

## Performance Analysis of 40 Gb/s PDM-DQPSK Optical Label Switching System with Frequency Swept Coherent Detected Spectral Amplitude Code Labels

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**Abstract:** In this paper, we present the performance of 40 Gb/s polarization division multiplexed-differential quadrature phase shift keying (PDM-DQPSK) optical label switching system with frequency swept coherent detected spectral amplitude code labels in simulation. In this system, the payload consists of two 10 Gbaud channels which are orthogonally polarized. Direct detection is selected to demodulate the PDM payload in the receiver. 4 bits of 156 Mb/s spectral amplitude code (SAC) label is frequency-swept coherently detected. The label and payload signal performances are assessed by the eye diagram opening factor (EOF) and bit error rate (BER) as function of received optical power (ROP) and optical signal to noise ratio (OSNR). For back-to-back system and 156 km transmission, label eye opening factors are 0.93 and 0.85 respectively, while payload's optical signal-to-noise ratio is 29.9 dB and received optical power is -11.5 dBm for a bit error rate of  $10^{-9}$ . The payload could well be demodulated after 1,800 km transmission at a BER of  $10^{-3}$  using forward error correction (FEC).

**Keywords:** Coherent detection, optical label switching (OLS), polarization division multiplexed (PDM), polarization tracker, spectral amplitude code (SAC).

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### I. Introduction

Transmission with expansive and large information carrying capacity has been a motivating force in telecommunication research. Spectrally efficient multilevel formats, like differential quadrature phase-shift-keying (DQPSK), combined with polarization division multiplexing (PDM) represent a proven solution to target and upgrade next generation Ethernet transport [1]. The ever-growing transmission capacity demand in optical transmission systems has brought out the necessity of increasing the spectral efficiency by employing different transmission techniques and also increasing transmission speed in optical networks. One optical technique used to improve the efficiency of optical communication systems is polarization division multiplexing (PDM). Polarization multiplexing serves to double the data rate using field-proven formats. Combined with differential quadrature phase shift keying (DQPSK), four bits are transmitted per symbol. POLMUX implies a higher sensitivity to polarization effects, such as polarization mode dispersion (PMD) and polarization dependent loss (PDL). Optical label switching (OLS) technique is considered a way to increase transmission speed in optical networks [2]. This comes from the fact that high speed baud rate payload signals can be switched with the routing information carried in simple accompanying labels that can be processed at lower bit rates. OLS beats the electronic bottleneck of system switches and disposes off optical-electronic-optical change to diminish the transmission delay. One simple and robust way of creating optical labels is introducing spectral tones into the payload signal spectrum-spectral amplitude coding (SAC) labeling [3], [4]. We introduce a SAC label detection system based on optical coherent detection, which produces an electronic signal that can be shaped into a control signal for an optical switching fabric by applying digital signal processing (DSP) algorithms. SAC has been applied in optical code division multiple access (OCDMA) and spectral code labeled systems [5], [6]. In this paper, we build up a 40 Gb/s polarization division multiplexed-differential quadrature phase shift keying (PDM-DQPSK) transmission system with 156 Mb/s SAC labels each in simulation. Frequency-swept coherent detection is employed to decode the SAC label. The high speed payload is directly detected which gets rid of complicated digital signal processing (DSP) procedure [7], [8]. By analyzing the factors that affect the quality of the received signal, we optimise the parameters and obtain good transmission performance for both the payload and label.

### II. Operation Principle of Frequency-Swept Coherent Detection

The receiver exploits knowledge of the carrier's phase to detect the signal. In a SAC label framework, SAC label and payload occupy the same time space however diverse wavelengths. Labels are encoded in

wavelength domain, and recognized by their amplitudes [9], [10]. Fig. 1 shows the schematic diagrams of SAC label in both wavelength and time domain.

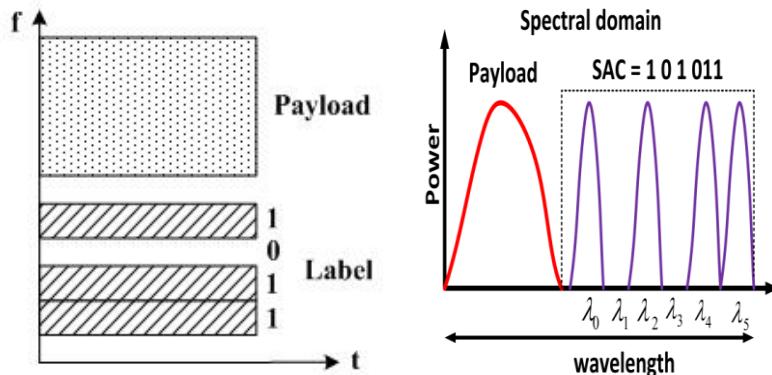


Fig. 1: Schematic diagrams of spectral amplitude code (SAC) label: (a) time domain; (b) wavelength domain.

