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Comparison for 100 Gb/s PDM-DD Short Reach Optical Communication System Transmission Performance with PAM4, CAP16 and DMT

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Abstract: A promising way to significantly meet the demands of short reach systems is polarization division multiplexing with direct detection (PDM-DD). In this paper, we compare three advanced modulation formats performance on PDM-DD system.
OCIS codes: (060.2330) Fiber Optics communications; (060.4080) Modulation; (060.4230) Multiplexing;

1. Introduction

As predicated by CISCO in its recent study, 86% of global internet traffic will be data center (DC) related [1]. These include intra DC transmission typically limited to less than 300m and inter DC transmission which can be up to 20km. Intensity modulation combined with direct detection (IM-DD) systems, which are technologically simple, cost effective and small form-factor, become the most practical solution for short reach optical communication. While standard IM-DD systems support 1 degree of freedom hence 1 dimensional modulation only. For short reach optical communication limited by DD and other low-cost implementation constraints, innovative transceiver configurations and DSP are actively being pursued to exploit such additional degrees of freedom inherent in PDM. The capacity of short reach transmission systems has been increased significantly [2-4]. Another way to increase the capacity is by using advanced modulation formats including pulse amplitude modulation (PAM), carrier-less amplitude and phase modulation (CAP) and discrete multi-tone (DMT) modulation [5,6].

In this paper, we present a detailed comparison on the performance of three advanced modulation formats by using the same PDM-DD system. We focus on realizing a bit rate of 100 Gb/s with commercially available components. The comprehensive simulation results are carried out to evaluate the performance of each modulation format in terms of received optical power (ROP), receiver bandwidth and chromic dispersion (CD). Discussion will be given on the performance of these simulation results.

2. Principles

PDM signals can be described in a vector notation in Stokes space. The transmitted Stokes vector consists of four Stokes parameters which are

$$S_0 = \left|E_{t,x}\right|^2 + \left|E_{t,y}\right|^2, \quad S_1 = \left|E_{t,x}\right|^2 - \left|E_{t,y}\right|^2, \quad S_2 = 2\,\mathrm{Re}\left\{E_{t,x}E_{t,y}^*\right\}, \quad S_3 = 2\,\mathrm{Im}\left\{E_{t,x}E_{t,y}^*\right\} \tag{1}$$

and $S_0 = \sqrt{S_1^2 + S_2^2 + S_3^2}$, where $E_{t,x}$, $E_{t,y}$ denote the transmitter electric fields of X and Y polarization respectively. After fiber transmission, the state of polarization (SOP) of the transmitted signals will be changed randomly. With polarization rotation, the received Stokes vector is given by

$$\begin{bmatrix} S_0' \\ S_1' \\ S_2' \\ S_3' \end{bmatrix} = \begin{bmatrix} \left|E_{r,x}\right|^2 + \left|E_{r,y}\right|^2 \\ \left|E_{r,x}\right|^2 - \left|E_{r,y}\right|^2 \\ 2\,\mathrm{Re}\left\{E_{r,x}E_{r,y}^*\right\} \\ 2\,\mathrm{Im}\left\{E_{r,x}E_{r,y}^*\right\} \end{bmatrix} = \underbrace{\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos 2\theta & -\sin 2\theta\cos\varepsilon & \sin 2\theta\sin\varepsilon \\ 0 & \sin 2\theta & \cos 2\theta\cos\varepsilon & -\cos 2\theta\sin\varepsilon \\ 0 & 0 & \sin\varepsilon & \cos\varepsilon \end{bmatrix}}_{\text{SOP Rotation matrix in Stokes space}} \cdot \begin{bmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{bmatrix} \tag{2}$$

where θ and ε denote the random polar angle and azimuth angle respectively.

3. Simulation and results

We have proposed the PDM-DD scheme in [3]. Here, the transmitter is used two externally modulated laser (EMLs) to modulate two intensity data streams onto two orthogonal polarizations as depicted in Fig. 1. At the receiver, the PDM signals are divided into two different SOPs with a fixed π/4 polar angle difference and each of SOP signals is then split into two arbitrary but orthogonal polarization components by a polarization beam splitter (PBS). The outputs are detected using four single-ended avalanche photodiodes (APDs).

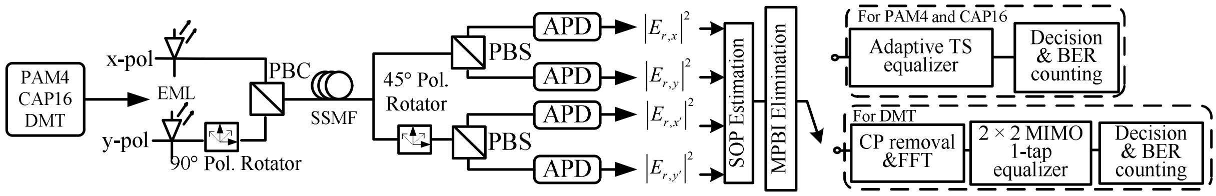

Fig.1. Simulation setup and DSP block diagrams for of 100 Gb/s PDM-DD system. PBC: polarization beam combiner; SSMF: standard single mode fiber; TS: Training symbols; CP: Cyclic Prefix; MPBI: mixed polarization beat interference.

