Signed frequency offset measurement for direct detection DPSK system with a chromatic dispersion offset

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Abstract: We demonstrated a method for the measurement of signed frequency offset between optical source and delay interferometer (DI) for 10Gb/s DPSK signals based on asynchronous delay-tap sampling technique with a chromatic dispersion (CD) offset. The demodulated DPSK signals show asymmetrical property and amplitude shoulder appears on the waveforms with frequency offset and a fixed CD offset together. The delay-tap sampling scatter plots also show the asymmetry related to the asymmetrical signal distortion. Our proposed method cannot only realize the measurement of the magnitude of frequency offset but also the polarity. The measurement range is from −2GHz to + 2GHz and the sensitivity can reach ± 100MHz. The simulation and experimental results are demonstrated and in good agreement.

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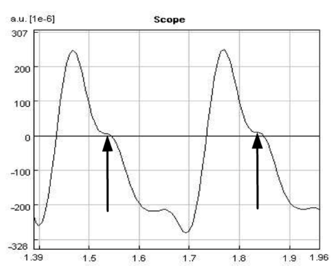
1. Introduction

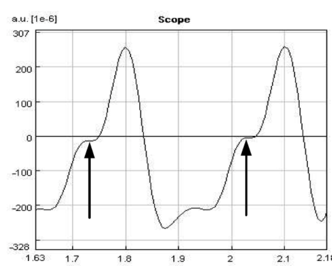
Differential phase-shift keying (DPSK) signal is a promising candidate to be applied in the high speed and large capacity systems because of its superior performance compared with conventional on-off keying (OOK) signal such as an improvement of 3dB optical signal-to-noise ratio (OSNR) when balanced detectors (BD) are employed [1–3]. The delay interferometer (DI) is always utilized as a demodulator for direct detection DPSK system. Stable operation of demodulation is quite important for balanced DPSK receivers. Essentially, the carrier wavelength of optical source should align with that of the DI. A slight carrier frequency offset results in large signal performance degradation [4,5]. For example, it has been reported that a frequency offset of ~400 MHz between the DI and optical source gives rise to a sensitivity penalty of 1dB in 10Gb/s DPSK system [5]. The frequency offset needs to be evaluated exactly and promptly in high speed systems and reconfigurable networks. Hitherto, several frequency offset monitoring techniques have been proposed; such as pplying a phase modulated pilot tone at the transmitter [6], using a half bit rate amplitude modulated pilot tone [7], or measuring the total RF power of the received DPSK signals [8]. However, these methods could not differentiate the polarity of frequency offset of the optical source. Since the frequency offset can either be blue shift or red shift, it is necessary to monitor the magnitude and sign of frequency offset between DI and optical source simultaneously. Our proposed method cannot only measure the absolute value but also the drift direction of this frequency offset. It can also simplify and improve the performance of the control loop required to continuously trim the phase of the DI to ensure regular and stable operation of direct detection DPSK system.

In this paper, we demonstrated a method for measuring signed frequency offset based on delay-tap sampling technique [9] with a chromatic dispersion (CD) offset. The demodulated signal shows asymmetric distortions and amplitude shoulder appears on either the trailing or leading edge with frequency and CD offsets, which is reflected in the corresponding delay-tap plots. Such asymmetric features are then used to estimate signed frequency offset. The measurement range of frequency offset can extend from −2GHz to 2GHz and the sensitivity can reach ± 100MHz.

2. Operating Principle



(a)



(b)

Fig. 1. Received signal profiles with (a) 2GHz and (b) −2GHz frequency offset at CD offset of 340ps/nm.

