Photonic Balancing in DPSK Detection Using Pulse Collision in a Semiconductor Optical Amplifier

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Abstract *We present a new DPSK receiver scheme where counter-propagating pulses collide in a saturated semiconductor optical amplifier, realizing photonically balanced single-ended detection. Decreased fluctuation of the mark level and 1.1-dB increased Q-factor is demonstrated experimentally at 22.3 Gbit/s.*

Introduction

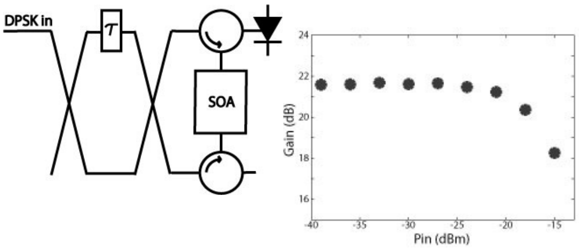
Future fiber optic transmission systems will utilize the D(Q)PSK modulation format due to the improved receiver sensitivity and the enhanced robustness to nonlinearities[1]. In a typical DPSK balanced receiver a one-bit delay interferometer (DI) converts the differentially phase encoded data into intensity modulated data. The two output arms of the DI carry optical signals that are logical opposites which terminate in a photodiode. The two generated electrical currents are subtracted one from another. The receiver's decision circuit uses this difference signal to differentiate between a binary 0 and 1. This process decreases the required optical signal to noise ratio by about 3 dB compared to direct detected intensity modulated signals or single-ended DPSK detection in only one arm[1].

In this paper we present a DPSK receiver balanced in the photonic (rather than in the electronic) domain where the pulses from each output arm of the demodulator collide in a saturated semiconductor optical amplifier (SOA) before detection by a photodiode. The interaction of the logically opposite pulses in the SOA serves a purpose analogous to balanced detection. For the first time we show how this scheme decreases the fluctuations of the mark level while maintaining the standard deviation of the space level. This improves the Q factor received by the photodiode, and the scheme could serve as an alternative to balanced detection.

A similar setup has been proposed as a phase regenerator for DPSK signals[2]. Our scheme can realize a balanced receiver with single-ended detection in a proof-of-concept experiment with a DPSK signal with data rate 22.3 Gbit/s and duty cycle 0.33. For the first time we also present how the scheme affects the standard deviation of the mark and space levels.

Principle of Operation

As shown in Fig. 1(a), a DPSK signal is input into a DI with one-bit delay which demodulates the DPSK signal. The intensity modulated signals from the two arms of the demodulator are logical opposites. These two signals then counter-propagate and collide in the semiconductor optical amplifier. During every bit slot, a strong pulse, representing binary data, enters one side of the SOA, and a weak "pulse," consisting of noise, enters the other side. The combined power of the pulses saturates the SOA and depletes the gain medium, so both pulses experience the same gain.



(a) (b)

Figure 1(a): Schematic of the photonic balanced DPSK receiver. Figure 1(b): Gain vs. input power for the SOA.

We consider the SOA as an ideal limiting amplifier, with the same gain for signals in both directions and their combined output power at constant level. One of the signals after the SOA has the power above half of saturated SOA total output power, and the other signal power is below that level. By setting the receiver decision level at half of SOA total output power, the single-ended receiver can achieve the functionality of balanced receiver: comparison of the two logically complementary DI output powers.

The variation in the strong pulse peak intensity is decreased due to the nonlinear gain of the SOA. The measured gain curve for the SOA used is shown in Fig. 1(b). When the SOA operates in the nonlinear regime mark pulses with higher intensity experience less gain and mark pulses with lower intensity absorb more gain from the SOA. As a result, the SOA acts as a limiting amplifier and thus lessens the fluctuations of pulse heights in the detected signal.