The structure of a frequency swept coherent detection scheme of SAC label is shown in Fig. 2. Fig. 2 (a) is a SAC label which has 4 bits code “1010” in wavelength domain. Fig. 2 (b) is a 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 transferred to baseband electrical signal in time domain after photo-detection (PD). Therefore, the label signals can be recovered by low pass filters (LPF) as shown in Fig. 2 (c). The spectrum of the resultant (after coherent detection) is composed of several beating products between LO and label signal. The use of DSP based receivers also opens the way for straight forward integration with digital control of optical switching fabrics.

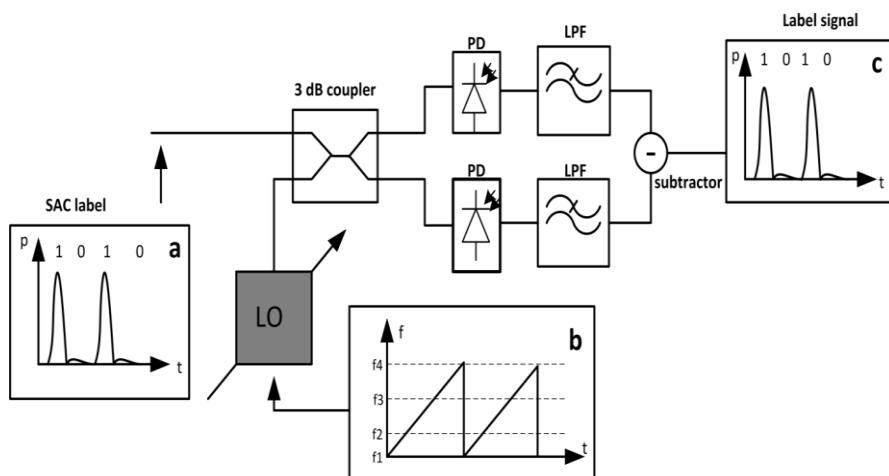


Fig. 2: Principle of frequency-swept coherent detection of SAC label: (a) input SAC label in wavelength domain; (b) frequency-swept LO; (c) output SAC label in time domain.

### III. System Model

The simulation setup of the 40 Gb/s PDM-DQPSK SAC transmission system is executed using VPI Transmission Maker 8.3 as shown in Fig. 3. A continuous wave (CW) laser at 1552.60 nm and 10 MHz linewidth is considered as optical source. Two orthogonal polarization channels are generated by one distributed feedback (DFB) laser source [11]. A 10 GBaud DQPSK signal at 1552.60 nm is split by a polarization beam splitter (PBS) into two beams. One beam goes through 0 degree polarization controller (PC), while the other one goes through 90 degree PC after 1 ns delay to make two signals uncorrelated. A polarization beam combiner (PBC) is employed to combine the two orthogonal polarization signals into one beam of 40 Gb/s PDM-DQPSK payload. The SAC label generation unit is made up of a laser, an optical switch and a pseudo random binary sequence (PRBS) generator. For the generation of SAC label signal, a 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, 1553.04 nm, respectively. The frequency interval between each label is 5 GHz while the spacing between payload and label is 40 GHz, so as to control the laser pulse signal and encode SAC label. By combining the payload and label, we obtain an optical packet of 40 Gb/s PDM-DQPSK payload and 156 Mb/s four-code SAC label. A standard single mode fiber (SSMF) and dispersion compensation fiber (DCF) are used