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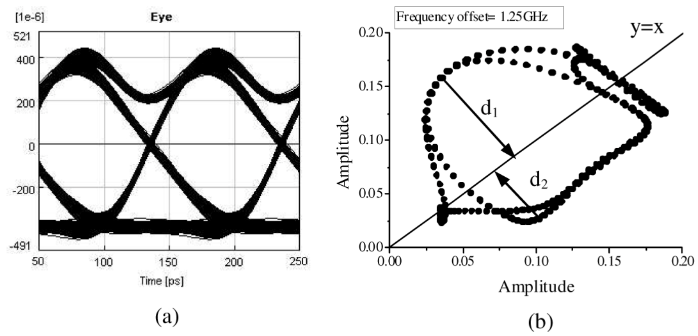

Fig. 2. (a) Eye diagram and (b) corresponding delay-tap plot of demodulated DPSK signal with 1.25GHz frequency offset and CD offset of 340ps/nm.

With ideal demodulation using a balanced detector and perfectly tuned DI, a DPSK signal will show be symmetric about the center of each bit with maximum eye-opening. The frequency offset of optical source results in imperfect interference with the DI and consequently leads to eye diagram closure and receiver performance degradation. With residual CD from the transmission link, the waveform distortion will exhibit asymmetry and amplitude shoulder will appear on the rising and falling edges depending on the sign of frequency offset. It should be noted that without residual CD, signal waveform will be symmetric even though there is frequency offset [10]. Figure 1(a) and 1(b) show the demodulated signal waveforms with frequency offsets of 2GHz and −2GHz and CD offset of 340ps/nm. The amplitude shoulders emerged on the trailing or leading edges depending on the polarity of frequency offset. As shown in Fig. 1, amplitude shoulders which are shown by upward black arrows appeared at half of the transition of demodulated signal waveform. The waveform asymmetric distortion can be reflected by scatter plots obtained by delay-tap sampling process.

Asynchronous delay-tap sampling technique has been recently proposed for multi-parameter monitoring [9,11,12]. Delay-tap sampling method employs a delay line tap to sample twice with a fixed delay in one sampling process to obtain a pair of data. The first and second sampling point are recognized respectively as x and y. The sampling points x and y are amplitude values of the signal waveform from which the data pair (x, y) is obtained. Then two dimensional scatter plots are constructed using the data pair. The amplitude values x and y correspond to the X and Y axes respectively. All the data pairs are in one-to-one correspondence to the points in the quadrant. Since the order of data pairs does not influence the plots shape, the time variable is not used in this method. The data pairs are obtained from single or adjacent pulses, therefore the scatter plot can directly reflect the pulse shape change and extract the waveform evolution which has a strong relationship with the system parameters or impairments in the transmission link. In the study, we use half bit period as the time delay in the delay-tap sampling process since the amplitude shoulder locates at half of the trailing or leading edges. Figure 2(a) and 2(b) show the eye diagram and corresponding scatter plot of demodulated signals with a CD of 340ps/nm and frequency offset of 1.25GHz. The eye diagram shows clear inclination and the delay-tap plot exhibits asymmetry with respect to the diagonal. Signal profile and eye diagram will become seriously distorted when the magnitude of frequency offset increases.

The asymmetry of the delay-tap plots in the first quadrant can be used to estimate the frequency offset. Here d_1 is the largest distance from the points in the space $x<y$ to the diagonal $y = x$ and d_2 is the largest distance from points in the space $x>y$ to the diagonal. A variable distance ratio *DR* is defined to characterize the amount of asymmetry of the delay-tap plots by calculating the ratio of distance d_1 over d_2:

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$$DR = 10log_{10}(\frac{d_1}{d_2}) \quad (1)$$

Distance ratio is smaller than 0dB with a red shift of the frequency of optical source while it is larger than 0dB with blue shift of the frequency of optical source. And also the absolute value of *DR* will increase with an increase of absolute value of frequency offset. Hence, the level of signed frequency offset can be represented quantitatively by the distance ratio *DR* and therefore signed frequency offset estimation can be realized.