After polarization recovery, the two orthogonal signals $|E_{r,x}|^2, |E_{r,y}|^2$ can be obtained [3]. This is followed by ISI compensation. Note that single-carrier PAM4/CAP16 or multi-carrier DMT signals are equally applicable in this system as long as appropriate DSP blocks are implemented. For single-carrier signals, time-domain equalization can be used, the LMS algorithm can be adopted to update the filter taps initially with training mode and switching to directed decision mode upon convergence. For DMT signals, frequency-domain one-tap equalizers are used after cyclic prefix removal and FFT operation. Note that this scheme uses four APDs which cannot resist the CD influence.

(i)

System Parameter	Values
Wavelength	1310/1550 nm
DAC/ADC resolution	8bit
Modulation Format	PAM4/CAP16/DMT
Baud Rate	50G/25G/-
Tx bandwidth (3dB)	18GHz
Laser Linewidth	10MHz
Laser RIN	-160dB/Hz
Fiber Length	20km
CD	17e-6s/m^2

(ii)

APD Parameter	Values	
Type	25 GHz APD	20 GHz APD
3dB-bandwidth	18 GHz	12.5 GHz
responsibility	0.76A/W	0.9A/W
Dark Current Multiplied	100nA	10nA
Dark Current Non Multiplied	20nA	0
Avalanche Multiplication	5	10
Lionization Coefficient	0.3	0.2
PD thermal noise	20pA/Hz$^{0.5}$	10pA/Hz$^{0.5}$

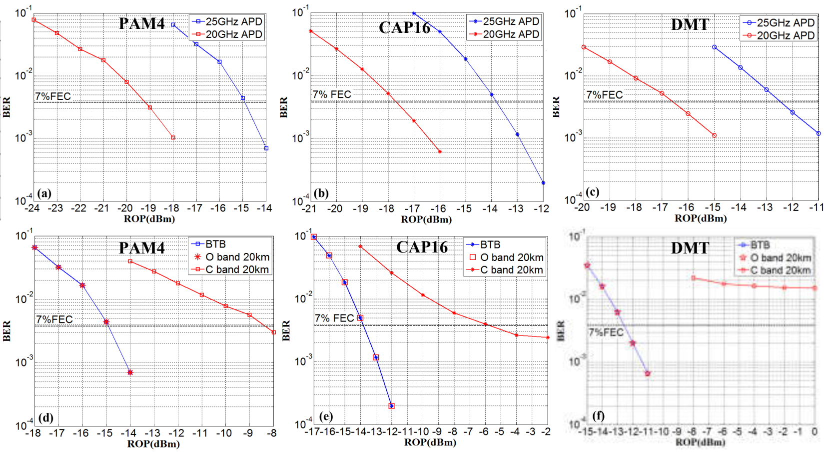

Fig.2. (i) Key parameters for 100 Gb/s PDM-DD system. (ii) Key parameters for receiver APD. (a)-(f) Simulation results 100 Gb/s PDM-DD system with different modulation formats.

Fig.2 (i) shows the key parameters for 100 Gb/s PDM-DD simulation system. For the different bandwidth commercial APDs, we give the key parameters in (ii). (a)-(c) show the BER as a function of ROP for 100 Gb/s PAM4, CAP16 and DMT with different type APDs. Receiver sensitivities of -14.9/-19.2dBm, -13.9/17.8dBm and -12.8/16.8dBm were obtained for PAM4, CAP16 and DMT at a BER of 3.8e-3 for 25/20GHz APD, respectively. Due to the lower noise figure of 20GHz APD, it has a better performance. (d)-(f) show the BER as a function of ROP for 100 Gb/s PAM4, CAP16 and DMT PDM-DD system transmission over 20 km with different wavelength by using 25GHz APD. Receiver sensitivities of -14.9dBm, -13.9dBm and -12.8dBm were obtained for PAM4, CAP16 and DMT at a BER of 3.8e-3 for BTB and O band transmission, respectively. Receiver sensitivities of -8.5dBm and -6dBm were obtained for PAM4, CAP16 at a BER of 3.8e-3 for C band transmission, respectively. It can be seen that PAM4 outperforms CAP-16. DMT performance is the worst among the three modulation formats. This is due to the high PAPR of DMT signal, limited 8bit resolution of DAC/ADC and the nonlinearity of EML.

Acknowledgments

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