Polarization dependent frequency shift induced BER penalty in DPSK demodulators

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***Abstract*— We experimentally analyzed the induced penalty due to polarization dependent frequency shift (PDf) for 10 GHz and 40 GHz DPSK demodulators, revealing a strong correlation with the PDf ratio and filtering effect of the delay interferometer.**

I. INTRODUCTION

Differential phase shift keying (DPSK) is one of the promising modulation formats for next generation high speed long haul optical communication systems due to the 3-dB improvement in the receiver sensitivity when using balanced detection and its robustness to fiber nonlinear effects compared to on-off keying (OOK) format [1]. DPSK is usually demodulated in a Mach-Zehnder delay interferometer (DI) with a one bit delay in one arm, such that the phase in one time slot interferes with the successive time slot [2]. However, the polarization dependence of the demodulator introduces a polarization dependent frequency shift (PDf) which causes a frequency offset between the laser's frequency and the transmissivity peak of DI, degrading the performance of DPSK systems [1,3]. PDf arises from birefringence in the demodulator paths resulting in a polarization phase shift $\Delta\varphi$, following the relation: $PDf = \frac{\Delta\varphi}{2\pi}\cdot FSR$. The free-spectral-range (FSR) of DI is typically chosen to be equal to the bit rate, such that the delay between the two paths of the interferometer is equal to exactly one bit period.

In [4], we showed that the PDf induced penalty of a 10 Gb/s non-return-zero (NRZ)-DPSK demodulator and demonstrated that we can reduce the effective PDf by a factor of two by properly adjusting the phase difference between the two arms of the DI. In this paper, we present experimental results of the PDf of a 40 GHz DPSK demodulator. By comparing the results with [4], we show that PDf ratio, defined as PDf/FSR, plays a predominant role in determining the performance of the demodulator. We also investigate the optical filtering effect incurred from PDf through an experiment on a 40 Gb/s return-zero (RZ)-DPSK signal. For the same PDf, the signal suffers more degradation because of the filtering effect imposed by the FSR of the demodulator.

II. EXPERIMENT SETUP & METHODOLOGY

The experiment setup for PDf measurement is shown in Figure 1. The light is generated from a distributed feedback (DFB) laser with a central frequency at 1551.7 nm, and modulated with a Mach-Zehnder modulator (MZM) at 40 Gb/s, appropriately biased to create DPSK modulated data. The MZM is driven by a pseudorandom bit sequence with a length

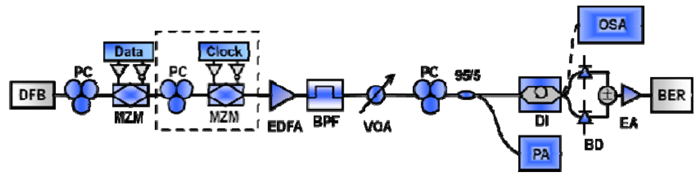

Figure 1. Schematic of the experiment setup.

of 2^{31}-1. The second MZM is driven by a 40 GHz clock signal to generate 40-Gb/s RZ pulses. The EDFA is used to compensate the losses of the modulators and the out-of-band noise generated is filtered out by using a 1-nm bandpass filter (BPF). A variable optical attenuator (VOA) is used to compensate the PDL of the 95/5 splitter as well as the demodulator such that the bit error rate (BER) floor, is the same for all states of polarization (SOP). The polarization controller (PC) before the DI is employed to change the SOP of the light entering the DI. In order to track the signal's SOP, a polarization analyzer (PA) is utilized. The DI has a PDf of 600 MHz and an FSR of 40 GHz. The signal spectrums of both the constructive port and the destructive port are observed using a complex optical spectrum analyzer (OSA) with a maximal resolution of 0.16pm (20MHz). By looking at the signal spectrum of the destructive port, we can tune the DI's peak transmissivity to align it with the laser's frequency for any arbitrary SOP. By looking at the signal spectrum of the constructive port, we can monitor the polarization dependent frequency shifts. To observe small frequency shifts of the optical spectrum, the measurements were done at the nulls of the spectrum, points where the spectrum exhibits sharper and more abrupt transitions.

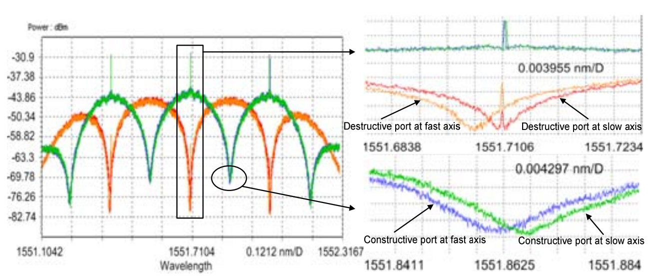

Figure 2. The aligning process and the PDf measurement.

By adjusting the PC in front of the DI, we set the SOP of the signal entering the DI to cover the entire Poincaré sphere. We have recorded a 2-tuple of orthogonal SOPs that provides the maximal frequency shift. These two SOPs represent the fast and the slow axis of the DI. We have tuned the DI to maximally transmit one of these two SOP, such that the signal will experience the worst BER penalty due to PDf. To quantify this BER penalty, we have measured the impact of a frequency offset of the laser on BER. The measurement consisted of detuning the laser's frequency alignment to the DI and measuring the BER for both SOP. Figure 2 shows the aligning process and the measured PDf of 600 MHz.

