Signed chromatic dispersion monitoring of 100Gbit/s CS-RZ DQPSK signal by evaluating the asymmetry ratio of delay tap sampling

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Abstract: In this paper, we theoretically and experimentally demonstrated the residual chromatic dispersion (CD) monitoring of 100-Gbit/s carrier suppress return-to-zero differential quadrature phase shift keying (CS-RZ DQPSK) signals by evaluating the asymmetry ratio of delay tap asynchronous sampling. This scheme can easily differentiate the positive and negative residual CD of the fiber link. The resolution of this scheme is better than 8ps/nm and the measurable range is around ± 24ps/nm for 100Gbit/s CS-RZ DQPSK signals. We can also simultaneously realize both signed CD monitoring and demodulation of CS-RZ DQPSK signal based on only one demodulator.

OCIS codes: (060.2360) Fiber optics links and subsystems; (260.2030) Dispersion.

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1. Introduction

The rapid increase of internet traffics has created the need to migrate the current predominately 10Gbit/s optical transmission systems to 40Gbit/s or 100Gbit/s systems. An effective residual CD monitoring scheme is very important for such high speed transmission systems [1,2]. Many schemes for realizing the residual CD monitoring have been proposed and demonstrated [3–12]. Most of them need to add additional monitoring components into the transmission system, such as RF modulated ASE noise, pilot tone or optical frequency modulated (FM) signal onto the distributed feedback (DFB) laser [3–5]. However, additional pilot tone, ASE noise or optical FM signal will degrade the system performance. In addition, any change to the transmitter will increase the cost and complexity of the system and thus is not practical for upgrading from current commercial communication systems. Recently, a CD monitoring scheme was proposed by comparing the phase of recovered clock of received I and Q channel signals of a DQPSK modulated data [6]. No additional monitoring signal needs to be added to the transmitter. However, clock recovery and high speed phase comparator are necessary, which also results in the increased system complexity and cost. Asynchronous sampling method, such as amplitude histogram based on overall power statistics distribution, can avoid the clock recovery [7], and thus has inherent low cost. However, since different impairments can cause similar degradation in amplitude histogram, it is difficult to distinguish them [8]. Recently, delay tap asynchronous sampling has been proposed for multi-parameter monitoring [8-10], and even applied to commercial WDM system [9]. Delay tap sampling can resolve the power evolution within each bit, providing a direct measurement of waveform distortion without clock extraction [8–10]. This method uses a delay tap line so that a pair of data could be obtained during one sampling process. Because the data pair obtained are from the same data pulse or the adjacent pulses, they can reflect the pulse shape information which has a strong relationship with the transmission impairments in fiber link. However, all proposed delay tap sampling schemes up to now cannot differentiate between positive and negative residual CD of the fiber link. Recently, we proposed a scheme based on delay-tap sampling using a imperfectly tuned delay interferometer (DI) to realize the signed CD monitoring of non-return-to-zero differential phase-shift keying (NRZ-DPSK) and return-to-zero differential phase-shift keying (RZ-DPSK) signals [12]. However, this signed CD monitoring scheme designed for DPSK signal introduces a $\pi/4$ phase shift at one arm of a conventional DPSK demodulator, resulting in big degradation of the demodulated DPSK signal. As a result, we need two demodulators at the receiver of a DPSK communication system in order to simultaneously realize both signed CD monitoring and demodulation of DPSK signal. Based on our previous study of the signed CD monitoring of DPSK communication system, we also proposed a signed residual CD monitoring scheme for RZ-DQPSK signal by simulation [13]. Since the inherent phase shift at one arm of the conventional DQPSK demodulator is $\pi/4$, we can simultaneously realize both signed CD monitoring and demodulation of CS-RZ DQPSK signal based on only one demodulator.