3. Experiment setup

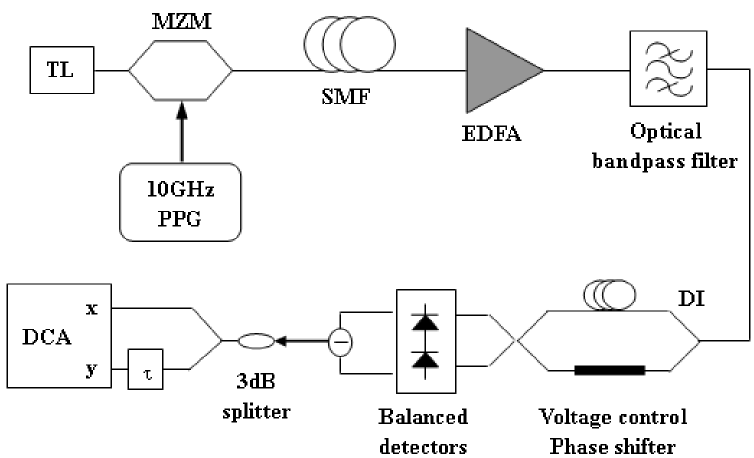

Fig. 3. Experimental configuration of signed frequency offset measurement for DPSK signals.

Figure 3 shows the signed frequency offset measurement system for 10Gb/s nonreturn-to-zero (NRZ)-DPSK direct detection system. The transmitter consists of a tunable laser (TL) operated at 1549.7nm to match the DI for perfect demodulation. The frequency setting resolution of the TL (Anritsu product MG9541A) is 12.5MHz. The optical carrier was modulated by a Mach-Zehnder modulator (MZM) which was biased at the transmission null point of the transmission curve to generate the DPSK signal. The modulation signal is a 10Gb/s NRZ pseudo-random bit sequence (PRBS) of length 2^{23}-1 from a pulse pattern generator (PPG) with a swing of $2V_{\pi}$. This technique of performing phase modulation produces a perfect 180° phase variation. A 20km long standard single mode fibre (SMF) was introduced as the CD offset module. An erbium-doped fibre amplifier (EDFA) was used to compensate for the losses caused by the fibre and other components. Just before the DI, a tunable optical bandpass filter with a 3dB bandwidth of 0.6nm was employed to eliminate the out-of-band amplified spontaneous emission (ASE) noise. At the receiver, the DPSK signal was demodulated by a free space based DI and then launched into the BD. The electrical output signal was split into two arms where an electrical delay line was introduced in one arm. The delay τ was set at half bit period. Finally, the two signals were fed into a digital communications analyzer (DCA) to implement the asynchronous delay-tap sampling process. The eye diagrams and the data required for generating scatter plots were obtained from the DCA (Agilent product 86100). This method avoids the additional RF components, transmitter modifications and also the clock recovery module.

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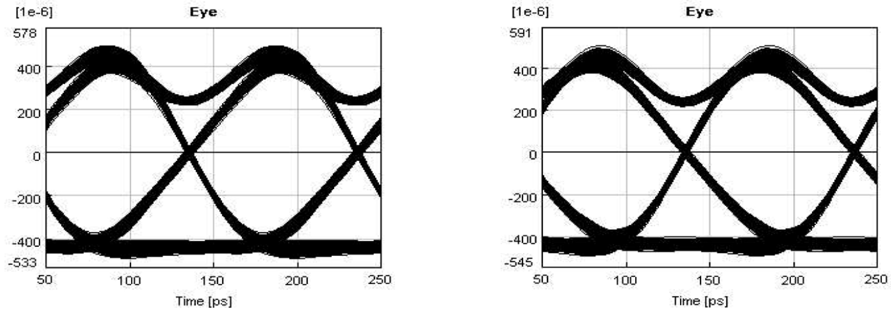
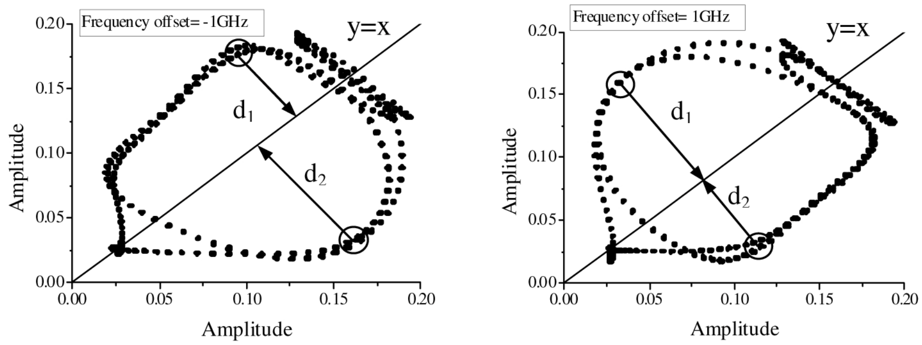
4. Results and Discussions