as the transmission fiber for each setup. For this part, chromatic dispersion (CD), polarization mode dispersion (PMD) and loss of SSMF are 0.16 ps/nm/km, 0.2 ps/km<sup>1/2</sup> and 0.2 dB/km, respectively, while the parameters of DCF are -0.8 ps/nm/km, 0.2 ps/km<sup>1/2</sup> and 0.5 dB/km, respectively. An erbium-doped fiber amplifier (EDFA) is installed in the link to compensate for lost power. A polarization tracker is installed to transform the arbitrary polarization state to settled polarization state. The polarization tracker recovers 0 degree and 90 degree of two orthogonal polarization states of PDM payload signal in order to mitigate the 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. For the payload in each setup, the polarization beam splitter (PBS) separates the signals in the X and Y demultiplexes the PDM signal based on the fact that the polarization states have been set to orthogonal X and Y. The signal is filtered by an optical band pass filter (OBPF) with bandwidth of 80 GHz and demodulated by a DQPSK receiver. For the label, a frequency swept laser is simulated by using an optical frequency modulator, driven by a ramp wave generator. A frequency-swept range from 1552.91 to 1553.05 nm is used in order to cover all the label available frequencies for the setup. The SAC labels are combined with the frequency-swept LO by a 3 dB coupler, and the combined signal is transferred to electrical domain by a balanced photo detection receiver. The electrical label signal is filtered by a 100 MHz dual-low-pass filter (LPF) and the original SAC label obtained.

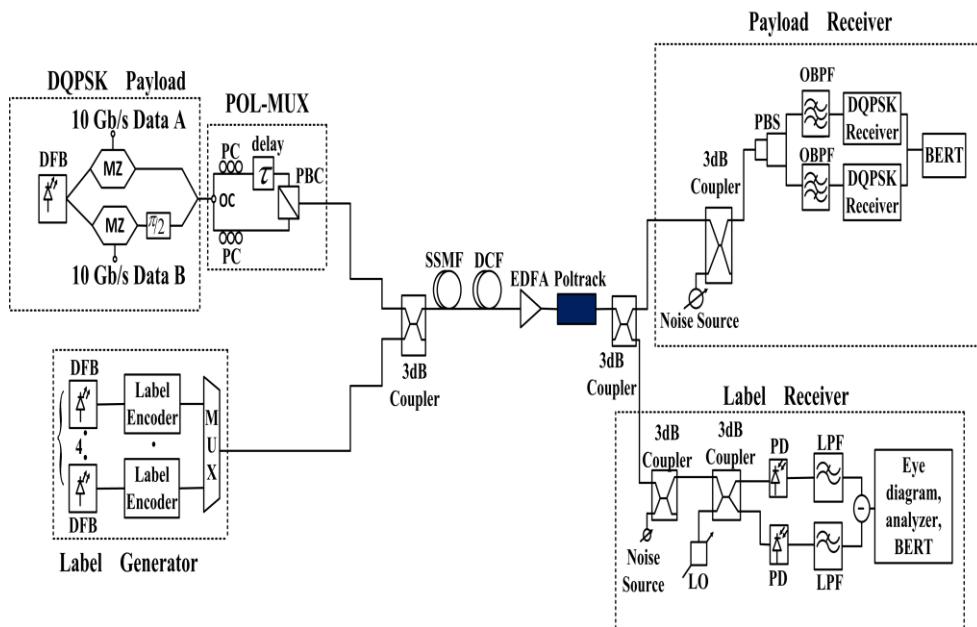


Fig. 3: Simulation setup of 40 Gb/s PDM-DQPSK SAC label system.

#### IV. Performance Analysis and Results of the System

The reception quality of the payload is affected by the laser linewidth. In Fig. 4, for 100 kHz and 1 MHz laser linewidth cases, the bit error rate (BER) is smaller than the BER in a 10 MHz laser linewidth in both the BTB and 156 km transmission conditions for the same optical signal to noise ratio (OSNR) and received optical power (ROP). To achieve good transmission performance, system should operate with current conventional DFB lasers with a typical linewidth value in the order of up to 10 MHz.

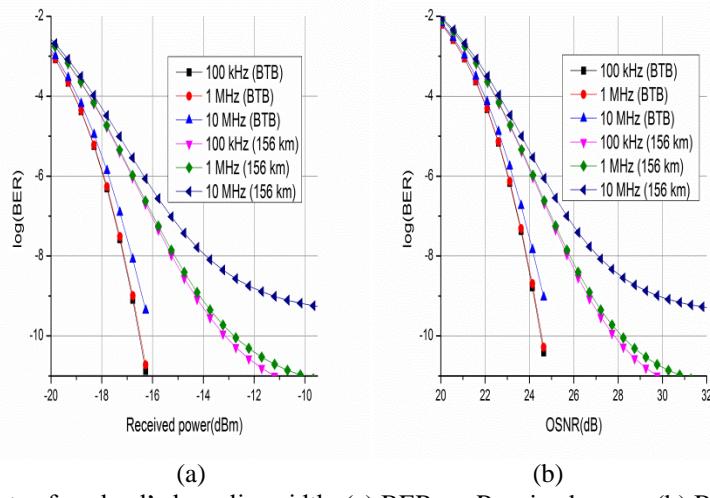


Fig. 4: Effects of payload's laser linewidth: (a) BER vs. Received power (b) BER vs. OSNR.

