

# Design and Analysis of a Novel FSO Transmission Scheme Using Pulse Amplitude Modulation

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**Abstract.** In this letter, a novel scheme which can realize high-speed optical signals transmission and reception by using 4-pulsed amplitude (4-PAM) modulation and demodulation in 10 Gb/s free-space optical (FSO) systems. In this scheme, one PAM sequence generator module, one M-element pulse generator (MPG) module and one Mach-Zehnder Modulator are used to generate 10Gb/s 4-PAM optical signals. And then, the generated optical signal is transmitted in free space. Finally, it is directly detected and demodulated (IM/DD). We measure time-domain sequential waveform curves, optical spectrum curves, eye diagrams, and analyze the reception performance of 10Gb/s 4-PAM signals before and after transmission.

## Introduction

Four level pulsed amplitude modulation (4-PAM) technology has started gaining the research focus really in free-space optical communication environment, because the existing standardized passive optical network (PON) system cannot support the rapid development of today's technology, such as the increasing demand of internet communications, video, cloud computing and other services. Furthermore, this kind of demand will be more and more in the next few years [1]. In order to solve this problem, it is possible to introduce a modulation format with high spectral efficiency which has a higher data transmission rate and a lower communication cost. Several modulation schemes, including pulse-amplitude modulation (PAM), carrierless amplitude and phase modulation (CAP) and orthogonal multi-pulse modulation (OMM) are studied for 100Gb/s transmission rate. In the above-mentioned several modulation schemes, 4-PAM format is the most effective format to solve the problems of short-distance data transmission and interconnection. And because the cost of the transceiver is low especially in the system modules which has high cost requirements such as Ethernet optical modules and PON modules, the 4-PAM modulation format can suit the need of low cost of the optical communication and shows perfect performance [2]. Moreover, the 4-PAM modulation can produce signals with higher spectral efficiency than the non-return-to-zero (NRZ) binary modulation format, and can realize the high-speed transmission of information data with lower bandwidth for FSO applications. With the development of FSO technology, the high-spectrum efficiency transceiver which supports multi-level optical signals has attracted wide attention.

FSO is a good type of broadband access system, the atmosphere is a transmission medium and the optical communication system work in the range of terahertz tube spectral, the system has a few advantages. The beam orientation of ray can provide high power efficiency, and the ability to provide high data rate transmission. Moreover, FSO usually be used in intensity modulation and direct detection system [3], that is simply set up.

Considering the influence of atmospheric turbulence, the Gamma-Gamma channel model can be used to simulate and study. The Gamma-Gamma light intensity flashing model is directly related to the atmospheric characteristics through the double-scale parameter. This model considers light intensity is composed of the multiplication which can accurately describe the fluctuation characteristics of the received light intensity in the case of strong turbulence. Since the

Gamma-Gamma model takes into account the influence of turbulence at each scale, this model can apply weak turbulence area to strong turbulence area [4-8].

In this paper, the 4-PAM optical signal is generated and it is transmitted over Gamma-Gamma channel of FSO and then received. We measure and analyze time-domain sequential waveform curves, optical spectrum curves, and eye-diagrams, and discuss the receiver sensitivity of 10Gb/s 4-PAM signals before and after transmission.

### System model

Fig.1 shows the system set up for the 4-PAM signals transmission. One PAM sequence generator module and the M-element pulse generator (MPG) module is used to generate 10Gb/s 4-PAM electrical signals. The continuous wave laser (CW) transmits the continuous wave signal to MZM. One 4-PAM optical signal is generated by external modulator, and its transmission is in the FSO channel. The variable optical attenuator (VOA) is placed behind the channel to adjust the received optical power. The applied fiber parameter in this work is, fiber dispersion (CD) is 16ps/nm/km, attention is 0.2dB/km, and nonlinear coefficient is  $2.6 \times 10^{-20} \text{ m}^2/\text{W}$ . At the receiver, the noise signal (OBF) with different bandwidth is first generated by using a third-order optical Bessel filter [9]. The received optical signal is then amplified by an erbium-doped fiber amplifier (EDFA) which can compensate for transmission attenuation and detected by the photodetector (PIN) to make sure it complete the conversion of photoelectric. A third-order Bessel low-pass filter (LPF) with the cutoff frequency of 7.5GHz and it can be used to suppress out-bands noise [10].