(a) (b)

Fig. 4. Simulation results of eye diagrams with CD of 340ps/nm and frequency offset of (a)-1GHz; (b)1GHz.



(a) (b)

Fig. 5. Simulation results of delay-tap plots with CD of 340ps/nm and frequency offset of (a)-1GHz; (b)1GHz.

Figure 4(a) and 4(b) show the simulation results of demodulated 10Gb/s NRZ-DPSK signals' eye diagrams with frequency offset of respectively −1GHz and 1GHz at CD offset of 340ps/nm. The received power is measured to be −3dBm. The eye diagrams show similar level of inclination but the direction of inclination is reversed with opposite polarity of frequency offset. The reason being the amplitude shoulders displayed on the opposite edges of signal profile with opposite polarity of frequency offset as clearly evident in Fig. 1. The asynchronous delay-tap sampling scatter plots corresponding to the eye diagrams in Fig. 4 are shown in Fig. 5(a) and 5(b) respectively. The asymmetry of the delay-tap plots with respect to the diagonal reflects the asymmetric distortions to the received signal. The direction of asymmetry in the delay-tap plots are opposite with positive and negative frequency offset and the asymmetric distortion increases with the magnitude of frequency offset.

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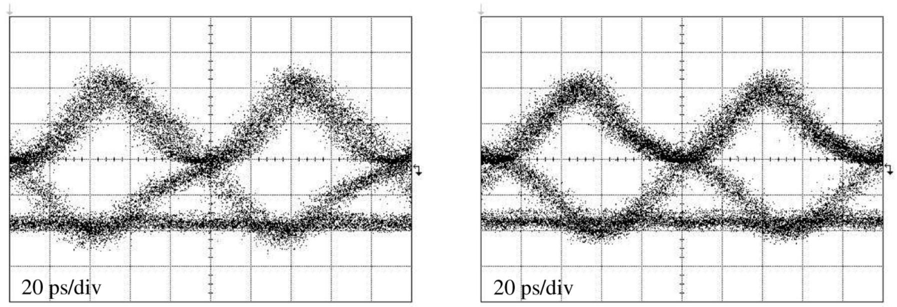
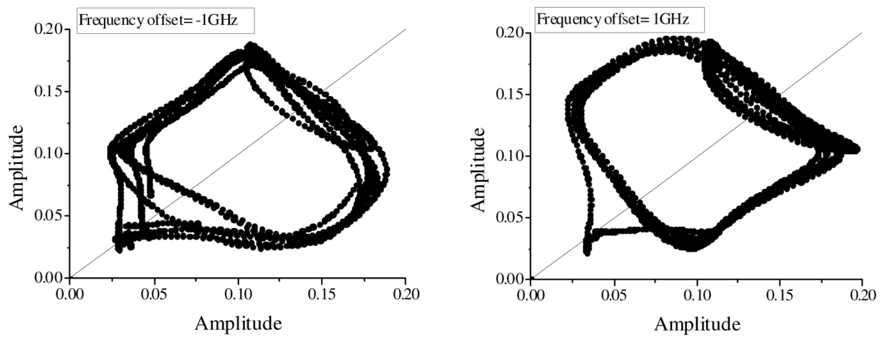


(a) (b)

Fig. 6. Experimental results of eye diagrams with CD of 340ps/nm and frequency offset of (a)-1GHz; (b)1GHz.



