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Effects of Polarization Tracker on 80 and 112 Gb/s PDM-DQPSK with Spectral Amplitude Code Labels

Aboagye Adjaye Isaac, Fushen Chen, Yongsheng Cao, Deynu Faith Kwaku

***Abstract*—We investigate the effects of polarization tracker on 80 and 112 Gb/s polarization division multiplexing (PDM)-differential quadrature phase shift keying (DQPSK) optical label switching system with spectral amplitude code (SAC) labels in simulation. The label and payload signal performances are assessed by the bit error rate (BER) as function of eye opening factor (EOF), received optical power (ROP) and optical signal to noise ratio (OSNR). For BTB, 138 km and 120 km transmission for 80 and 112 Gb/s respectively, the label EOFs are 0.94 and 0.86 for 80Gb/s, 0.93 and 0.90 for 112Gb/s. The payload's OSNR for BTB without/with label and after 138 km and 120 km respectively are 22.8, 23.0 and 25.6 dB for 80Gb/s and 22.1 , 22.3 and 23.2 dB for 112 Gb/s at a BER of 10^{-9}. The payload's ROP for BTB without/with label and after 138 and 120 km respectively are -15.3, -15.1 and -12.5 dBm for 80 Gb/s and -14.5, -14.4 and -13.3 dBm for 112 Gb/s at a BER of 10^{-9}. A 1,260 and 900 km long haul transmission of the payload is achieved for 80 Gb/s and 112 Gb/s respectively using forward error correction (FEC) at a BER of 10^{-3}.**

***Index Terms*—Coherent detection, Optical label switching (OLS), Polarization mode dispersion (PMD), Polarization tracking, Spectral amplitude code (SAC).**

I. INTRODUCTION

As the demand for high transmission speed and capacity is growing in optical transmission systems, it has become necessary to increase the spectral efficiency by employing different transmission techniques. PDM serves to double the data rate. Combined with DQPSK, four bits are transmitted per symbol. The utilization of PDM permits the increase of transmission limit as various signals can be transmitted over orthogonal conditions of polarization of the same light [1]. Optical label switching (OLS) technique is considered a way to increase transmission speed in optical networks [2]. Polarization in optical fiber can sometimes vary quite fast and the communication systems should be able to track this. Polarization mode dispersion in high data rate systems can significantly diminish the data-carrying capacity of a telecommunications network.

Optical polarization tracking is independent of the transmission information rate. The principle test of this configuration is to give an exact and quick polarization tracking. Recent executions have demonstrated automatic tracking at low speed or without specification of the speed [3], [4]. A key difficulty with polarization mode dispersion (PMD) is that it is a random phenomenon. The penalties it produces change randomly over distance and time as the ambient temperature and other environmental parameters vary. The polarization tracker restores the state of polarization (SOP) of the signal affected by polarization-mode dispersion.

In this paper, we implement a high-speed tracking system for payloads (80 and 112 Gb/s PDM-DQPSK) with 156 Mb/s SAC labels in simulation. We demonstrate stable transmission over a fiber link using polarization tracker to restore the SOP of the input signal as close as possible to the SOP of the reference signal. This will mitigate the polarization mode dispersion (PMD) impairement. We enhance the parameters with a specific end goal; to get great transmission execution for both the payload and label. Coherent detection is applied to intercept the SAC label. The high speed payload is directly detected [5]-[8], which get rid of complicated digital signal processing (DSP) procedure [9], [10].

The rest of the paper is organized as follows; Section 2 shows the operational principles of our proposed coherent detection. The simulation setup of SAC labelling scheme for 80 and 112 Gb/s PDM-DQPSK SAC label system with polarization tracker is presented in section 3. In section 4, we assess the polarization of optical signal. Section 5 shows the configuration of the proposed polarization tracking. In section 6, the simulation results are presented and analyzed. In section 7, we conclude the paper.

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II. FREQUENCY-SWEPT COHERENT DETECTION

In this paper, we apply a frequency swept coherent detection as a way of recognizing SAC labels which has been proposed in our previous paper "100 Gb/s PDM-DQPSK Optical Label Switching System with Spectral Amplitude Code Labels"[11]. The structure of a frequency swept coherent detection plan of SAC label is shown in Fig. 2. The SAC Label is shown in Fig. 2 (a) which has 4 bits code of "1010" in wavelength domain. Fig. 2 (b) shows the frequency-swept local oscillator (LO) whose swept frequency covers the entire SAC label's frequencies. The SAC label and LO are combined by a 3 dB coupler and the hybrid signal is shown in Fig. 2 (c).