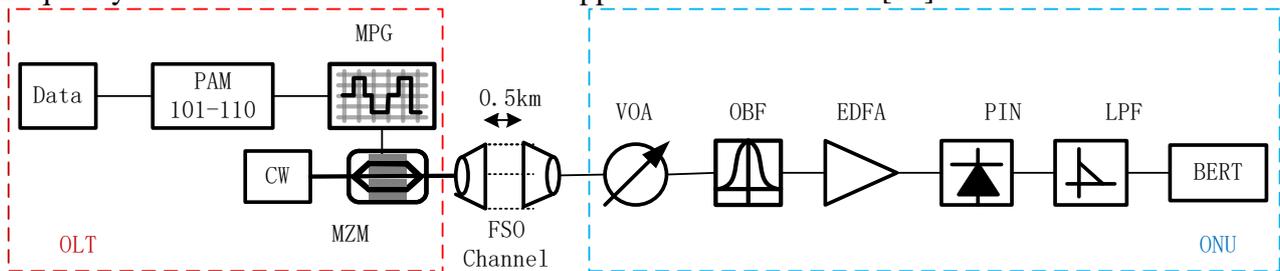


Fig.1. System setup for the 4-PAM signal transmission (CW: Continuous wave; MPG: M-ary pulse generator; FSO: free-space optical; VOA: Variable optical attenuator; OBF: Bessel optical filter; EDFA: Erbium-doped optical fiber amplifier; PIN: Photodetector; MZM: Mach-Zehnder Modulator; LPF: Low pass filter; BERT: Bit error rate tester.)

### Results and Analysis

The performance of the system is evaluated by the time-domain sequential waveform diagrams in our research. The time-domain sequential waveform diagrams of the 4-PAM signals before and after transmission are shown in Fig2.(a) and (b). The 4-PAM optical signal phase diagrams of the transmitted and received can be seen clearly that has the same change curve, and the received optical signal exhibits a slight waveform change.

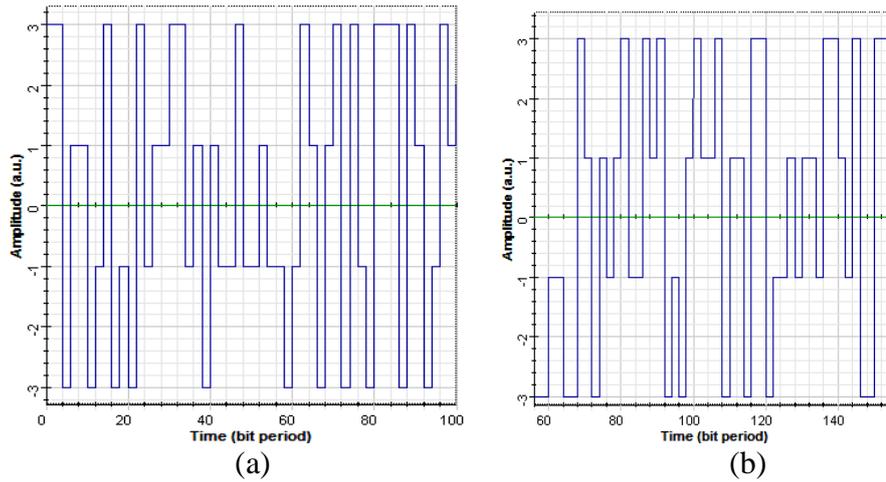


Fig.2. Time-domain sequential waveform diagrams of 4-PAM signals ((a) before and (b) after transmission in free space)

Two optical spectra diagrams of 4-PAM signals which are before and after transmitted are shown in Fig 3.(a) and (b), respectively. Since the EDFA is used to compensate for the transmission attenuation. The peak power of the optical power of the system has almost no loss.

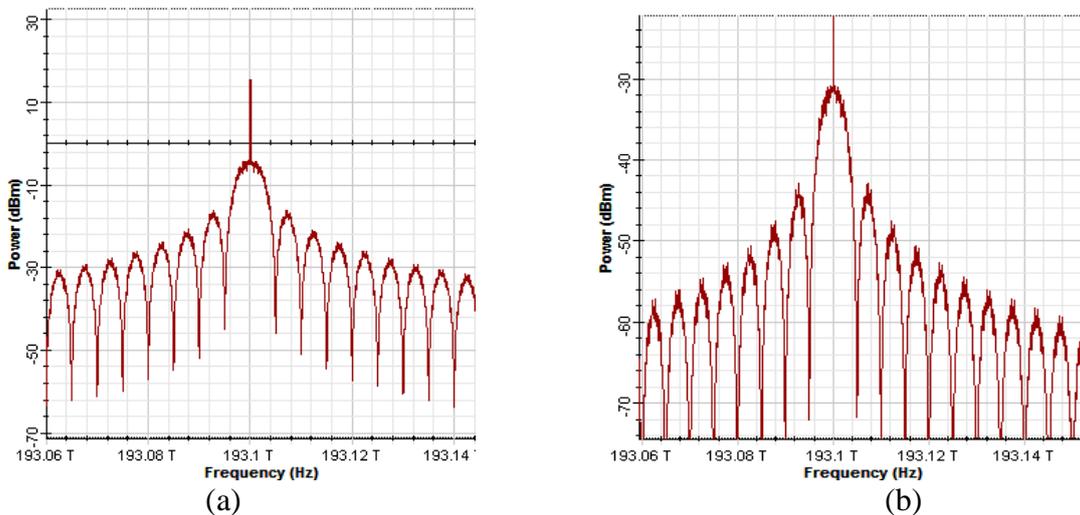


Fig.3. Optical spectra diagrams of 4-PAM signals. (a) before transmission and (b) after transmission.