(a) (b)

Fig. 7. Experimental results of scatter plots with CD of 340ps/nm and frequency offset of (a)-1GHz; (b)1GHz.

Figure 6(a) and 6(b) show the experimental results of eye diagrams of demodulated NRZ-DPSK signal with frequency offset of −1GHz and 1GHz and CD offset of 340ps/nm respectively. The amplitude shoulders appear at half of the transition of the demodulated signal and eye diagrams show an obvious inclination. Figure 7(a) and 7(b) show the experiment results of the scatter plots corresponding to the eye diagrams shown in Fig. 6. The eye diagrams show opposite inclination direction and the scatter plots show opposite point direction with opposite frequency offset. It means that the signed frequency offset measurement can be realized by calculating the *DR* using Eq. (1).

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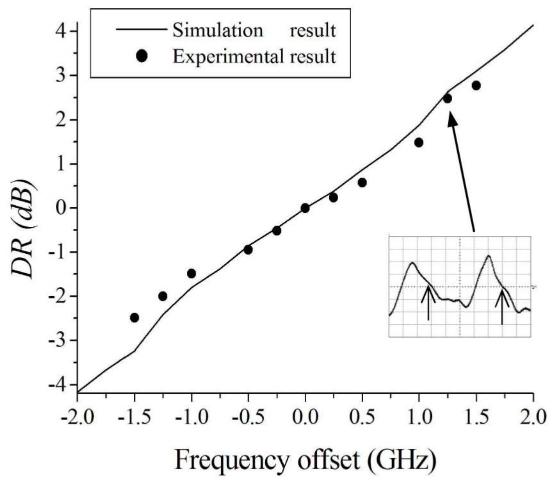

Fig. 8. Distance ratio *DR* vs. frequency offset results obtained from simulations and experiments. Insert: amplitude shoulders appear on the trailing edges of demodulated DPSK signals with frequency offset of 1.25GHz and CD offset of 340ps/nm.

Nevertheless, the largest distance may be obtained from a discrete point related to amplitude noise in experiment. The influence of ASE noise can be removed by using the distance averaging method. First finding the point which has largest distance and then making a circle around it with an appropriate tolerance as radius. Then computing the average distance of all the points inside the circle to the diagonal. In this case, the average distances d_1 and d_2 can be used instead of the absolute largest distance for *DR* calculation. From simulations and experiments, we found that 1/7 normalized amplitude is an appropriate value of radius for the elimination of noise effect. The averaging process can effectively eliminate discreteness caused by noise but if the signal distortion is too serious or the OSNR value is smaller than 15dB, the asymmetry will be difficult to extract and subsequently this method will lose its effectiveness. Acceptable results with relatively high accuracy can be obtained by using averaging method.

Figure 8 shows the simulation and experimental results for distance ratio *DR* versus frequency offsets. The measurement results demonstrated in Fig. 8 were obtained with CD of 340ps/nm. The inset experimentally illustrates the appearance of amplitude shoulder on the trailing edges of demodulated DPSK signal with frequency offset of 1.25GHz and CD offset of 340ps/nm. The amplitude shoulders are on opposite edges of signal profiles with opposite polarity of frequency offset. The *DR* varies from −4.16dB to 4.14dB with frequency offset from −2GHz to 2GHz. Therefore, the shift direction of optical carrier frequency can be distinguished. The measurement accuracy can reach upto 100MHz with 0.1dB variation of *DR*. The simulation and experimental results are in close agreement with each other.

5. Conclusions

We have demonstrated a signed frequency offset measurement technique for direct detection NRZ-DPSK system. The amplitude shoulders emerged on the trailing or leading edges of the demodulated signals in the presence of frequency offset and a fixed CD offset. In particular, the demodulated signals and eye diagrams exhibit asymmetric distortions and inclinations. Asynchronous delay-tap sampling was employed to make use of such asymmetric distortions to estimate the signed frequency offset. Simulation and experiments were conducted and results indicate that the measurement range can reach ± 2GHz and the sensitivity up to ± 100MHz.

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