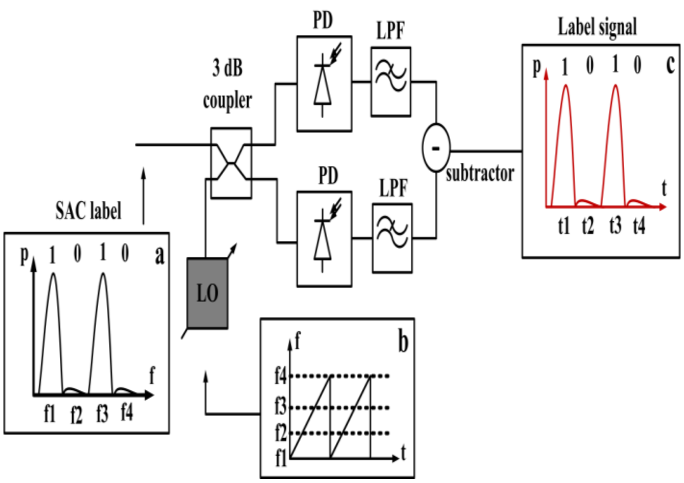

Fig 1 Frequency-swept coherent detection of SAC label: (a) Wavelength domain, (b) Frequency-swept Local Oscillator, (c) Label signal in time domain.

III. MODEL SETUP

The system setup of the 80 and 112 Gb/s PDM-DQPSK SAC transmission system is executed using VPI Transmission Maker 8.3. As shown in Fig. 3, continuous wave (CW) laser at 1552.60 nm and 10 MHz linewidth is considered as source. Two orthogonal polarization channels are generated by one distributed feedback (DFB) laser source for each setup. A 20 and 28 Gbaud DQPSK signal at 1552.60 nm is split by a polarization beam splitter (PBS) into two beams. Polarization beam combiner (PBC) is employed to combine the two orthogonal polarization signals into one beam of 80 and 112 Gb/s PDM-DQPSK payload respectively for each setup. The SAC label generation unit is made up of a laser, an optical switch and a pseudo random binary sequence (PRBS) generator. Four DFB laser array and a label encoder are applied, and at a label rate of 156 Mb/s. The chosen label laser wavelengths are at 1552.92, 1552.96, 1553.00 and 1553.04 nm respectively which are independent of the laser linewidth used for the generation of the payload signal. By adding the payload and label, we get an optical packet of 80 and 112 Gb/s PDM-DQPSK payload and 156 Mb/s four-code SAC label respectively for each setup. A standard single mode fiber (SSMF) and dispersion compensation fiber (DCF) are used as the transmission fiber for each setup.

A polarization tracker is installed in each setup to mitigate the polarization mode dispersion (PMD) impairment. After polarization tracker, the packet is split to two branches by a 3 dB coupler and fed into both payload and label receivers to demodulate payload and label respectively. The payload is determined using direct detection. For the label, a frequency swept laser is simulated by using an optical frequency modulator for each setup with a range of 1552.91 to 1553.05 nm, in order to cover all the label available frequencies for each setup. The SAC labels are consolidated with the local oscillator (LO) by a 3 dB coupler. The electrical label signal is filtered by a 100 MHz for 80 Gb/s and 150 MHz for 112Gb/s dual-low-pass filter (LPF) and the original SAC label obtained.

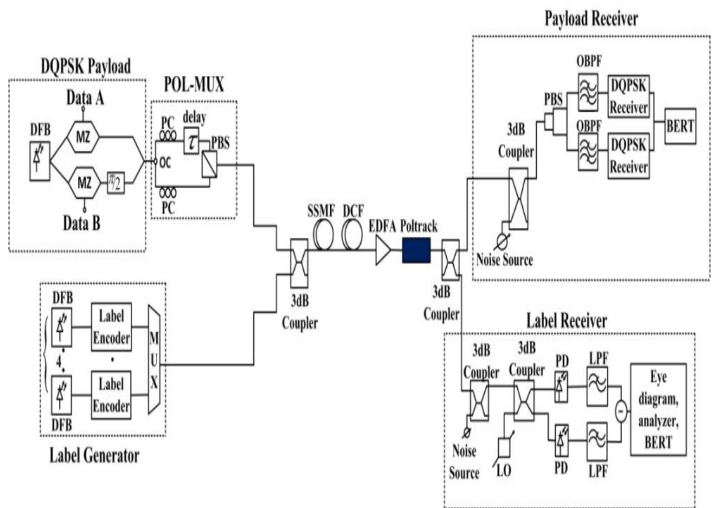

Fig 2 Setup of 80 and 112 Gb/s PDM-DQPSK SAC label system with a polarization tracker.

