Polarization Dependent Power Penalty in DPSK Demodulation

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Abstract: We analyze the power penalty associated with polarization dependency in DPSK demodulation and we show that this power penalty can be directly determined from the FSR of the delay interferometer. We demonstrate polarization-dependent phase shift mitigation by optimization of the phase component on one of the branches of the delay interferometer.

OCIS codes: (060.2340) Fiber optics components, (060.5060) Phase modulation, (060.2330) Fiber optics communications

1. Introduction

In the coming years, applications such as video, gaming, and high-speed Internet will be responsible for the tremendous traffic growth on the optical transport network. Differential phase shift keying (DPSK) is arguably becoming a format of choice in the deployment of next generation optical communication systems. At higher data rates such as 40 Gb/s and 100 Gb/s, the optical signal to noise ratio (OSNR) margin and tolerance to nonlinear effects are drastically reduced. DPSK is normally 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 [1]. However, it has been demonstrated that a frequency offset between the laser and the DI's transmissivity peak degrades the performance of DPSK systems [2-4]. A related effect arises from the polarization dependence of the demodulator resulting in a polarization dependent frequency shift (PDf) which also causes performance degradation [4,5]. PDf arises from birefringence in the demodulator path resulting in a polarization phase shift $\Delta\varphi$. The PDf is $\Delta\varphi/2\pi$ multiplied by the free-spectral-range (FSR) of a given interferometer, such that PDf scales linearly with FSR. The FSR 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.

The frequency offset between the laser and DI's transmissivity peak is related to the phase error by $\Delta f = \Delta\varphi*\mathrm{FSR}/2\pi$. This phase error can be caused by the polarization phase shift originating from birefringence in a demodulator, such as in bent optical fibers, which results in PDf. The spectral representation of PDf is typically measured by using Jones Matrix Eigen analysis (JME). We can evaluate the PDf by measuring the polarization dependence of either BER or power versus frequency offset. This last method requires a complete system setup but provides the real penalty associated with PDf.

In this paper, we demonstrate 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. Although the physical PDf of the device remains constant, we show that the absolute frequency shift of the peak transmissivity is halved. We also show a method of precisely measuring the polarization dependent loss (PDL) of a DI.

2. Experimental Results

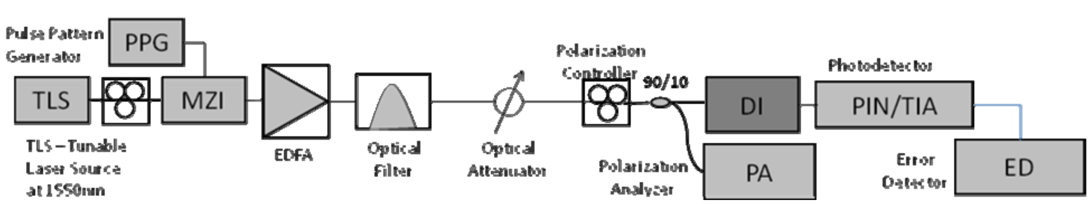

Fig. 1 Experimental Setup for measuring PDf penalty and PDL of a DPSK demodulator.

The experimental testbed for PDf penalty measurements is shown in Fig. 1. The channel is modulated with a Mach Zehnder modulator (MZI) at 10 Gb/s, appropriately biased to create DPSK modulated data. The optical modulator is driven by a pseudorandom bit sequence with a length of 2^{31}-1. In order to reduce any PDL influence on measurements, we amplify the optical signal to a high enough level to be detected by the photo-detector without errors. To reduce the noise generated by the EDFA, we filter the signal. An optical attenuator is used at the DI's

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input to compensate for the PDL of the coupler. The demodulator has a measured PDf of 360MHz and an FSR of 11.98GHz. Because of the sweep resolution of our measurements, we have chosen a high PDf demodulator to maximize the PDf effect.

