i\varphi_o(\vec{r})\big) = E_o(\vec{r}) \exp(\Phi) \tag{2}$$

Where $A(r)$ is amplitude of the laser in the turbulence atmospheric, ϕ is the exponential factor due to turbulence given as:

$$\Phi = Ln\left(\frac{A(\vec{r})}{A_o(\vec{r})}\right) + i[\phi(\vec{r}) - \phi_o(\vec{r})]$$
$$= \chi + iS \tag{3}$$

Where X represents the fluctuation of the log-amplitude of the field and S is the phase fluctuations. This equation predicts a fluctuation in intensity and phase of receiving signal due to turbulence is weak and assuming that the refractive index structure coefficient C_n^2 is symmetrical along the beam path, Rytov suggested a variance for the log-irradiance given as [11]:

$$\sigma^2_{ln\,IR} = \langle (ln\,I - \langle ln\,I\rangle)^2\rangle = 1.23 C_n^2 k^{7/6} L^{11/6} \tag{4}$$

Where k is wave number, $k=2\pi/\lambda$, L is propagation distance and I is intensity signal. However in practical FSO for plane wave in weak condition and for the symmetrical turbulence of the log-amplitude fluctuation is given by [9,10]:

$$\langle \chi^2 \rangle = 0.31 C_n^2 k^{7/6} L^{11/6} \tag{5}$$

By neglecting other source noises, we assume the only dominant noise source is atmospheric turbulence which gives the log-amplitude as:

$$\chi = ln\left(\frac{A(\vec{r})}{A_o(\vec{r})}\right) = ln\left[\frac{A_o(\vec{r})+A_n(\vec{r})}{A_o(\vec{r})}\right] = ln(1+\varepsilon) \tag{6}$$

Where $A_n(\vec{r})$ is the amplitude of noise and $\varepsilon = A_n(\vec{r})/A_o(\vec{r})$ is the ratio of the amplitude of noise to signal. Both SNR and BER are used to evaluate the quality of the communication systems. The BER performance depends on the average received power, the scintillation strength, receiver noise and threshold bits (1 or 0) detection [7]. Here the dual-detection approach is a modification from the conventional OOK detection that using direct detection where improves power received and eliminated the need of complex adaptive threshold. The SNR for case only dominant turbulence noise in term of mean signal and noise intensity I_o and $\langle I_n \rangle$ given as:

$$SNR = \frac{I_o}{\langle I_n \rangle} = \frac{\langle A_o^2(\vec{r})\rangle}{\langle A_n^2(\vec{r})\rangle} = \frac{1}{\langle \varepsilon^2 \rangle} \tag{7}$$

So, the BER for OOK modulation can be written as [10]:

$$BER = \frac{1}{2} erfc\left(\frac{Q}{2}\right) = \frac{e^{(-\frac{Q^2}{2})}}{Q\sqrt{2\pi}} \tag{8}$$

where $erfc()$ the complementary error function and Q is defined as:

$$Q = \frac{A_1 - A_0}{\sigma_1 + \sigma_0} \tag{9}$$

Where A_1, σ_1 are the mean signal and noise at the receiver for a bit '1' respectively, and for a bit '0' the mean signal and noise are denoted as A_0, σ_0.

For conventional OOK bit detection,

$$A_1 = < A_o(\vec{r}) >, A_o = 0 \;and\; \sigma_1 + \sigma_0 = < A_o(\vec{r}) >$$

$$SNR = \frac{<A_O^2(\vec{r})>}{<A_n^2(\vec{r})>} = Q^2 \tag{10}$$

However for case dual-detection approach,

$$A_1 = < A_o(\vec{r}) >, A_o = < -A_o(\vec{r}) > \;and\; \sigma_1 + \sigma_0 = < A_o(\vec{r}) >$$

$$SNR = \frac{<2A_O^2(\vec{r})>}{<A_n^2(\vec{r})>} \tag{11}$$

For weak turbulence model, ε is very small thus (6) is given as [10]:

$$\chi = \ln\,(1+\varepsilon) \approx \varepsilon \tag{12}$$

When turbulence is strong, the SNR and χ can be relating using Tailor series for function $f(x) = (e^x - 1)^2$ and can be approximately to:

$$SNR = \frac{1}{\langle \chi^2 + \chi^3 + \cdots \rangle} \cong \frac{1}{\alpha \langle \chi^2 \rangle} \tag{13}$$