IV. POLARIATION OF OPTICAL SIGNAL

The polarization of an optical signal can be described in a vector notation by separately describing the electric field vector of the x and y components,

$$\begin{pmatrix} E_x \\ Ey \end{pmatrix} = \begin{pmatrix} \sqrt{P_x}\exp\left(j\left[\omega_0 t + \varphi_x(t)\right]\right) \\ \sqrt{P_y}\exp\left(j\left[\omega_0 t + \varphi_y(t)\right]\right) \end{pmatrix}. \qquad (1)$$

The SOP of an optical signal can be described using the vector notation of the complex envelope,

$$\begin{pmatrix} \sqrt{P_x}\exp\left(j\varphi_x\right) \\ \sqrt{P_y}\exp\left(j\varphi_y\right) \end{pmatrix} = \left(\sqrt{P_x+P_y}\exp\left(j\phi_x\right)\right)\begin{pmatrix} \cos\psi \\ \exp\left(j\left|\phi_x-\phi_y\right|\right)\sin\psi \end{pmatrix}, \quad (2)$$

Where ψ is defined such that $\tan\psi = \sqrt{P_x}/\sqrt{P_y}$. The Stokes vector consists of four stokes parameters,

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$$\vec{S} = \left[S_0 \ S_1 \ S_2 \ S_3 \ \right]^T . \tag{3}$$

The degree of polarization (DOP) defines the distance from $\vec{S}$ to the center of the pointcare sphere. Expressed in terms of the Stokes parameter, the DOP is equal to,

$$DOP = \frac{\sqrt{S_1^2 + S_2^2 + S_3^3}}{S_0} \tag{4}$$

V. CONFIGURATION OF PROPOSED POLARIATION TRACKING

The polarization tracker accepts the Input signal after passing through the fiber link (SSMF) with randomly varied PMD as shown in Fig. 3 (a) and then proceeds to the polarization unit as shown in Fig. 3 (b).

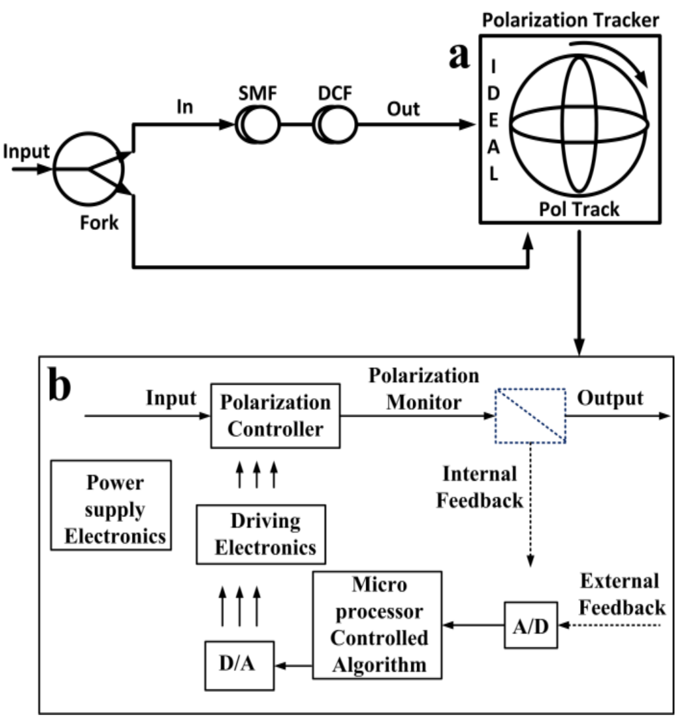

Fig 3 Polarization tracking function diagram.

The polarization unit consists of the polarization control unit, PMD monitoring unit, and the control algorithm unit. The compensation unit is composed of a polarization controller whose function is to transform the state of polarization (SOP) of the input optical wave into output state, and a differential group delay line with the purpose of eliminating the DGD of the input optical signals. We used DOP as the feedback signal in the PMD monitoring unit. The polarimeter detects the DOP of the signal to indicate the PMD effect. The logic control unit adjusts the voltages algorithm 0~5V according to the DOP feedback signals. The polarization tracker automatically maximizes DOP to achieve PMD compensation. It also adjusts the state SOP towards a reference SOP. The execution time of one control iteration is about 5 μs. The reference signal is taken at the point preceding this fiber link. The error signal from the polarization monitor is fed back to the polarization controller to maintain a linear SOP at the output.

VI. ANALYSIS AND RESULTS OF SYSTEM

To achieve good transmission performance of the system, a distributed feedback laser (DFB) with a linewidth value of 10 MHz is used throughout the simulation. A frequency spacing of 40 GHz is chosen between the payload and the labels while a frequency spacing of 5 GHz is chosen between labels. 5 MHz label optical source linewidth and 100 kHz local oscillator (LO) linewidth are considered as the typical parameters in the simulation.

