Experimental Investigation of Receiver Sensitivity of RZ-DQPSK Modulation Format Using Balanced Detection

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Abstract: We investigate experimentally the power penalty obtained by doubling the data rate from 10Gb/s using RZ-DPSK modulation format to 20Gb/s using RZ-DQPSK modulation format. The measurement results confirm theoretical limits and compare balanced and single-ended detection.

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1. Introduction

Optical differential quadrature phase shift keying (DQPSK) has been shown to be a promising modulation format for achieving spectrally efficient data transmission to double the capacity in conjunction with robustness towards fiber nonlinear effects [1,2]. In [2] we proposed a transmitter setup using RZ pulse shaping and an implementation, which allows an economic upgrade of binary RZ-DPSK transmission to quaternary RZ-DQPSK transmission using a subsequent phase modulator.

In this paper, we measure the performance of RZ-DQPSK in terms of receiver sensitivity and make a comparison to RZ-DPSK for both single-ended and balanced detection. Two aspects have major influence on the theoretically achievable sensitivities:

First, it is known, that for binary DPSK using a balanced detector an improvement of approximately 3dB is achieved [3]. We confirm this improvement of 3dB for balanced detection also for DQPSK transmission. Second, using a Mach-Zehnder interferometer as differential receiver is an autocorrelating technique where a delayed replica of the received signal is used to enable detection without a local oscillator (LO). This induces an additional power penalty compared to coherent detection, which incorporates an LO with phase and frequency synchronization. This penalty turns out to be more severe for quaternary transmission compared to binary transmission [4].

In this paper we access both aspects experimentally. Section 2 depicts the setup for measuring the receiver sensitivity for RZ-DPSK and RZ-DQPSK, respectively. The measurement results are given in section 3 as well as the discussion of the sensitivities obtained against the background of theoretical considerations. Section 4 concludes the paper.

2. Measurement setup

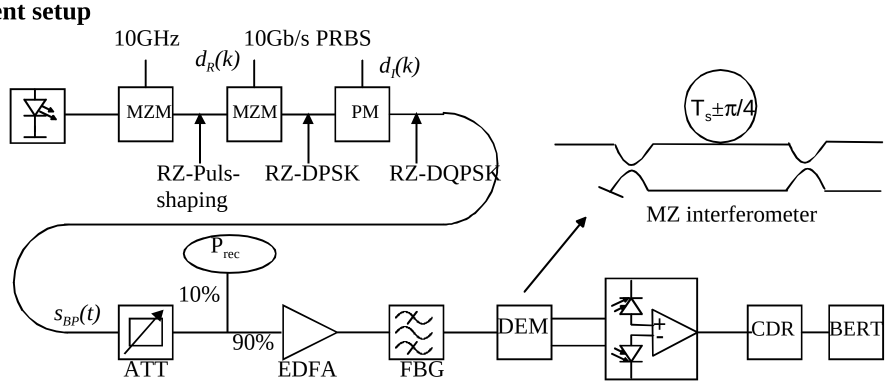

Fig. 1: Experimental setup for RZ-DQPSK at 20Gb/s with autocorrelation detector

To measure the receiver sensitivity of RZ-DQPSK format the setup according to fig. 1 was implemented. The transmitter consisted of an external cavity laser (ECL) operating at a wavelength of 1539.75nm followed by two $LiNbO_3$ Mach-Zehnder modulators (MZM) that were operated in push-pull mode. The first MZM was driven with the 10GHz clock signal to generate the RZ-pulse train. This was done by biasing the modulator at the zero in its characteristic curve. The second MZM was used to form a phase-shift keyed signal. This MZM was biased at the zero in its characteristic curve, too. It was driven with a 10Gb/s non-return-to-zero (NRZ) electrical pseudo random bit sequence (PRBS) of length 2^9-1. This sequence is referred to as d_R because it forms the real part of the RZ-DQPSK signal.

The subsequent phase modulator (PM) consisted of a single $LiNbO_3$ optical wave guide with one electrode. It was driven with the complementary PRBS signal as used for the second MZM. According to the PRBS signal d_R, this sequence is referred to as d_I because it forms the imaginary part of the RZ-DQPSK signal. The driving voltage of the PRBS signal was adjusted to achieve a phase shift of 90° for the high level at the electrical input and 0° for the low level. An RF phase shifter was used to synchronize d_R and d_I. It should be noted that the transit time for the optical signal from the second MZM to the PM was 10.5ns. This ensures that the two PRBS signals are uncorrelated.

An optical monitor coupler was used to measure the power of the transmitted signal before entering the 2-stage preamplifier. The small-signal gain and the noise figure of the erbium-doped fiber amplifier (EDFA) were 32dB and 4.5dB, respectively. Two external optical isolators (insertion loss: 0.2dB each) were placed in front of the preamplifier. After amplifying the signal it was filtered by a fiber bragg grating (FBG) with a center frequency of 1539.75nm and a bandwidth of 0.2nm to suppress the out-of-band ASE noise.