In term of power received, the receiver's sensitivity determines the amount of received optical power needed to achieve the required SNR for a given expected communication performance. The signal power received at the communications detector can be expressed as [8]:

$$Received\ Signal, P_{REC} = P_T G_T T_T \tau_{ATM} S G_R \tau_R \tag{14}$$

Where $\tau_T$is the transmitter optical efficiency, τ_{ATM} is the value of the atmospheric transmission at the laser transmitter wavelength, $\mathcal{S}$ is the free-space loss, $G_R$is the receiver antenna gain, and τ_R is the receiver optical efficiency. The transmitter gain, free-space loss, and receiver antenna gain are given by $G_T| = \frac{16}{\theta_T^2}$ (where $\theta_T$is the full transmitting divergence angle), $\mathcal{S} = (\frac{\lambda}{4\pi L})^2$ (where L is the range), and $G_R = (\frac{\pi D}{\lambda})^2$ (where D is the receiver diameter). τ_{ATM} may be written in terms of the atmospheric attenuation factor α given by -10 log $(\tau_{ATM})/L$. The expression received signal can be expressed as:

$$P_{REC}(Received\ Signal) = P_T G_T \tau_T \tau_{ATM} (\frac{\lambda}{4\pi L})^2 (\frac{\pi D}{\lambda})^2 \tau_R \tag{15}$$

Equation (15) can be written as

$$P_{REC} = P_T (\frac{D^2}{\theta_T^2 L^2}) \tau_T 10^{-\alpha L/10)} T_R \tag{16}$$

Normally an optical link typically consists of two transceivers, each made up of one (or more) transmitting laser(s) and receiving photo detector(s). Transmitting optics (telescope, lenses, mirrors) shape the transmitted laser beam which is collected by the receiver optics so that the received signal is focused onto the photo detector. The parameters of the communications are chosen so that sufficient signal from the lasers on one transceiver reaches the photo detector on the other transceiver through the atmosphere to differentiate signal with negligible error.

By given a laser transmitter power P_t, with transmitter divergence of θ_t, receiver telescope area A, transmit and receive optical efficiency τ_{opt}, the achievable data rate R can be obtained from

$$R = \frac{P_t \tau_{opt} \tau_{ATM} A}{\pi(\frac{\theta_t}{2})^2 L^2 E_p N_b} \tag{17}$$

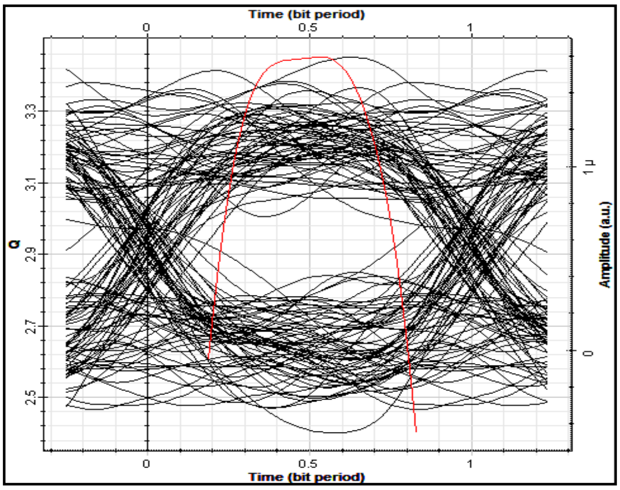
Where $E_p = hc/\lambda$ is the photon energy and N_b is the receiver sensitivity in # photons/bit.