In this scheme, the detected eye-diagrams before and after transmission are illustrated in Fig.4 (a) and (b), respectively. Although the eyes open clearly, and it is found that slight transmission impairments are introduced while a 4-PAM signal passes through 20 km fiber. These penalty is attributed to the dispersion-induced inter symbol interference.

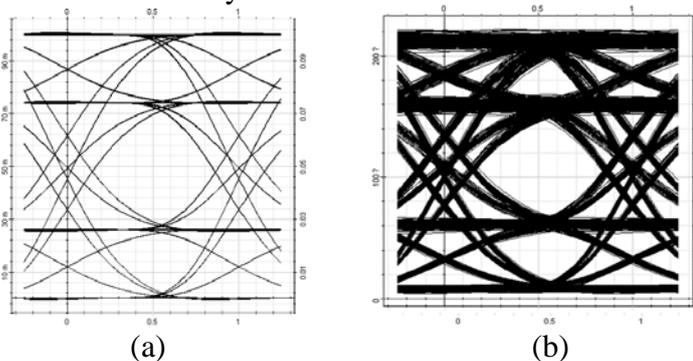


Fig.4. Eye-diagrams of 4-PAM signals before (a) and after (b) transmission

## Conclusion

In this letter, we suppose a novel scheme which can realize high-speed optical signals transmission and reception by using 4-PAM modulation and demodulation in 10Gb/s FSO systems. The received performance of the optical 4-PAM signal transmitted over the Gamma-Gamma channel has also been analyzed. Comparing with the traditional binary modulation format, 4-PAM format has the advantages of lower cost, higher spectrum efficiency, and it will be a potential select for future long distance broadband access.

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## References

- [1] Sotiropoulos, N., Koonen A.M.J. and de Waardt, H: Next-Generation TDM-PON Based on Multilevel Differential Modulation. *IEEE Photonics Technology Letters*, 25, 418-421. (2013)
- [2] Shao, Y., Wang, S.K., Tan, Z.F., Luo, Y.X. and Lai, Y.S: Seamless Integration of RZ-DQPSK-DWDM Optical Links with MISO-OFDM-QPSK System for Fourth Generation Wide-Area Coverage Mobile Communication. *Microwave and Optical Technology Letters*, 56, 797-801. (2014)
- [3] Ghiasi, A., Wang, Z. and Telang, V: Investigation of PAM-4/6/8 Signaling and FEC for 100 Gb/s Serial Transmission (2012)
- [4] Nichol, G. and Fludger, C: Update on Technical Feasibility for PAM Modulation. *IEEE 802.3 NG100GE PMD Study Group* (2012)
- [5] Wei, J.L., Cunningham, D.G., Penty, R.V. and White, I.H: Study of 100 Gigabit Ethernet Using Carrierless Amplitude/Phase Modulation and Optical OFDM. *Journal of Lightwave Technology*, 31, 1367-1373. (2013)
- [6] Olmedo, M.I. Zuo, T.J., Jensen, J.B., Zhong, Q.W., Xu, X.G., Popov, S. and Monroy, I.T: Multiband Carrierless Amplitude Phase Modulation for High Capacity Optical Data Links. *Journal of Lightwave Technology*, 32, 798-804. (2014)
- [7] Ingham, J.D., Penty, R.V. and White, I.H: Orthogonal Multipulse Modulation in Optical Data Communications (2013)
- [8] Sharif, M., Perin, J.K. and Kahn, J.M: Modulation Schemes for Single-Laser 100 Gb/s Links: Single-Carrier. *Journal of Lightwave Technology*, 33, 4268-4277. JLT.2015.2470523. (2015)
- [9] Szczerba, K., Westbergh, P., Karout, J., Gustavsson, J., Haglund, A., Karlsson, M., Andrekson, P., Agrell, E. and Larsson: A. 30 Gbps 4-PAM Transmission over 200 m of MMF Using an 850 nm VCSEL. *Optics Express*, 19, B203-B208. OE.19.00B203. (2011)
- [10] Man, J., Chen, W., Zhang, H., Li, Z.W., Fu, S. and Zeng, L: High Speed Optical Interconnects with PAM 4 Modulation for Short-Reach Applications. *IEEE CPMT Symposium Japan (ICSJ)*, Kyoto, 70-72. ICSJ.2015.7357362 (2015)