Transmission performance of the payload is assessed in our simulation. The eye open factor (EOF) of the back-to-back (BTB) is better opened than transmission after 138 km for 80 Gb/s and 120km for 112Gb/s respectively. For BTB, the labels EOFs are 0.94 and 0.93 for 80 and 112 Gb/s respectively whereas the label EOF after 138 km is 0.86 for 80 Gb/s and after 120 km is 0.90 for 112 Gb/s at a BER of 10^{-9}. The transmission penalty for BTB with labels is compared to BTB without labels while the penalties for 138 km and 120 km are compared to BTB with labels for 80 and 112 Gb/s respectively. This is shown in Tables I and II below:

For 80 Gb/s, the received power and OSNR values for BTB without label are -15.3 dBm and 22.8 dB while the BTB with label are -15.1 dBm and 23.0 dB respectively. There is a penalty of 0.2 and 0.2 dB respectively. After 138 km, the received power value is -12.5 dBm and OSNR value is 25.6 dB which results in a penalty of 2.6 and 2.6dB respectively.

TABLE I
TRANSMISSION PERFORMANCE AND PENALTY FOR ROP AND OSNR FOR 80 Gb/s AT A BER OF 10^{-9}

Transmission	ROP (dBm)		OSNR (dB)	
	Value	Penalty	Value	Penalty
BTB (w/o label)	-15.3		22.8	
BTB (with label)	-15.1	0.2	23.0	0.2
60 km	-14.8	0.3	23.4	0.4
90 km	-14.3	0.8	23.8	0.8
120 km	-13.4	1.7	24.7	1.7
138 km	-12.5	2.6	25.6	2.6

For 112 Gb/s, the received power and OSNR values for BTB without label are -14.5 dBm and 22.1 dB while the BTB with label are -14.4 dBm and 22.3 dB respectively. This results in a penalty of 0.1 and 0.2 dB respectively. After 120 km, the received power value is -13.3 dBm and OSNR value is 23.2 dB which resulted in a penalty of 1.1 and 0.9 dB respectively.

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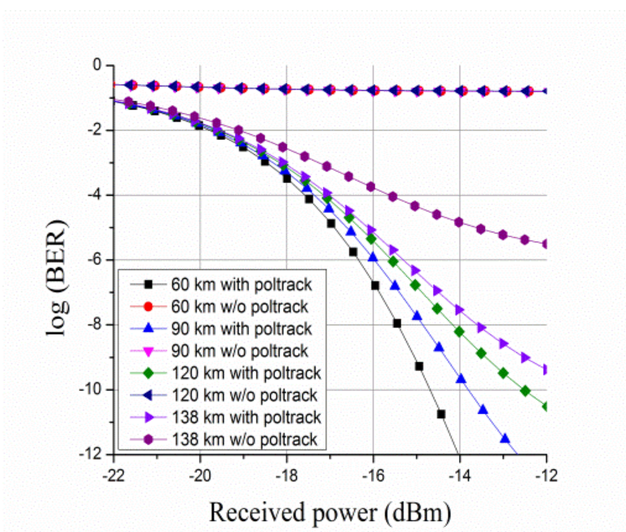
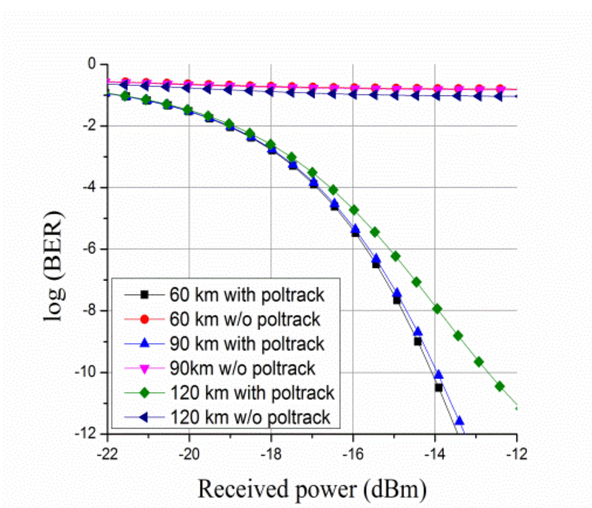
TABLE II
TRANSMISSION PERFORMANCE AND PENALTY FOR ROP AND OSNR FOR 112 Gb/s AT A BER OF 10^{-9}

Transmission	ROP (dBm)		OSNR (dB)	
	Value	Penalty	Value	Penalty
BTB (w/o label)	-14.5		22.1	
BTB (with label)	-14.4	0.1	22.3	0.2
60 km	-14.1	0.3	22.6	0.3
90 km	-14.0	0.4	22.9	0.6
120 km	-13.3	1.1	23.2	0.9

PMD produces a polarization state that changes arbitrarily. This makes it hard for the signal to be demultiplexed. The polarization tracker installed will repair the PMD impairment. Fig. 4 shows transmission with and without polarization tracker at distances of 60, 90, 120 and 138 km for 80 Gb/s and 60, 90 and 120 km for 112 Gb/s). The received power and OSNR at a BER of 10^{-9} are assessed.

