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A Simplified Experimental Demonstration of a Polarization Division Multiplexed Free Space Optical Communication System

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Abstract

In this paper we present a simplified polarization division multiplexing (PDM) free space optical (FSO) communication system. The system is based on sending two different information signals on two orthogonal polarizations. Results show that a vertically polarized 632 nm light signal suffers a great deal of attenuation in a FSO channel. Results also show that it is possible to generate a polarized light for its orthogonal polarization using polarization rotation, however, the insertion loss is very high. Finally we showed that it is possible to send two different information signals on two orthogonal polarization, however, the detected signals were heavily distorted

Keywords: free space optics (FSO), polarization division multiplexing (PDM), and orthogonal polarizations.

Introduction

Free space optical (FSO) communications is a wireless branch of optical communication that has been understudy for more than 30 years [1]. FSO offers an alternative to RF microwave communication, with the possibility of terabits per second transmission due to the high frequency carrier [1], [2]. The major advantages of FSO communication that it offers unregulated bandwidth in terahertz, and the simple design of the transceiver makes it a very attractive choice for commercial deployment.

An optical signal propagating through the atmosphere is subject to a number of impairments [3]–[8]. Atmospheric attenuation is due to the photon absorption by the molecular constituents in the atmosphere. The optical signal also suffers from scattering due to molecular particles that causes Rayleigh scattering. The random variation of temperature along the pass of optical signal result in varying refractive index, which causes a variation air packets, this phenomena is called turbulence. Thus an optical signal propagating along atmospheric turbulence channel will result a random variation in irradiance and phase. Fig. 1. shows a simplified FSO communication system.

Polarization is one of the most stable parameters of an optical signal traveling in a turbulent environment [9]. Many research work has used polarization shift keying to enhance the performance of FSO communication system [3], [8], [10]–[12]. The use of polarization multiplexing has been considered in wireless optical communications [11], [13], [14]. In this paper we demonstrate a simple polarization division multiplexing (PDM) scheme in wireless indoor environment.

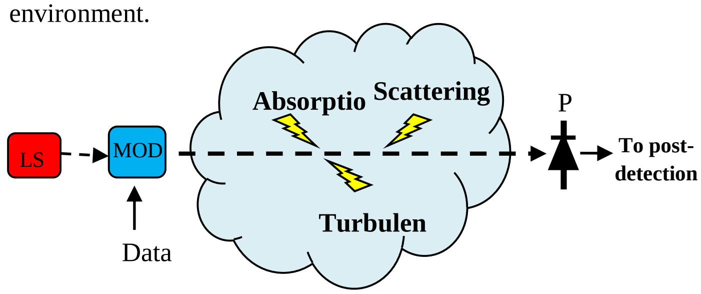


Fig. 1: FSO communication system LS: light source; MOD: modulator; PD: photodetector.

The rest of this paper is organized as follows; section II gives a brief introduction of PDM, section III shows the experimental setup. In section four, we analyze the results and in section V we conclude the paper.

I. Polarization Division Multiplexing (PDM)

The electrical fields of two orthogonal polarizations projected along the x-axis and the y-axis can be given by

$$E_x = Ae^{(j\omega t - kz)} \cdot \vec{x} \tag{1}$$

$$E_y = Ae^{(j\omega t - kz)} \cdot \vec{y} \tag{2}$$

where A is amplitude, ω is the angular of the optical carrier, k is the propagation constant, z is the distance, and x and y are the unit vector for x-axis and y-axis.

If these two polarizations are modulated with information signals $m_1(t)$ and $m_2(t)$, and assuming on off keying (OOK) modulation. The electrical field can be given by:

$$E_x(t) = \sqrt{P/2}\,\cos\left(m_1(t)\right)e^{j\omega t} \tag{3}$$

$$E_y(t) = \sqrt{P/2}\,\sin\left(m_2(t)\right)e^{j\omega t} \tag{4}$$

where P is the average power.