To quantify the performance of the DPSK receiver,

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we compare the measured eye diagram after the demodulator to the eye diagram at the output of the SOA. The measured values are: $\sigma_{1,0}$, the standard deviation of the mark, space level, and μ, the power difference between the means of the mark level and the space level. These values combine to form Q:

$$Q = \frac{\mu}{\sigma_1 + \sigma_0}.$$

Experimental Setup and Results

The experimental setup is shown in Fig. 2. Light from a DFB laser operating at 1550 nm is modulated by a Mach-Zehnder (MZ) modulator driven by a PRBS generator (2^{15}-1) at 22.3 GHz to generate a phase modulated signal. The signal is then modulated by another MZ modulator which acts as a pulse carver operating at 22.3 GHz. In between the modulators the signal is amplified and delayed to temporally match the modulators. This RZ-PSK data signal is not physically different from a DPSK signal – only logically different. The signal is combined with in-band ASE noise and is fed into an Erbium-doped fiber amplifier (EDFA). The amplified signal passes through a band pass filter and a variable attenuator. This signal then enters the DI where it is demodulated. The output from a DI arm is measured as the reference signal. A delay line is used to match the two arms between the demodulator and the SOA to ensure that the pulses arrive at the SOA simultaneously. After passing through the SOA the signal is sent through a band pass filter, an EDFA, and another band pass filter for measurements.

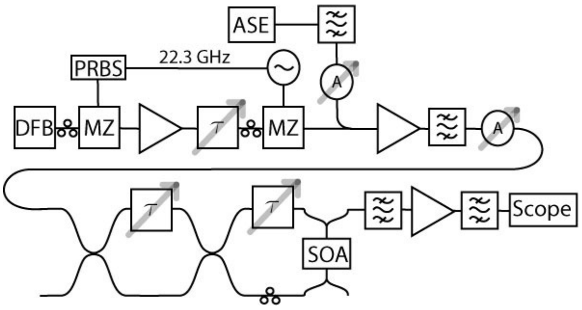

Figure 2: Experimental setup for proof-of-concept demonstration of the DPSK receiver.

Fig. 3 shows the standard deviation of the mark and space levels (σ_1 and σ_0) as a function of input power. The horizontal lines mark the σ_1 and σ_0 of the input signal measured after the demodulator, respectively. By comparing Fig. 3 and Fig. 1(b), we see that in the nonlinear regime of the amplifier, σ_1 at the output of the SOA is less than σ_1 at the reference. In the nonlinear operation of the SOA, σ_0 of the output decreases, but is never lower than the σ_0 of the input signal. The Q versus average input power is shown in Fig. 4. The improvement in the mark level leads to improvement in Q factor. The Q factor is improved by 1.1 dB compared to single-ended DPSK detection. Further optimization could lead to further improvement, suggesting this scheme could be used as an alternative to balanced detection.

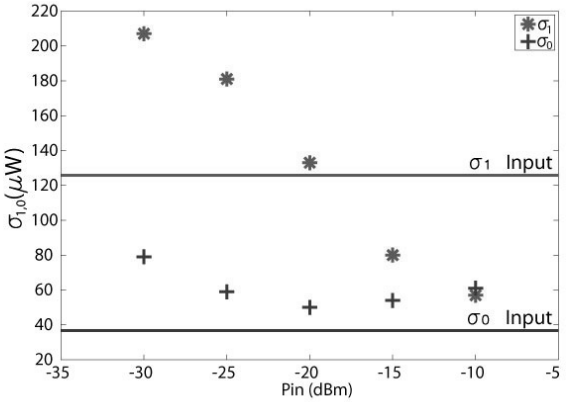

Figure 3: $\sigma_{1,0}$ vs. input power.

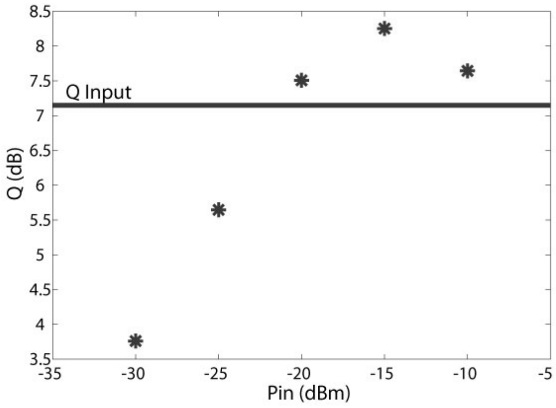

Figure 4: Q vs. input power.

Conclusions

We presented a receiver for DPSK signals. The receiver consisted of a DPSK demodulator where pulses from both output arms counter-propagated ("collided") in a saturated SOA. The pulse collision in the SOA improved the Q-factor by 1.1 dB. For the first time we demonstrated that this improvement came from compression of the mark level variation. This receiver provided an improvement analogous to balanced detection. This photonic level balancing can also be applied to optical signal processing implementations without any conversion to electrical signal.

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