The DI's transmissivity peak can be tuned to the laser frequency by adjusting the phase component in one of its arms. Due to a thermo-optic effect, the index of refraction is changed proportionally to the applied voltage. The phase difference between the two arms depends on both the applied voltage and the state of polarization (SOP) of the signal. Thus we can tune the DI's peak transmissivity to align it with the laser's frequency for any arbitrary SOP. The effective PDf is defined as the frequency shift between the laser's frequency and the transmission peak of the DI that is caused by polarization. Hence, the effective PDf will be maximized when the DI is tuned to maximally transmit an optical signal with an SOP that is on either the fast or the slow polarization axes of the DI.

By indirectly quantifying the PDf of the demodulator through either BER or power measurements, we need to devise a method to isolate the PDf from other effects that influence our measuring criteria such as PDL. We have chosen a fix set of SOPs that uniformly cover the Poincaré sphere. For a fixed laser frequency, we measured the peak transmissivity of each SOP by compensating thermo-electrically the PDf effect. Since there is a linear relation between the applied voltage and frequency shift, the PDf will be given by the maximal difference in applied voltage multiplied by a conversion factor. As a corollary of our measurements, the difference between the peak power values for different SOP will correspond to the PDL of the demodulator.

The maximal effective PDf was determined by power measurements (Fig. 2a), and BER measurements (Fig. 2b) and it was found to be 312MHz and 375MHz respectively. The measured power penalty associated with PDf was 0.05dB. The measured PDf penalty on BER was 1.5dB. BER penalty is defined as $10\cdot\log(BER_1/BER_2)$. We fitted our results to the profile of the DI's transmissivity and the curve was found to be $\sin^2(0.239*\text{Frequency})$, where Frequency is the frequency of the shift. Thus, the estimated FSR is 13.11GHz. The error between our estimated FSR and the real value is a combination of errors arising from lab measurements, curve fittings and the sweep resolution. The power penalty calculated from the fitted curve is 0.036dB and so, for a known FSR we can directly calculate the normalized power penalty caused by PDf using the mathematical relationship $\sin^2(\pi\cdot PDf/FSR)$.

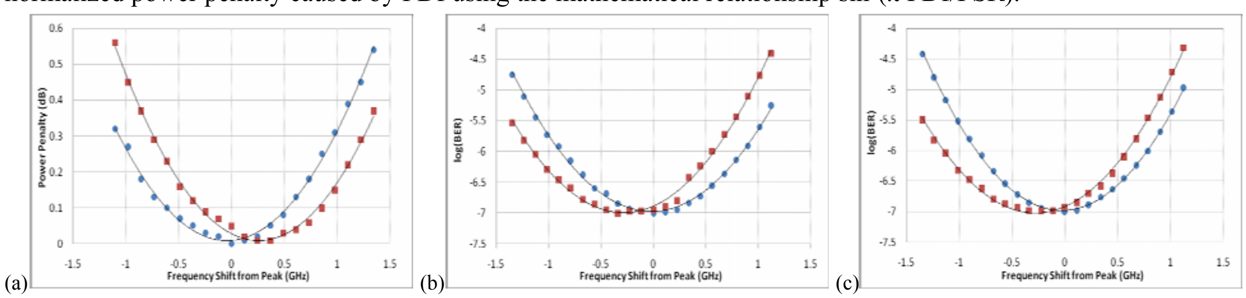

Fig. 2 (a) Power, (b) log(BER) vs. frequency shift for the maximal PDf, (c) log(BER) vs. frequency shift for the min effective PDf

(Dots: measured data, Solid lines: fitted curves)

To reduce the effective PDf, we have tuned the DI to maximally transmit an optical signal with an SOP that was in the mid-range of frequency shifts. The measured effective PDf is shown in Fig. 2c and it was 188MHz with a BER penalty of 0.46dB. Although the physical PDf remained constant, the shifts were from –PDf/2 to PDf/2, so the effective PDf is halved.

To conclude, we have shown that the PDf power penalty can be directly determined from the FSR of the DI. Also, by optimizing the tuning point of the DI, we can effectivelly reduce the PDf by a factor of 2 and improve the BER by 1dB.

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