When $E_x(t)$ and $E_y(t)$ enter a turbulence channel the polarization angle is given by:

$$\Phi = \tan^{-1}\left[\frac{E_x(t)}{E_y(t)}\right] \tag{5}$$

At the output of the turbulence region the electrical fields change to $E_{xx}(t)$ and $E_{yy}(t)$, which is due to fluctuation in the refractive index of the FSO channel. Thus this creates a shift in the polarization angle:

$$\Phi + \Delta\Phi = \tan^{-1}\left[\frac{E_{xx}(t)}{E_{yy}(t)}\right] \tag{6}$$

The mean change in the polarization angle is given by [15]:

$$\sqrt{\overline{[\Delta\Phi]^2}} = 2\pi\,\overline{[\Delta n]^2}\,\frac{L}{L_t} \tag{7}$$

where $\overline{[\Delta n]^2}$ is the mean square change in the refractive index and L_t in is the largest inhomogeneities in the channel.

It is worth mentioning that the linearly polarized light suffers more than other forms of polarization in a turbulent medium. This can be solved by using circular polarization in polarization shift keying (PolSK) systems [9].

II. Experimental Setup of a PDM FSO Communication System

In this section we describe the setup for the PDM transmission via using two orthogonal polarization. We performed three experiments:

1. FSO channel attenuation setup:

In the first experiment we tested the reach of our laser light in a free space environment. The setup is shown in Fig. 2.

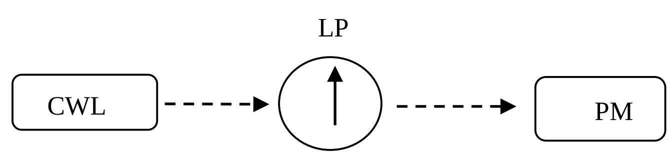
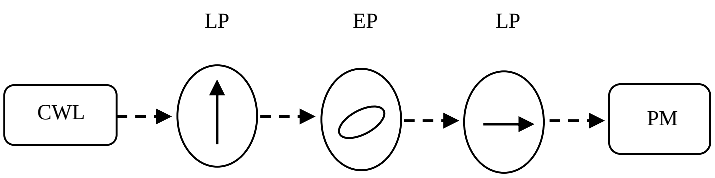


Fig. 2: Setup for distance measurement of FSO channel. CWL: continuous wave laser; LP: linear polarizer; PM: power meter.

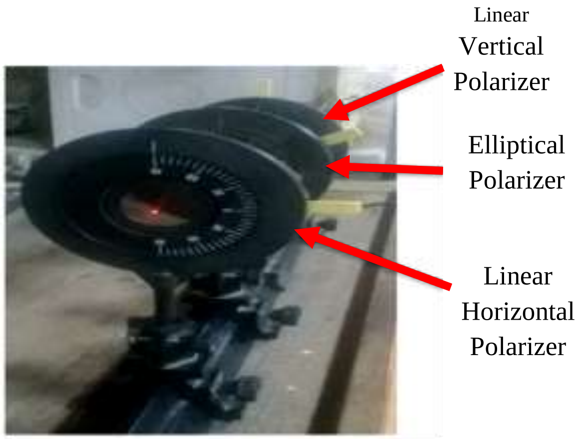
As can be seen in Fig. 2, a 605 nm HeNe laser signal is passed through a linear optical polarizer to insure that the signal is vertically polarized. The optical polarizer has an insertion loss of 3 dB. The distance between the optical polarizer is varied in order to find out the attenuation of the optical signal in FSO environment with respect to distance.

2. Polarization rotation setup:

In our second experiment, in order to generate a horizontal polarization from a vertically polarized HeNe Laser source the setup was made as shown in Fig. 3. The figure also shows that a HeNe laser signal that is passed through a linear polarizer to insure that the light is vertically polarized. The polarized light signal is then fed into elliptical polarizer. The angle of the elliptical polarizer is changed until the maximum horizontal light is detected by the power meter. The third linear polarizer is used to insure that the only horizontal polarization is detected.