In this paper, we showed the difference and pointed out the improvement between our proposed delay-tap sampling scheme for DQPSK signal and our previous work for DPSK signal in detail. We also demonstrated a signed CD monitoring experiment and simulation study for 100Gbit/s CS-RZ DQPSK signal based on an enhanced delay-tap asynchronous sampling scheme by evaluating the asymmetry ratio of delay-tap plot. This scheme can easily differentiate the positive or negative residual CD in a DQPSK based communication system and need not change the demodulator for DQPSK signal.

2. Principle of asymmetry of eye diagram for DPSK and DQPSK signals

In order to give a detailed analysis of the principle inducing the asymmetry of eye diagram and delay tap plot due to the residual CD, we study and compare the eye diagrams of DPSK and DQPSK signal respectively.

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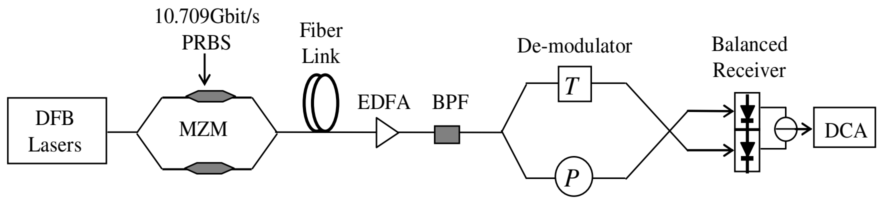
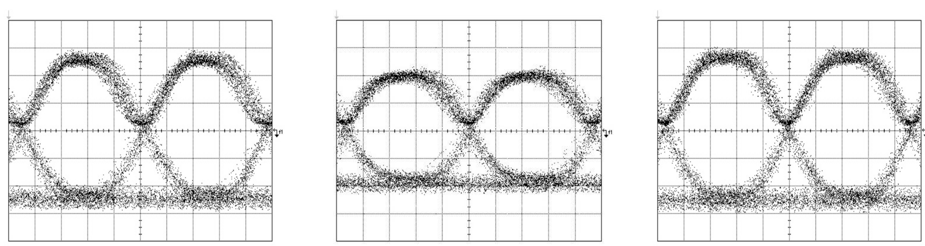


Fig. 1. Experimental setup for NRZ-DPSK signal

Figure 1 illustrates the experimental setup of a 10-Gbit/s NRZ-DPSK transmission system, which includes the transmitter, fiber link and receiver modules. One continuous-wave (CW) distributed feedback (DFB) lasers at the wavelengths of 1546.92nm is launched into a modulation module, through which CW lights were modulated into NZR-DPSK signals. The implementation of NRZ-DPSK is realized by using a dual driver Mach-Zehnder modulator (MZM) biased at the transmission null point.

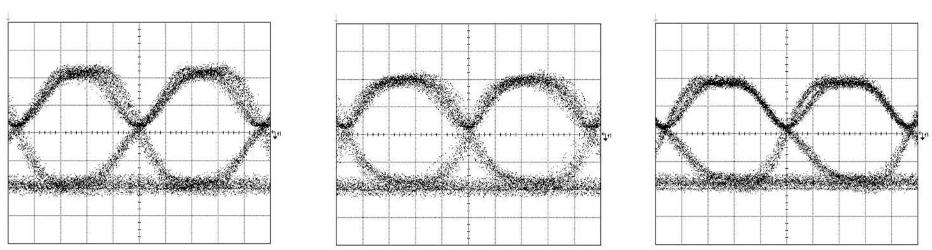
Fiber link consists of single mode fiber (SMF) with different lengths and dispersion compensation module (DCM), which are used to simulate different residual CD in fiber link. At the receiver, optical signal is first amplified using an Erbium doped fiber amplifier (EDFA). Before the demodulator, we use an optical tunable filter with 0.5nm bandwidth. A demodulator is used to demodulate the DPSK signal. T and P represent one bit delay and the relative phase shift between the two arms of the demodulator respectively. The relative phase shift P can be tuned by an external voltage controller. In this experiment, an integrated balanced photo receiver is adopted as an opto-electronics converter after the demodulator and a digital communication analyzer (DCA) with 70GHz bandwidth is used to monitor the eye diagram.