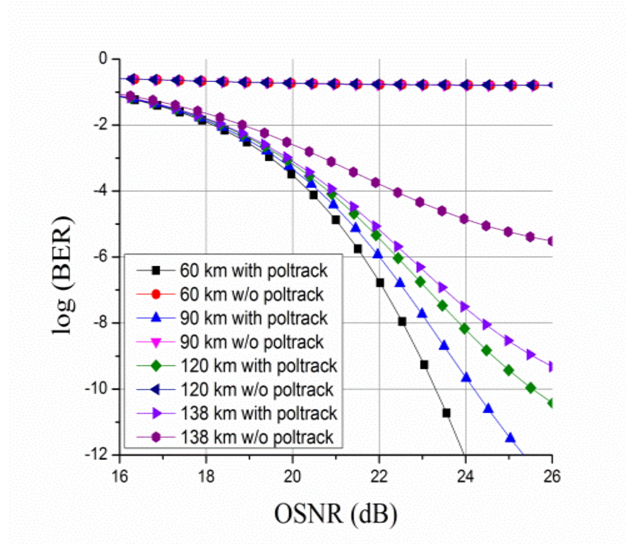


(a)

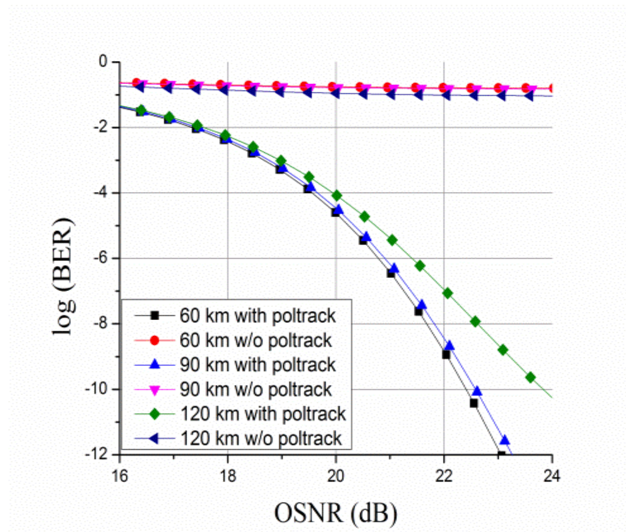


(b)

Fig 4 Effects of polarization tracker and PMD: BER vs ROP for (a) 80 Gb/s and (b) 112Gb/s



(a)



(b)

Fig 4 Effects of polarization tracker and PMD: BER vs OSNR for (a) 80 Gb/s and (b) 112Gb/s

As observed from Fig. 4 (a) and (b), without the polarization tracker, the signals cannot be demodulated due to PMD impairment.

We examined and studied long haul transmission with and without polarization tracker by creating loops to study the performance of the system. A loop consisted of a standard single mode fiber (SSMF) of length 75 km and a dispersion compensation fiber (DCF) of length 15 km adding up to a total length of 90 km per loop and an EDFA of 15 dB for 80 Gb/s transmission and 20 dB for 112 Gb/s transmission. Using BER of 10^{-3} and forward error correction (FEC), a transmission distance of 1,260 km and 900 km are achieved for 80 and 112 Gb/s respectively. Fig. 5 shows transmission with and without polarization tracker for ROP and OSNR using FEC at a BER of 10^{-3}.