RESULT AND DISCUSSION

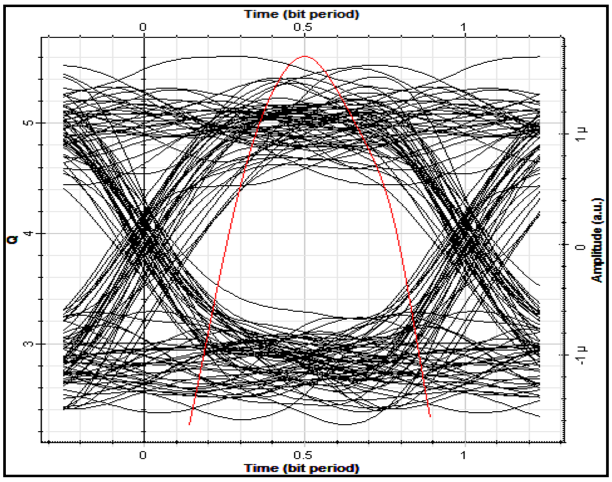
Table 1: Parameters used for simulation analysis

Parameters	Symbol	Value
Wavelength	λ	1550 nm
Data rate	Bit/s	622 Mbps
Diffuser strength	I_c	0.0001
Transmitter aperture diameter	T. D	5 cm
Receiver aperture diameter	R. D	20 cm
Beam divergence	θ	2 mrad

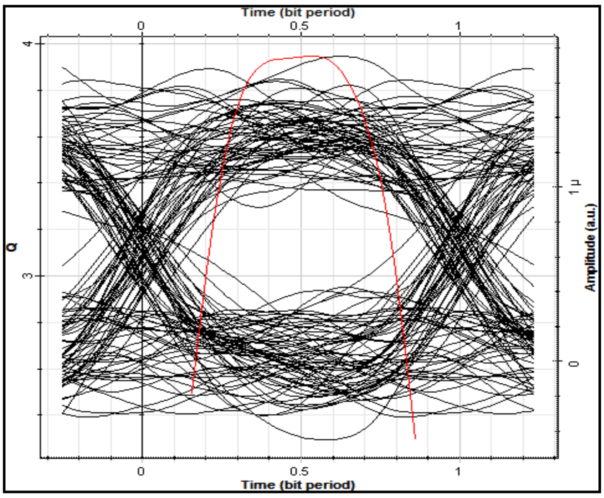
In simulation process, a few parameters need to set up for each technique. Also the parameters need to make sure consistency for both techniques which is OOK and DDM technique. Table 1 shows a few parameters that involved in simulation set up.



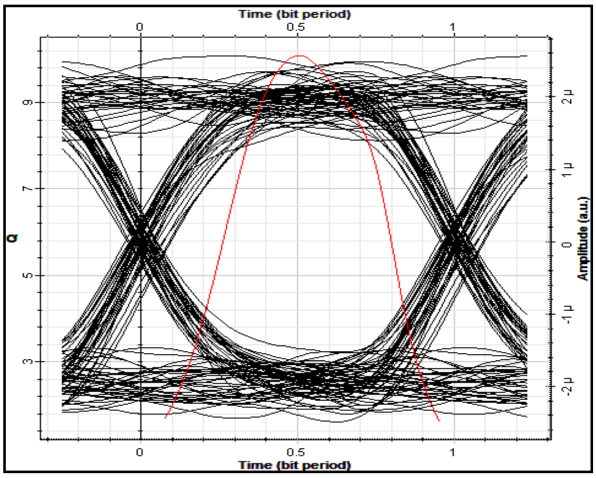
(a)



(b)



(c)



(d)

Figure 2: Diagram for (a) OOK technique for 0 dBm power transmit
(b) DDM technique for 0 dBm power transmit
(c) OOK technique for 5 dBm power transmit
(d) DDM technique for 5 dBm power transmit

By analyzing the display of the eye diagram, the system performances can be evaluated and measured. Figure 2 shows the eye diagram for the DDM and OOK techniques. It is clearly shows the eye diagram of DDM technique having a large eye-opening between the top and bottom level. The height of the eye-opening at specified time integral shows the noise margin or immunity to noise. While, for OOK technique shows the more the eye close the more difficult it is to differentiate between the ones and zeros in the signal. From this observation, DDM technique can successfully eliminate the noise compared to the OOK technique even given the different power transmit.