(a) (b) (c)

Fig. 2. (a) −160ps/nm; (b) 0ps/nm; (c) + 128ps/nm residual CD

Figures 2(a)–2(c) illustrate the measured demodulated eye diagram of 10Gbit/s NRZ-DPSK signal without phase difference between the two arms of demodulator under different residual CD (−160ps/nm, 0ps/nm and + 128ps/nm). We can find from
Figs. 2(a)–2(c) that all the demodulated eye diagrams are symmetric under different residual CD.



(a) (b) (c)

Fig. 3. (a) −160ps/nm; (b) 0ps/nm; (c) + 128ps/nm residual CD

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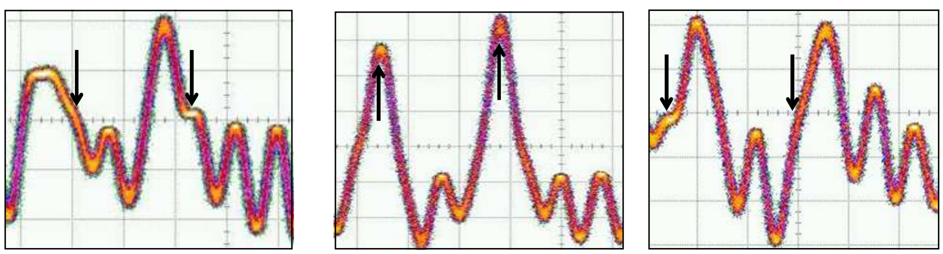
However, as we change the relative phase shift between the two arms of the demodulator from 0 to π/4, asymmetry of the demodulated eye diagram will become sensitive to the value and the polarity of the residual CD of the fiber link. Figures 3(a)–3(c) show the measured demodulated eye diagram of 10Gbit/s NRZ-DPSK signal with π/4 phase difference between two arms of the demodulator under different residual CD (−160ps/nm, 0ps/nm and + 128ps/nm). We can find that eye diagram is symmetric against the peak point without residual CD. Eye diagram will lean to the rising edge side with negative residual CD, while eye diagram will lean to falling edge side with positive residual CD. In addition, we also find that the degree of the slant of the eye diagram is determined by the amount of residual CD. In this way, we can measure the residual CD and differentiate between the positive and the negative residual CD by evaluating eye diagram.

The delay tap sampling can reflect all characteristics of the eye diagram and thus can realize residual CD monitoring in a fiber link and differentiate its polarity for DPSK based communication system in a low-cost [12]. However, as we have discussed in the introduction, this signed CD monitoring scheme designed for DPSK signal introduces a π/4 phase shift at one arm of a conventional DPSK demodulator. Therefore, this scheme will result in big degradation of the demodulated DPSK signal and thus is not practical for DPSK based transmission system.

Since the inherent phase shift at one arm of the conventional DQPSK demodulator is π/4, we can simultaneously realize signed residual CD monitoring and DQPSK signal demodulation based on only one demodulator. Hereinafter, we will study signed CD monitoring for CS-RZ DQPSK signals.



(a) (b) (c)

Fig. 4. Measured waveforms of demodulated CS-RZ DQPSK signals (a) −31ps/nm; (b) 0ps/nm; (c) 31ps/nm residual CD

Figure 4 illustrates the measured waveforms of the demodulated I channel 100Gbit/s CS-RZ DQPSK signals with different amount of residual CD (−31ps/nm, 0ps/nm or 31ps/nm). We choose the same pulse series and compare the waveforms of these pulse series with different residual CD. We can find that the waveforms of demodulated CS-RZ DQPSK signal are nearly symmetric against the peak position [arrow line in Fig. 4(b)] as there is no residual CD. But the waveform will become asymmetrical and shoulders will appear at the rising edges or falling edges with the increase of residual CD, which are illustrated by using arrow lines in Fig. 4(a) and Fig. 4(c) respectively. The position of the shoulders depends on the sign of the residual CD [12,13]. Negative residual CD will induce shoulders at the falling edges of pulses while positive residual CD will induce shoulders at the rising edges of pulses [12,13]. The degree of asymmetry is determined by amount of residual CD.