(a)

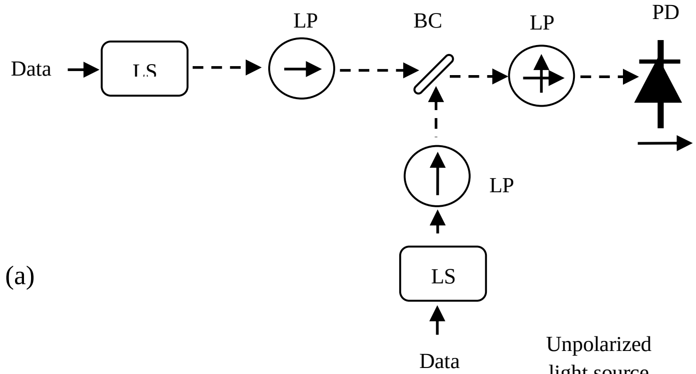


(b)

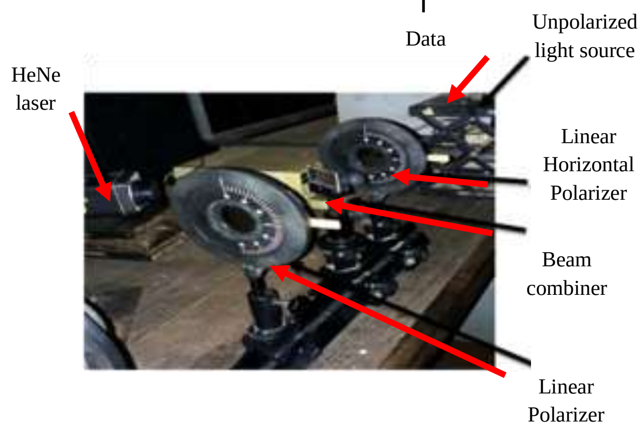
Fig. 3: Setup to generate a horizontal polarization from a vertically polarized light. (a) Block diagram, (b) Experimental setup. CWL: continuous wave laser; LP: liner polarizer; EP: elliptical polarizer; PM: power meter.

3. Polarization multiplexed FSO communication system setup:

In the third experiment we demonstrated that two different information signals can be sent on two orthogonal polarization. The setup for this experiment is shown in Fig. 4.



(a)



(b)

Fig. 4: Setup for PDM in FSO environment.(a) Block diagram; (b) Experimental setup LS: laser source; LP: linear polarizer; BC: beam combiner; PD: photodetector.

Fig. 4 shows the experimental setup for polarization modulated FSO system. Two lasers sources are used in this experiment. The HeNe light source is modulated by low frequency step signal, and then the output signal is fed into a linear vertical polarizer to generate vertically polarized light. The unpolarized laser is modulated by a stream of square waves at frequency of 1 KHz. The modulated signal is the passed through a linear horizontal polarizer to keep the horizontal polarization component only. The two orthogonally polarized signals are then combined using the beam combiner. A linear polarizer is used in order to specify which polarization that we want to detect. Table 1 shows the parameters values that was used in all of our experiments.

Table 1: Parameters for PDM FSO communication system

Component	Value
Lasers wavelength	632.8 nm
Power Meter Responsivity	0.4
Linear Polarizer (0º Angle)	3 dB
Elliptical Polarizer (0º Angle)	3 dB
HeNe 670 nm Source	1 mW
Unpolarized light source	8 mW
Beam combiner (direct beam)	2 dB

III. Results and discussion

1. *FSO channel characteristics results:*

Fig. 5 shows the received power of a HeNE laser signal at distances from 1 to 5 meters at different angles of the linear polarizer. As can be seen for all distances the detected power is at its maximum when the angle is 0º (vertical polarization) and at is minimum value at the angle of 90º (horizontal polarization). The longer the FSO channel the more attenuation the signal suffers. It is clear from the figure the HeNe laser that we used in our experiment is a vertically polarized source.

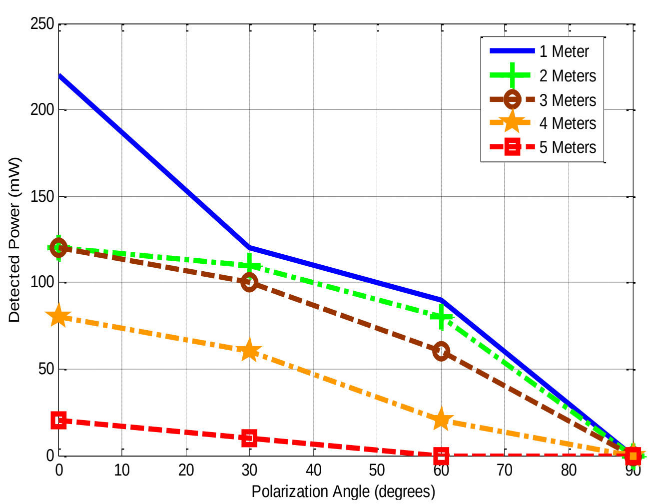


Fig. 5: Received power versus polarization angle for different FSO channel length.