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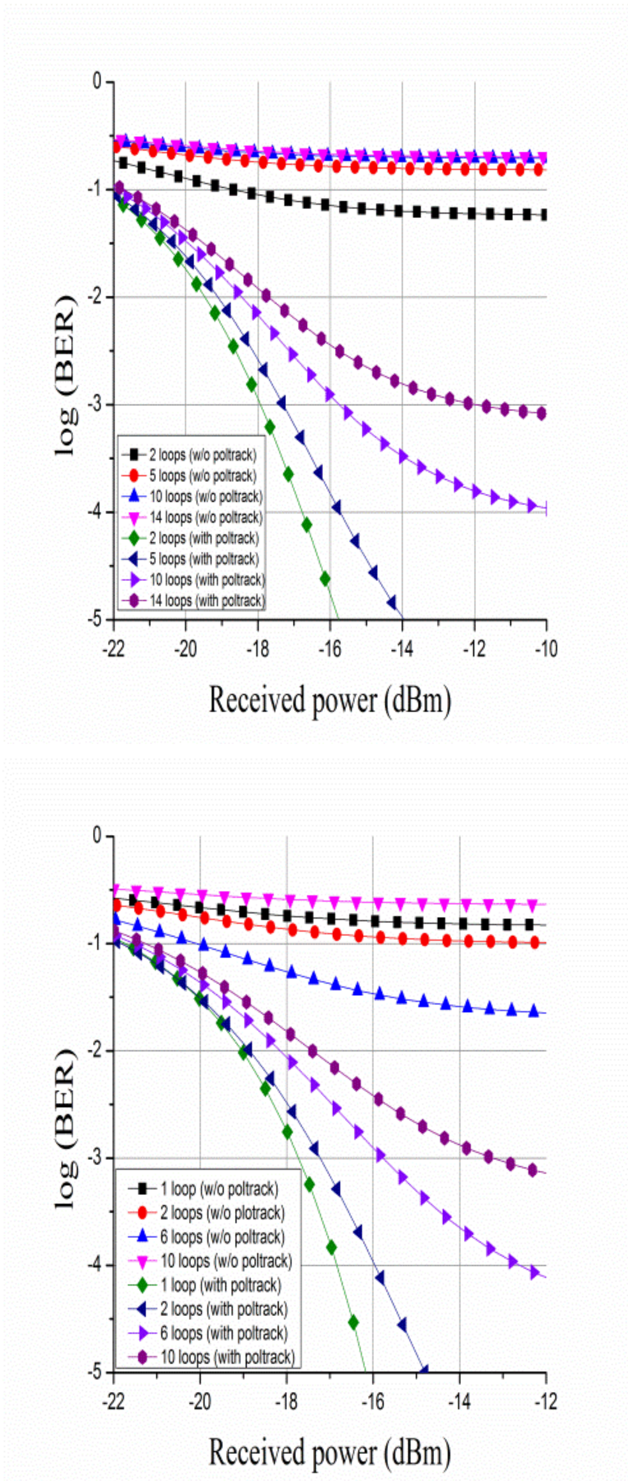
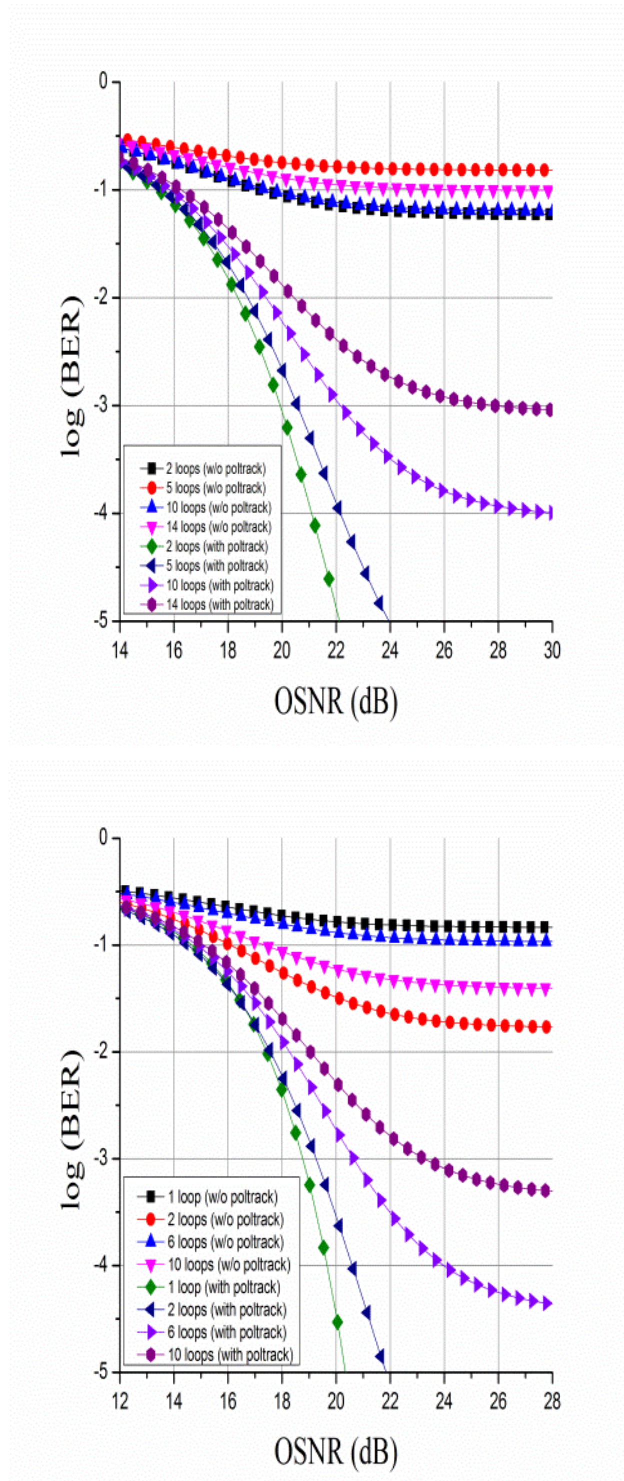


(a)

(b)

Fig 5 Loops with and without poltrack using FEC at a BER of 10^{-3}: ROP for (a) 80 Gb/s and (b) 112 Gb/s.