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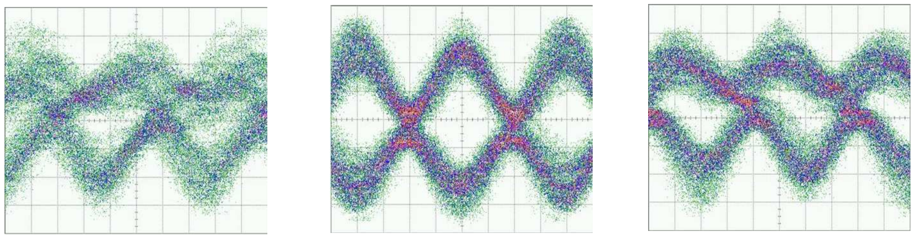

(a) (b) (c)

Fig. 5. Eye diagram of demodulated CS-RZ DQPSK signals with different residual CD (a) −31ps/nm; (b) 0ps/nm; (c) 31ps/nm residual CD

Since the eye diagram can reflect the distortion of a waveform directly, we can also study the distortion of eye diagram due to residual CD. Figures 5(a)–5(c) illustrates the eye diagrams of demodulated CS-RZ DQPSK signals with different residual CD. We can find that eye diagram is symmetric against peak point when there is no residual CD. Eye diagram will lean to the rising edge side when the residual CD is negative. When there is positive residual CD, eye diagram will lean to the falling edge side.

We can utilize the asymmetric characteristics of demodulated waveforms and eye diagram of DQPSK signal induced by positive or negative residual CD together with the delay tap sampling technique to differentiate positive and negative residual CD. In addition, delay tap sampling technique does not require clock recovery. As a result, this scheme will be much simpler and cost-effective than other CD monitoring scheme proposed for DQPSK signals.

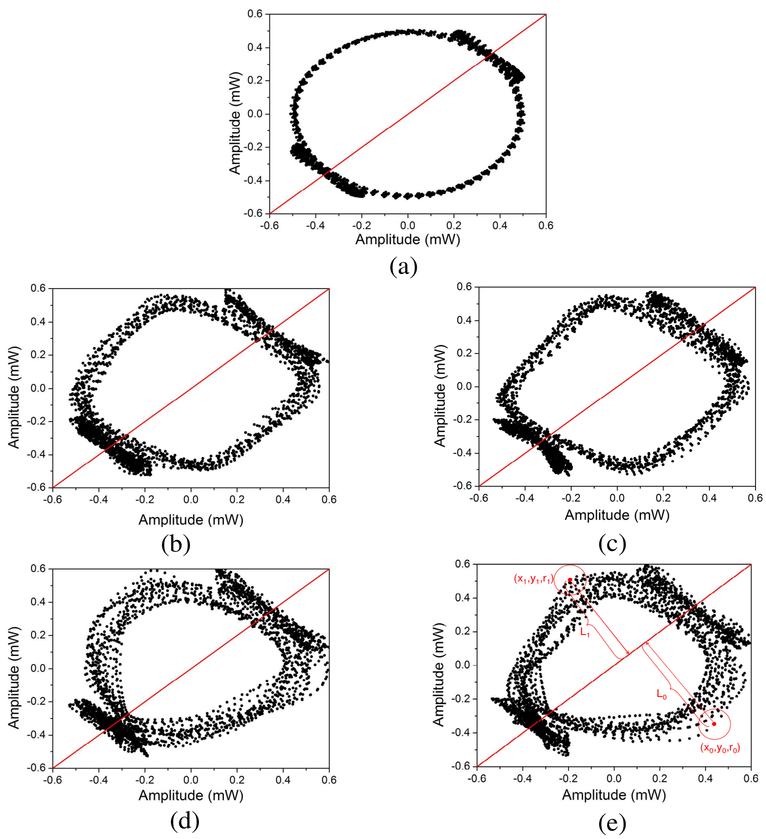

Fig. 6. Simulated delay-tap plots with different residual CD (a)0ps/nm; (b)-16ps/nm; (c)16ps/nm; (d)-24ps/nm; (e)24ps/nm