III. Experiment Results

First, we compared the PDf induced BER penalty for a 10 Gb/s NRZ-DPSK signal and a 40 Gb/s NRZ-DPSK signal. Figure 3 shows the plot of log(BER) versus frequency detuning for the fast and slow polarization axis of two DI, one with a FSR of 10 GHz and a second one with a FSR of 40 GHz. The PDf effect is showed in the zoomed area of figure 3. It is clear from the figure that the 10 Gb/s NRZ-DPSK signal is more sensitive to laser-DI misalignments. In the zoom-in figure, we can see that the 10 GHz DI has a maximal PDf of 360 MHz while the 40 GHz DI has a maximal PDf of 600 MHz. As shown in the zero-frequency shift point, the BER penalty of the maximal PDf for 10 GHz DI is around 1.1 dB while it is 0.12 dB for the 40 GHz DI. This effect can be explained by the PDf ratio. The PDf ratio of the 10 GHz DI is 0.04 while that of the 40 GHz DI is only 0.0175. This ratio enables us to compare DPSK demodulators with different PDf and FSR characteristics. The smaller the PDf ratio is, the smaller the impact on BER penalty will be. This agrees well with the measured results.

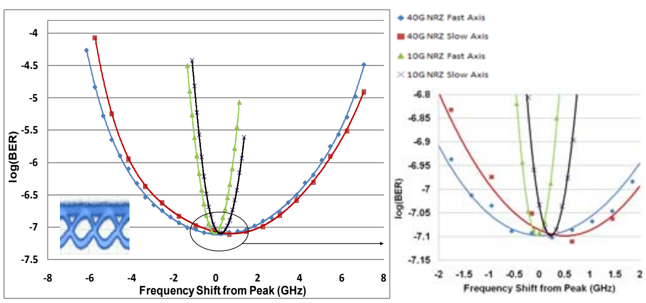

Figure 3. BER versus frequency detuning for the fast and slow polarization axis for 10 GHz and 40 GHz DI.

The PDf induced penalty was further compared for 40 Gb/s NRZ-DPSK signal and 40 Gb/s RZ-DPSK signal to study penalty incurred from PDf when the FSR of the DI is smaller than the bandwidth of the signal. Due to the RZ modulation, the spectrum width of the 40 Gb/s RZ-DPSK is almost doubled compared to the 40 Gb/s NRZ-DPSK. RZ demodulated signals have a lot of power in the side lobes compared to NRZ, which has most of its power in the main lobe. Thus the RZ signal suffers more from optical filtering imposed by the FSR of DI. To measure the penalty, we have set the minimal BER to be the same for both NRZ and RZ. This implies that in the case of RZ, the required OSNR to achieve the same BER level is greater to account for the power lost from optical filtering.

If the demodulator is perfectly aligned with the DI, the spectral filtering will be symmetrical and the demodulated signal will keep its symmetry. Any small variations of the alignment will break this symmetry, leading to the power filtering and spectrum distortion. As it can be seen from Figure 4, for the same frequency offset (we deliberately increase the frequency offset to make the results legible), RZ-DPSK suffers

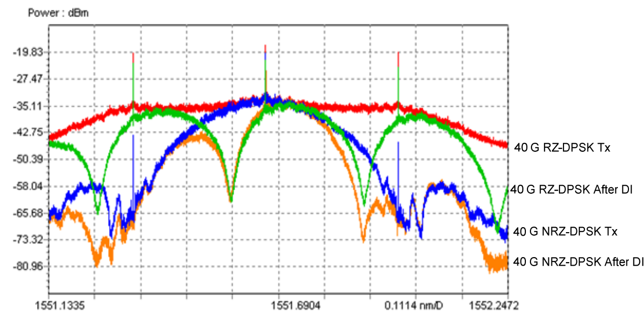

Figure 4. Comparison between 40G NRZ and RZ DPSK signals, both modulated and demodulated spectrums at a frequency offset of 11.425 GHz

more from the power filtering and spectrum distortion. Figure 5 shows the comparison of BER penalty between a 40 Gb/s RZ-DPSK and a 40 Gb/s NRZ-DPSK signal. As we can see from the figure, RZ is more sensitive to frequency shifts. The measured PDf induced BER penalty for the 40-Gb/s NRZ signal was measured to be 0.12 dB. For the 40-Gb/s RZ case, the PDf induced BER penalty was measure to be 0.46 dB. These results validate our analysis above.

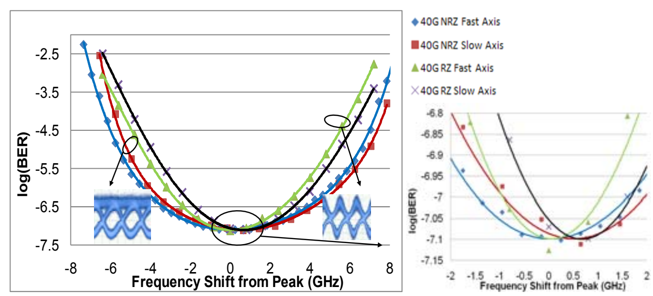

Figure 5. BER versus frequency detuning for 40G RZ and NRZ DPSK signals for the fast and slow polarization axis of a 40GHz DI.

IV. Conslusion

In this paper, PDf induced penalty for a 40 Gb/s NRZ-DPSK and a RZ-DPSK signal has been experimentally investigated. We found that the penalty has a large dependence on the PDf ratio, as well as on the optical filtering effect of the DI demodulator. The penalty ratio of different DIs can be determined by the PDf ratio, which is a figure of merit of the DI. We also showed that in cases where the signal bandwidth is wider than the FSR of the DI, the PDf induced penalty became larger due to the increase of power filtering and spectrum distortion.

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