(a)

(b)

Fig 5 Loops with and without poltrack using FEC at a BER of 10^{-3}: OSNR for (a) 80 Gb/s and (b) 112 Gb/s.

As observed from Fig. 5 (a) and (b), without the polarization tracker, the signals cannot be demodulated due to PMD impairment. PMD weakness may cause some ROP and OSNR penalty. Fig. 6 shows long haul transmission using polarization tracker and FEC at a BER of 10^{-3}.

Tables III and IV show the results obtained for ROP and OSNR after 14 loops for 80Gb/s and 10 loops 112 Gb/s.

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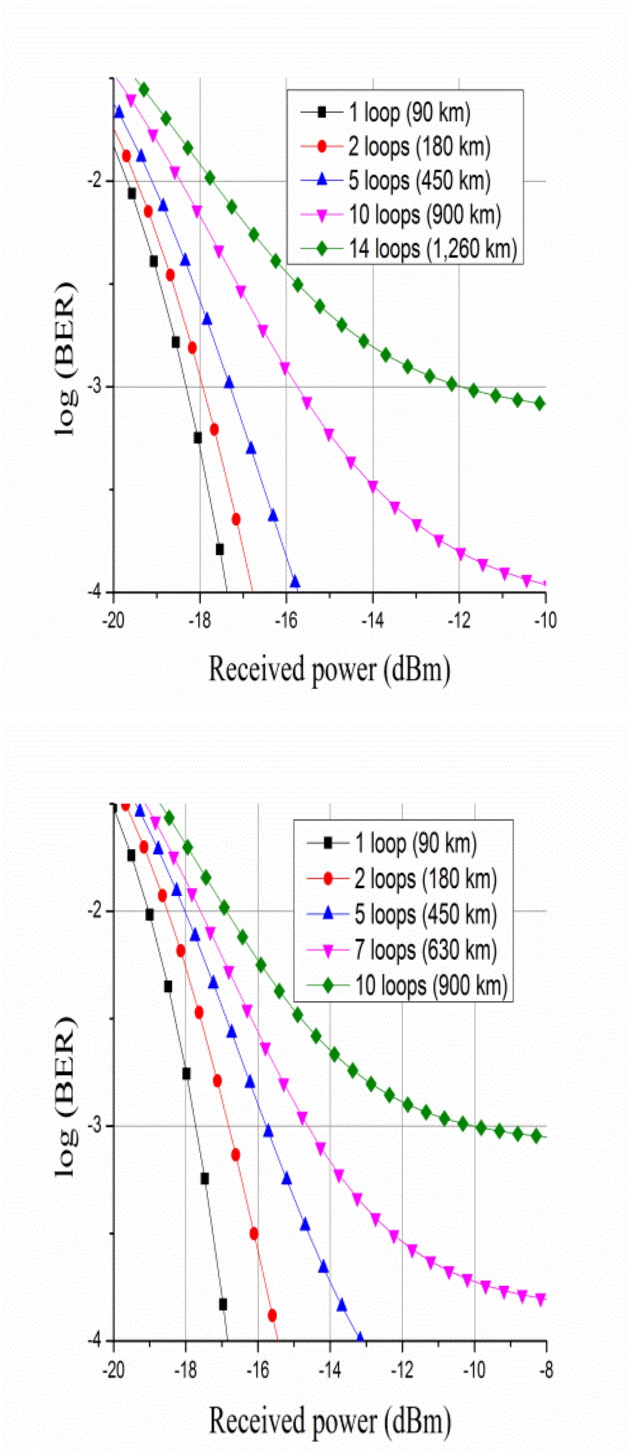
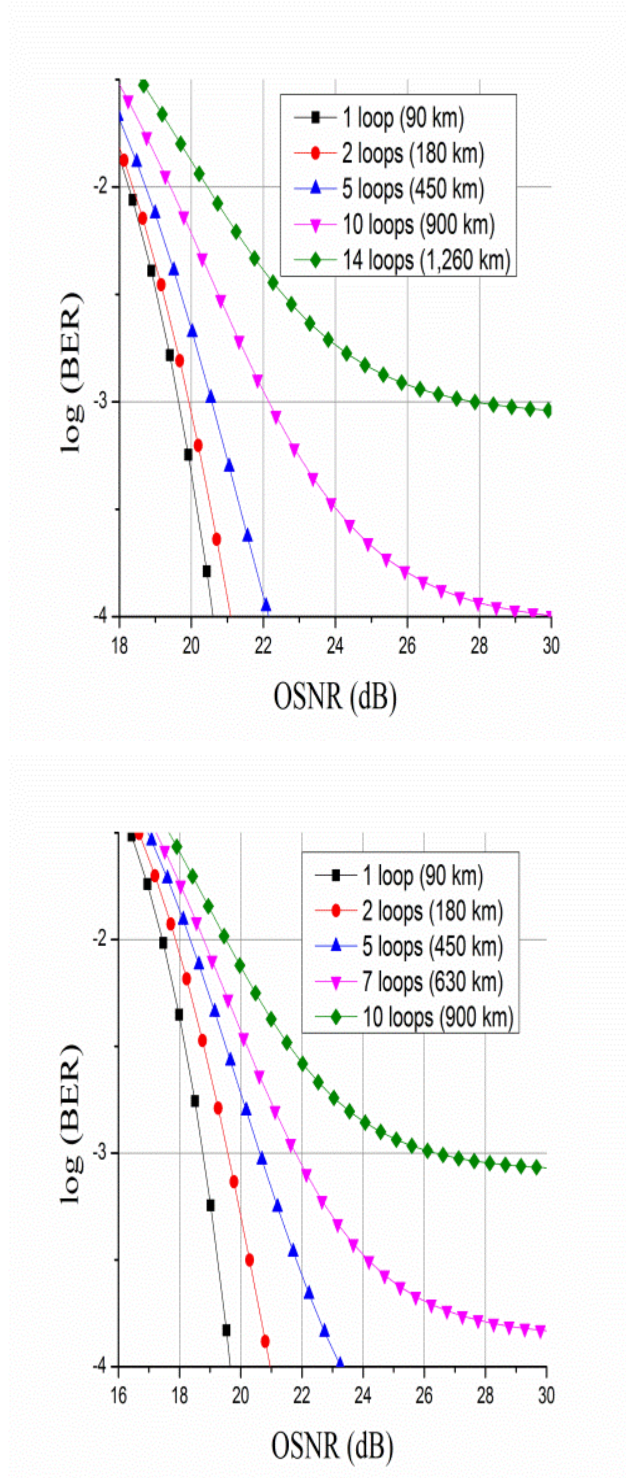