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The simulated delay tap plots of CS-RZ DQPSK signal for back-to-back (BTB), ± 16ps/nm and ± 24ps/nm residual CD are shown in Figs. 6(a), 6(b), 6(c), 6(d) and 6(e) respectively. We can see from Fig. 6 that the delay-tap plots is symmetric against the diagonal line y = x when there is no residual CD. Delay-tap plots will become asymmetric against the diagonal line y = x when residual CD appears and the asymmetric ratio will increase with the increasing of residual CD. In addition, delay-tap plots will flip against the diagonal line y = x depending on whether the residual CD is negative or positive. We can find from Fig. 6(a)–6(e) that the delay tap plot of CS-RZ DQPSK signal changes with residual CD and is sensitive to the sign of residual CD. To quantify this, we need to find a parameter to define asymmetry ratio of delay tap plots to represent different residual CD.

We first find the point (x_0, y_0) in Fig. 6(e) which has the largest distance to the diagonal line $y = x$ when $x > y$ followed by computing the distance of all the points in the circle with center (x_0, y_0) and radius of r (r = 0.1 was used) to the diagonal line. L_0 is obtained by computing the average value of all these distances obtained and then is used to represent the maximal deviation for $x > y$. Similarly, we can obtain the value of L_1 to represent the maximal deviation for $x < y$ We then define an asymmetric ratio to represent the deviation from symmetry of delay-tap plots against the diagonal line $y = x$ as follows:

$$\text{Asymmetry\_ratio} = \frac{L_0}{L_1} \tag{1}$$

In this way, we can monitor and also differentiate the positive or negative residual CD by evaluating asymmetry ratio of delay tap plots of CS-RZ DQPSK signals.

Figure 7 shows the asymmetric ratio of delay-tap plots for different amount of residual CD. The obtained ratio varies from 0.8 to 1.2 as the amount of residual CD changes from −32ps/nm to 32ps/nm. We can see from Fig. 7 that asymmetry ratio increases with the residual CD monotonously. This indicates that this method can be used to measure small residual CD and also differentiate positive and negative residual CD.

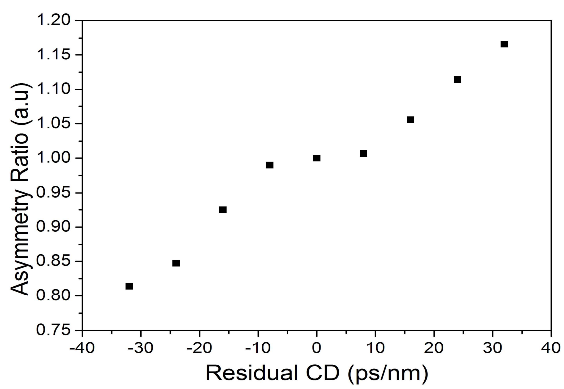

Fig. 7. Simulated asymmetric ratio of delay-tap plots

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3. Experimental setup for 100Gbit/s CS-RZ DQPSK system

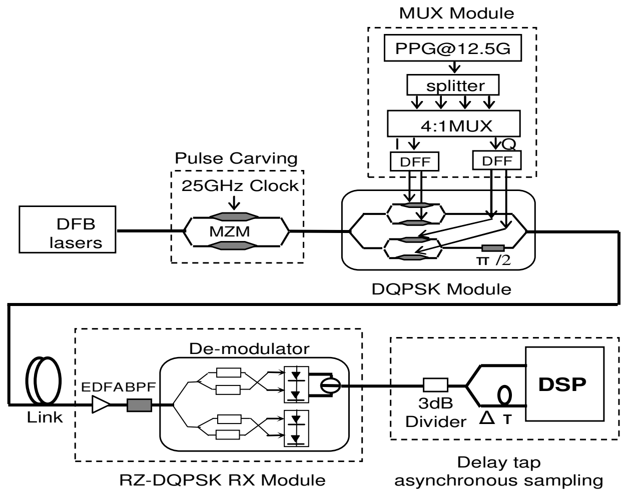

Fig. 8. Experimental setup of 100Gbit/s CS-RZ DQPSK signal; SMF: single mode fiber; DCM: dispersion compensation module; EDFA: Erbium doped fiber amplifier; BPF: band pass filter; DSP: digital signal processing;