The frequency spacing between the payload and the labels likewise the frequency spacing between the labels should be considered so as to avoid correlation. Small frequency spacing can lead to interference which will damage the reception quality where wider frequency spacing will lead to waste of bandwidth. For the purpose of this simulation, frequency spacing of 40 GHz is chosen between the payload and the labels while a frequency spacing of 5 GHz is chosen between labels. Polarization effects due to interaction between polarization mode dispersion (PMD) and polarization dependent loss (PDL) can significantly impair optical fiber transmission systems. When PMD and PDL are both present, they interact. Polarization division multiplexing (PDM) system is very sensitive to both PMD and PDL effects. PMD produces a polarization state that varies randomly and a PDL which breaks the orthogonality of the two polarizations. This makes it hard for the signal to be demultiplexed. The polarization tracker is installed to repair the PMD and PDL impairments. This caused a power loss of less than 0.1 dB in our simulation. Fig. 5 shows the effects of polarization tracker on PMD.

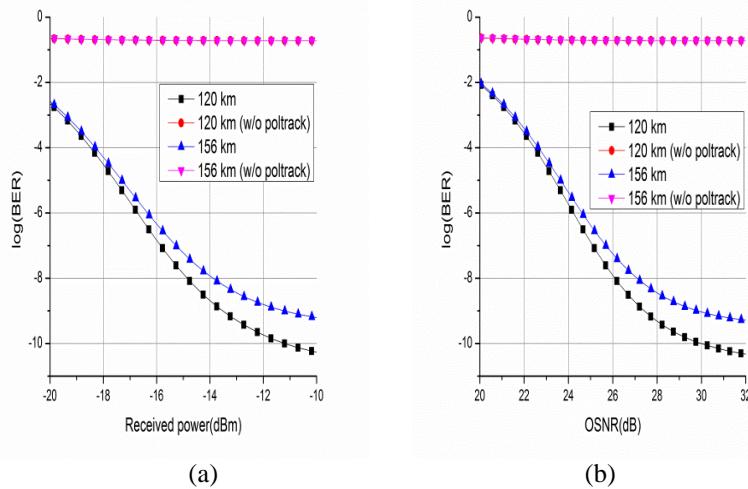


Fig. 5: Effects of polarization tracker and PMD: (a) BER vs. ROP for; (b) BER vs. OSNR

As observed from Fig. 5, without the polarization tracker, the signals cannot be demodulated due to PMD and PDL impairments. With a big PMD in the fiber, the polarization tracker cannot fully recover. PMD impairment may cause some ROP and OSNR penalty.

Eye diagram is a very successful way of quickly and intuitively assessing the quality of a digital signal. It serves as an additional testing procedure for verifying transmitter output compliance, and revealing the amplitude and time distortion elements that degrade the BER for diagnostic purposes. Eye opening factor (EOF) is usually used to measure the received quality of SAC label. Its expression is:

$$\text{EOF} = \frac{\text{EA} - (\sigma_1 + \sigma_0)}{\text{EA}} \quad (1)$$

Where EA is the eye amplitude,  $\sigma_0$  and  $\sigma_1$  are the standard deviations of the sample points of '0' bits and '1' bits within the sample range. In our transmission, the EOF of the BTB is better opened than transmission after 156 km. For BTB, the label EOF is 0.93 whereas the label EOF after 156 km is 0.85. A long distance transmission of the SAC label with a high speed payload is achieved with the method of frequency-swept coherent detection.

The transmission performance of the payload is shown in Fig. 6. The graph shows the transmission penalty for BTB with labels and without labels while the penalty for 156 km is compared to BTB with labels.