(a)

(b)

Fig 6 Long haul transmission at a BER of 10^{-3} using FEC: BER vs ROP for (a) 80 Gb/s (b) 112Gb/s.



(a)

(b)

Fig 6 Long haul transmission at a BER of 10^{-3} using FEC: BER vs OSNR for (a) 80 Gb/s (b) 112Gb/s.

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TABLE III
LONG HAUL TRANSMISSION FOR 80 Gb/s USING BIT ERROR RATE (BER) OF 10^{-3} AND FORWARD ERROR CORRECTION (FEC).

Distance (km)	BER	80 Gb/S	
		ROP (dBm)	OSNR (dB)
90 (1 loop)	10^{-3}	-18.31	19.66
180 (2 loops)	10^{-3}	-17.92	19.95
450 (5 loops)	10^{-3}	-17. 28	20.60
900 (10 loops)	10^{-3}	-15.73	22.18
1,260 (14 loop)	10^{-3}	-11.93	27.89

TABLE IV
LONG HAUL TRANSMISSION FOR 112 Gb/s USING BIT ERROR RATE (BER) OF 10^{-3} AND FORWARD ERROR CORRECTION (FEC).

Distance (km)	BER	80 Gb/S	
		ROP (dBm)	OSNR (dB)
90 (1 loop)	10^{-3}	-17.73	18.78
180 (2 loops)	10^{-3}	-16.79	19.59
450 (5 loops)	10^{-3}	-15.78	20.64
630 (7 loops)	10^{-3}	-14.61	21.79
900 (10 loop)	10^{-3}	-10.05	26.36

VII. CONCLUSION

The effects of Polarization Tracker on 80 and 112 Gb/s PDM-DQPSK transmission system with 4-bits 156 Mb/s SAC label is presented using automatic high-speed polarization controller. The polarization tracker in direct detection brings an insertion loss under 0.5 dB. When the signal SOPs are perfectly aligned to the PBS, the power of the RF signal is minimized to zero. For BTB, 138 km and 120 km transmission for 80 and 112 Gb/s, the label EOFs are 0.94 and 0.86 for 80Gb/s, 0.93 and 0.90 for 112Gb/s. The payload's OSNR for BTB without label, BTB with label and after 138 and 120 km are 22.8, 23.0 and 25.6 dB for 80Gb/s and 22.1 , 22.3 and 23.2 dB for 112 Gb/s at a BER of 10^{-9}. The payload's ROP for BTB without label, BTB with label and after 138 and 120 km are -15.3, -15.1 and -12.5 dBm for 80 Gb/s and -14.5, -14.4 and -13.3 dBm for 112 Gb/s at a BER of 10^{-9}. A 1,260 and 900 km long haul transmission of the payload is also achieved for 80 Gb/s and 112 Gb/s respectively using forward error correction (FEC) and loops at BER of 10^{-3}. The simulation results revealed that the 80 and 112 Gb/s payload show good BER vs ROP and BER vs OSNR performances with reduced complexity and high spectral efficiency. The good performance of the system has potential application in future for all optical label switching.

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