Figure 8 illustrates the experimental setup of a 100-Gbit/s CS-RZ DQPSK transmission system, which includes transmitter, fiber link and receiver modules. One continuous-wave (CW) distributed feedback (DFB) laser at the wavelengths of 1546.92nm is launched into a modulation module, through which CW light was modulated into CS-RZ DQPSK signals. The first module at the transmitter is a typical implementation of pulse carver with half clock frequency of 25GHz by using a dual driver Mach-Zehnder modulator (MZM) biased at transmission null point. The second module at the transmitter is a data multiplexing module, in which 50Gbit/s electrical data is generated by electronically multiplexing four channels of 2^7-1 pseudo-random bit sequence (PRBS) data at 12.5 Gbit/s with suitable time delays between each other. Two output data at 50 Gbit/s of electric 4:1 MUX serve as I and Q signals for the DQPSK modulation module and there is 108 bit relative time delay between the I and Q channels in order to avoid pattern correlation. After D-type flip flop (DFF) and amplification I, $\overline{I}$, Q and $\overline{Q}$ channels are used to modulate an integrated nested DQPSK MZM.

Fiber link consists of SMF with different lengths (750m, 1.25km and 1.75km) and DCM used to simulate different residual CD. At the receiver, optical signal is first amplified using a pre-amplifier. Before the photo detector (PD), we use an optical tunable filter with 1nm bandwidth. The selected signal channel is de-modulated into 50Gbit/s I and Q components by using a free space based tunable interferometer. An integrated balanced PD is adopted after the demodulator.

In the delay tap asynchronous sampling module, the demodulated CSRZ-DQPSK signals are split to two channels and one channel is delayed by 1/2 symbol period relative to another to realize the delay tap sampling process. Both channels of sampled signals are converted to digital signals. Then, the obtained data information is processed in a digital signal processing module. In our experiment, we use DCA (Agilent sampling oscilloscope 86100) to serve as the sampling module. The sampling rate of the DCA used in our experiment is as low as 40Hz. We used the same DCA in the delay tap sampling module for 10Gbit/s DPSK signal. Asynchronous sampling can be used for delay sampling module in our configuration, so trigger signal is not needed and this means clock recovery is avoided.

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4. Experimental results and discussion