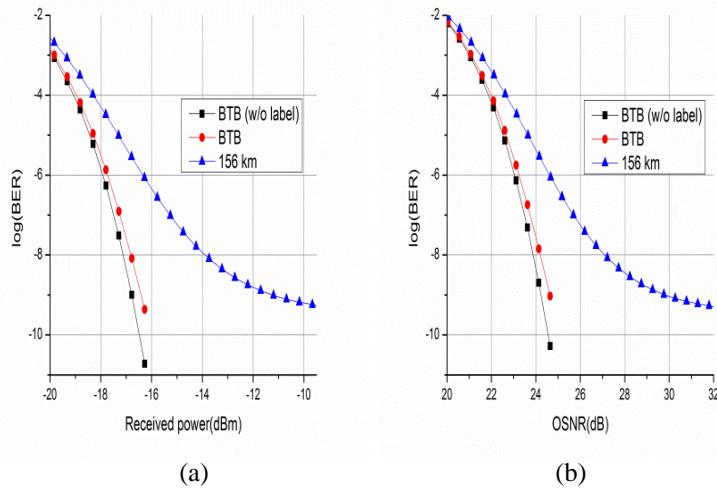


Fig. 6: Transmission performance of the payload: (a) BER vs. Received; (b) BER vs. OSNR.

From Fig. 6, the received power and OSNR values for BTB without label are -16.7 dBm and 24.3 dB while the BTB with label are -16.4 dBm and 24.7 dB respectively. This results in a penalty of 0.3 and 0.4 respectively. After 156 km, the received power value is -11.5 dBm and OSNR value is 29.9 dB which results in a penalty of 4.9 and 5.2 respectively.

Lastly, we examine and study long haul transmission by creating loop to study the performance of the system using forward error correction (FEC). The 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. The loop also consisted of an EDFA to compensate the power loss. Using BER of  $10^{-3}$  and forward error correction (FEC), a transmission distance of 1,800 km is achieved with ROP and OSNR values of -13.58 dBm and 27.36 dB respectively. The intensity dependent impairments are reduced automatically.

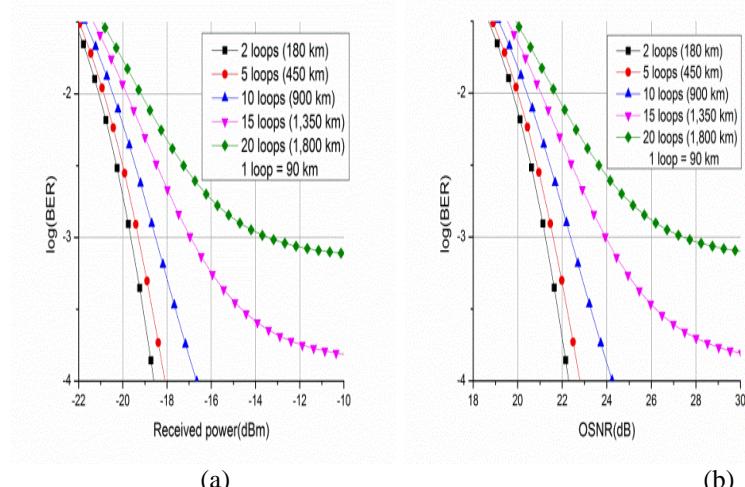


Fig. 7: Long haul transmission using forward error correction (FEC): (a) BER vs. ROP (b) BER vs. OSNR.

## V. Conclusion

The performance and analysis of 40 Gb/s PDM-DQPSK transmission system with 4-bits 156 Mb/s SAC label each respectively is presented. The payload signal is demodulated using direct detection while the SAC label is detected using frequency-swept coherent detection. The polarization tracker in direct detection brings an insertion loss of less than 0.5 dB and a few watts of power consumption. The laser linewidth of the payload is optimized to 10 MHz. The frequency spacing between the payload and the label is 40 GHz and the spacing between the labels is optimized to 5 GHz. The transmission performances of both the payload and label are good. For BTB and 156 km transmission, the label EOF is 0.93 and 0.85 respectively. The payload's OSNR for BTB without label, BTB with label and after 156 km is 24.3, 24.7 and 29.9 dB respectively. The payload's ROP for BTB without label, BTB with label and after 156 km is -16.7, -16.4 and -11.5 dBm respectively at a BER of  $10^{-9}$ . A 1,800 km long haul transmission of the payload is also achieved using forward error correction (FEC) at a BER of  $10^{-3}$ . These results indicate that the high speed payload and SAC label are compatible. The good performance of the system has potential application in future for all optical label switching.

## VI. Acknowledgement

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