2. *Polarization rotation results:*

Fig. 6 shows the results obtained for the polarization rotation experiment in order to generate a horizontal polarized light signal from a vertically polarized signal. As can be seen from the figure, the maximum detected horizontal polarized signal power was at an angle of 60º of the elliptical polarizer. However, the detected power was only 4.4 µW, which shows that this scheme of rotation is not well suited for FSO environment were the channel loss is very high.

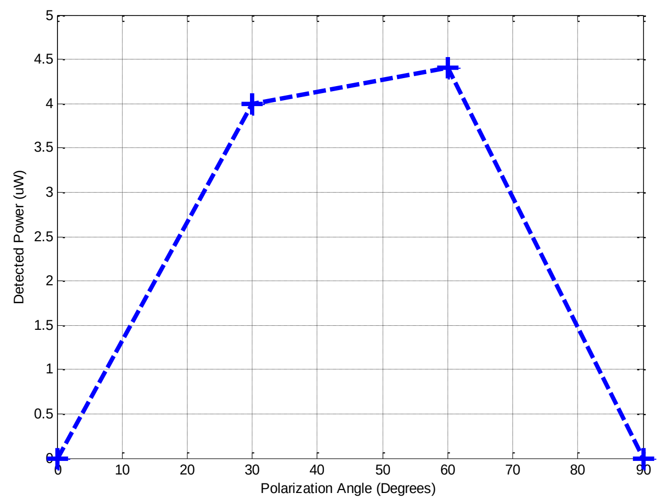


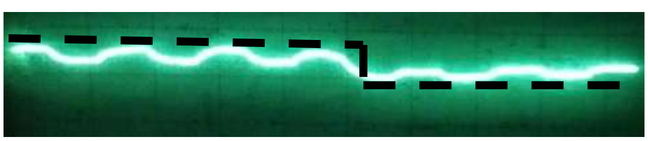
Fig. 6: Received power versus elliptical polarization angle for polarization rotation

3. *Polarization multiplexing results:*

From the previous experiment results it was clear that we cannot use the polarization rotation method to generate the horizontal polarization due to the low power of the signal. To overcome this we used a commercial unpolarized light source. The light source was horizontally polarized by passing it through a linear horizontal polarizer. Fig. 7(a) shows the received signal of horizontal polarization only, the received power was 4 mW. Fig.7(b) shows when both orthogonal polarization are transmitted but only the horizontal polarization was detected. As can be seen the signal suffers from a great deal of distortion due to the presence of vertical polarized signal, however, it possible extract the information signal. Fig. 7(c) shows the detected signal of the vertical polarization, when both orthogonal polarizations are transmitted. The figure shows that signal is very distorted and is very difficult to extract the information from the vertical polarization, and it can be seen clearly the presence of the other information signal. The reason for this is the very large power difference between the two polarized signals. The horizontal polarization power was around 4 mW and the vertical polarization power was 0.2 mW. Another factor that is causing this polarization distortion is the beam combiner. The beam combiner is adding some sort of polarization rotation on each of the two orthogonal polarization, which is resulting in distorted signals at both polarizations. We suspect that many of the imperfection in our results obtained was mainly due to the equipment used in the experiment. much improved results can be achieved if higher quality equipment were used.

(a)

(b)



(c)

Fig. **7**: Received power versus elliptical polarization angle for polarization rotation (a) horizontal polarization without PDM, (b) horizontal polarization signal detected with PDM, (c) vertical polarization with PDM

IV. **Conclusion**

In conclusion, a simplified experimental setup for polarization multiplexed FSO system was implemented. Results show that for 632 nm laser, the signal strength drops dramatically with the channel length. Results also show that polarization rotation can be performed using elliptical polarizer, however, the insertion loss is very high. The experiments also showed that it is possible to transmit two different information signals on two orthogonal polarizations. However, the received signals are heavily distorted due to mainly the interference between the two signals which resulted from the equipment used.

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