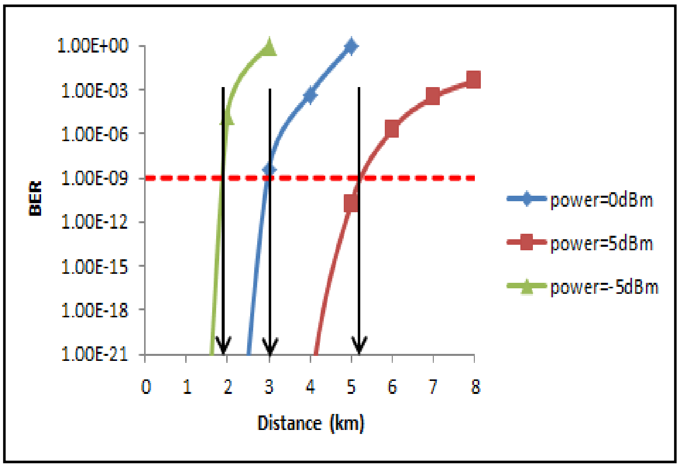


Figure 3: Distance versus BER performance for various power transmit level of DDM

Figure 3 shows the distance versus performance BER for various power transmit level in DDM technique with data rate of 622 Mbps. The distance varies from 0 to 8 km without any amplification requirement for this system. It clearly shown from the figure 3, at performance analysis BER 10^{-9} the DDM modulation technique with 5 dBm power transmit had shown a better performance in comparison with other power transmit level. The 5 dBm power transmit can go up to 5.2 km distance meanwhile for -5 dBm power transmit can only achieved 1.9 km distance and 3 km distance for 0 dBm power transmit.

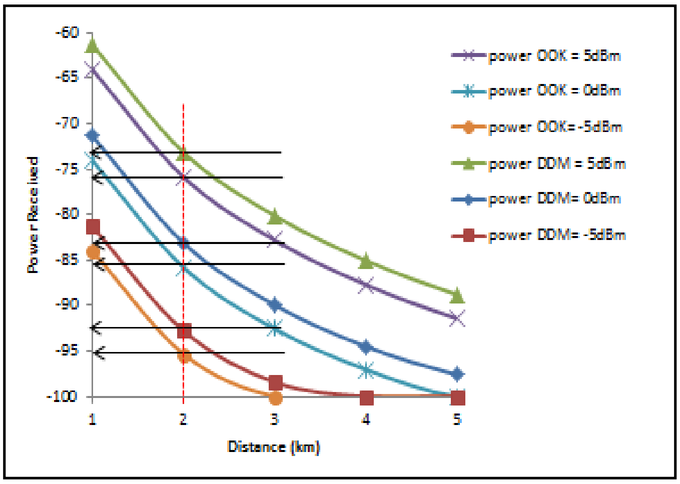


Figure 4: Distance versus Power Received for various power transmit level of OOK and DDM technique

The Figure 4 shows the distance versus power received for modulation technique of OOK and DDM. As an example of 2 km distance propagation, the received power for conventional OOK with 5 dBm power transmit is -76 dBm but in DDM approach with 5 dBm power transmit, the received power is -73 dBm. DDM technique also performs better for 0 dBm and -5 dBm power transmit compare with OOK. It is -83 dBm and -93 dBm power received respectively. Meanwhile for OOK the power received is -86 dBm for 0 dBm power transmit and -95 dBm for -5 dBm power transmit. The inference from figure 4, DDM technique able to produce high power received at the receiver part with good signal detection compared to OOK technique. This shown the improvement of power received approximately about -50 dB increased.

CONCLUSION

In contribution of this paper, the dual diffuser modulation (DDM) improves the performance of the FSO in atmospheric turbulence channel. In our analysis show that DDM can improve the distance performance when adjust the power transmit and -50 dB increased of power received when compared to the OOK technique. Also power levels at the transmitter fit into the range of 0 dBm to 5 dBm where the optimum performance obtained.

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