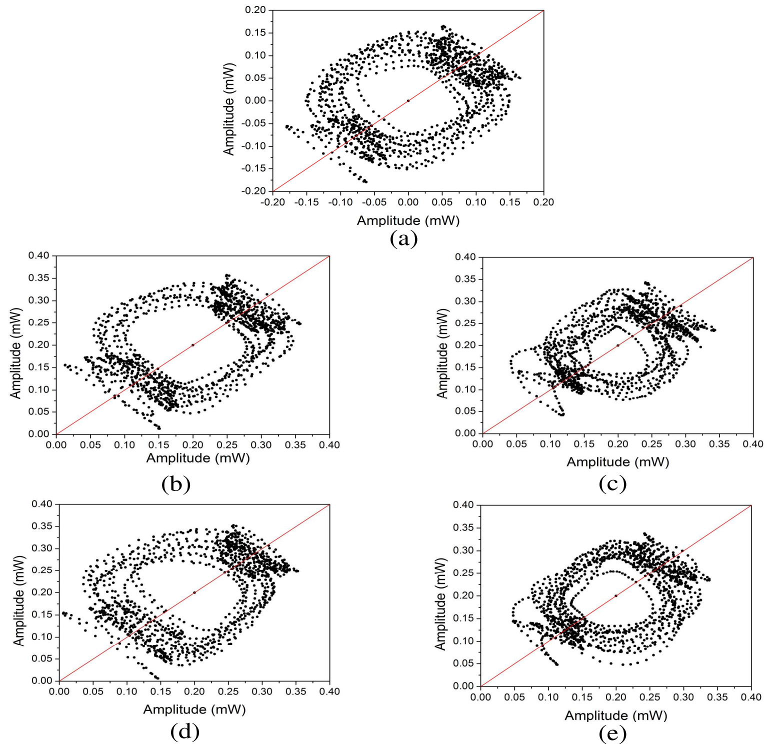

Fig. 9. Experimental delay-tap plots with different residual CD (a)0ps/nm; (b)-16ps/nm; (c)16ps/nm; (d)-22ps/nm; (e)24ps/nm

The measured delay tap plots for back-to-back (BTB) transmission with ± 16ps/nm, 22 and −24ps/nm residual CD are shown in Figs. 9(a), 9(b), 9(c), 9(d) and 9(e) respectively.

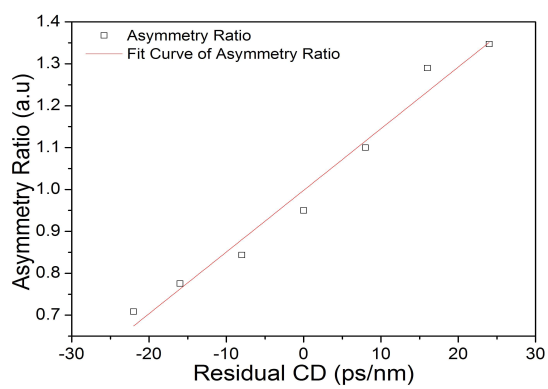

Fig. 10. Measured asymmetry ratio of delay-tap plots

Figure 10 shows the asymmetric ratio of delay-tap plots for different amount of residual CD, ranging from 0.7 to 1.3 as the residual CD changes from −24ps/nm to 24ps/nm. This measurable range is not very high compared with that of 10Gbit/s RZ-DPSK signal [12], which is about ± 720ps/nm. However, this measurable range is already high enough for 100Gbit/s CS-RZ DQPSK communication system because the system cannot work at all when the residual CD in the fiber link is beyond ± 24ps/nm. We can find from Fig. 10 that the asymmetry ratio increases with the residual CD monotonously. This indicates that this method can be used

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to measure small residual CD and also differentiate the positive and negative residual CD. We can find from Fig. 10 that the trend of the measured asymmetric ratio match well with the simulated results. Comparing with simulation results, the limited bandwidth of experimental system components has resulted in increased slope in asymmetry ratio for residual CD within the range of ± 8ps/nm and as a result high CD monitoring sensitivity can be obtained than simulated results. As a result, measured asymmetric ratio can also differentiate residual CD within the range of ± 8ps/nm.

The influence of added amplified spontaneous emission (ASE) noise level on this scheme is insignificant [12], because the parameter for asymmetry ratio was obtained by averaging the distance of all the points in a circle to the diagonal line. In this way, the averaging effect could remove the influence induced by increased ASE noise level.

However, the delay control in the delay tap module is more important and difficult for 100Gbit/s CS-RZ DQPSK communication system compared with 10Gbit/s DPSK communication system if we want to obtain the accurate residual CD value in the fiber link. Since the pulse width for 100Gbit/s CS-RZ DQPSK signal is only 20ps, we have to realize an accurate control of the half bit delay around 10ps in the delay tap sampling module.

5. Conclusions

In this paper, we studied and compared the principle of the asymmetry shown in eye diagram and delay tap plot for DPSK and DQPSK signals induced by residual CD of the fiber link. We demonstrate a simple CD monitoring scheme by evaluating asymmetric ratio of delay tap plots for 100Gbit/s CSRZ-DQPSK signal. This scheme can easily differentiate positive and negative residual CD in fiber link and its resolution is better than 8ps/nm.

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