The real (in-phase) and imaginary (quadrature) part of the DQPSK signal were detected by a Mach-Zehnder interferometer (MZI) that incorporated a delay of one symbol duration of 100ps (autocorrelation detector). It was based on two spliced fiber couplers. The phase difference between the signal and its delayed replica was adjusted thoroughly via temperature control of the length of the arms of the MZI. To detect the real and imaginary component of the DQPSK signal the phase difference of the two band-pass signals has to be adjusted to +45° and –45°, respectively. In this way both components were measured separately on a data rate of 10Gb/s per tributary. It is worth noting that this MZI is the same that is used for detecting binary DPSK signals. The two outputs from the MZI were fed to a commercially available, low-noise balanced receiver with a bandwidth of 14GHz. The optical path lengths to the balanced receiver were roughly guaranteed by an appropriate splicing. In case of single-ended detection only one output of the MZI was used and connected to a standard photo diode with 12GHz bandwidth. After clock- and data recovery (CDR) the BER was measured.

For these measurements there was no differential quaternary precoder available. In contrast to binary DPSK transmission the precoded PRBS signal is not just the delayed PRBS input signal. This problem was bypassed by taking into account that the input data streams are mapped to the output of the transmission line in a deterministic way. Thus, BER-measurements were allowed by programming the BER-tester with the expected data sequences at the receiver. To determine the expected data streams at the receiver the transit time from the second MZM to the PM has to be considered. With longer PRBS signals it is more and more complicated to determine the expected output sequences. Up to now this has been done in our lab for a PRBS length of 2^9-1.

To measure the performance of binary RZ-DPSK format a similar setup as in fig. 1 was used. For generating the RZ-DPSK signal the subsequent phase modulator was omitted. Moreover, the phase difference in the receiver-MZI was adjusted to 0°. Note that the transmission bit rate for DQPSK is 20Gb/s whereas for DPSK it is 10Gb/s.

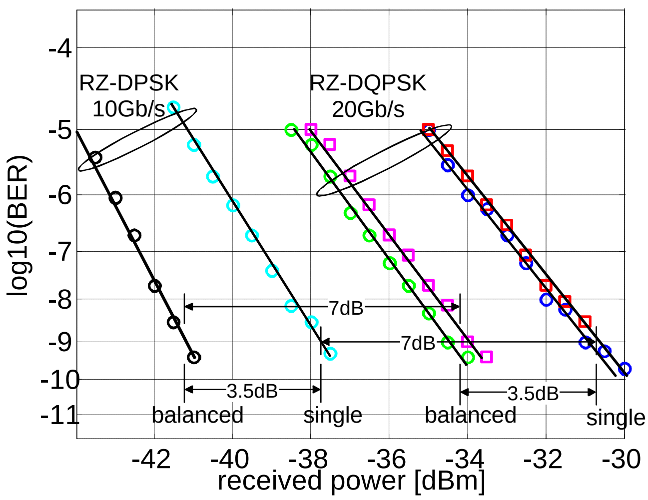

Fig. 2: Measured BER values for RZ-DPSK format at 10Gb/s and RZ-DQPSK at 20Gb/s (real (?) and imaginary (?) component) for balanced and single ended-detection, respectively

3. Results and discussion

Fig. 2 shows the measured BER values for RZ-DQPSK and RZ-DPSK for both single ended and balanced reception, respectively.

The measured eye diagrams for the imaginary channel of RZ-DQPSK single ended and balanced detection are given in fig. 3. To measure these eye diagrams the received power at the preamplifier was set to –10dBm to reduce the noise sufficiently.

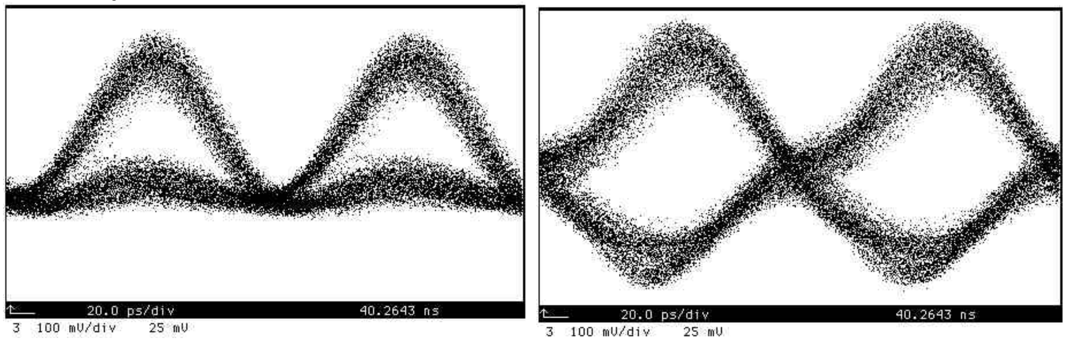

Fig. 3: Measured eye diagrams for imaginary channel of RZ-DQPSK at 20Gb/s for single ended detection (left) and balanced (right)

The BER-curves given in fig. 2 confirm the sensitivity properties known from theory [4] and mentioned in the introduction:

For both RZ-DPSK and RZ-DQPSK transmission, the balanced detector performs 3.5dB better compared to the single-ended detector. 0.5dB are attributed to the better thermal noise properties of the balanced detector, which is confirmed by the fact, that for high BERs where the thermal noise is completely negligible compared to the ASE noise, there is only a difference of 3dB [5]. This is known to be equal to the maximum performance improvement achievable for balanced detection with sufficiently narrowband filtering in front of the MZI [6].

Moreover, if we compare RZ-DPSK and RZ-DQPSK, for both detection strategies (i.e. balanced/single-ended) RZ-DQPSK performs approximately 7dB worse than RZ-DPSK. This is explained as follows:

Taking the step from binary to quaternary transmission (doubling the transmission bit rate) using the same signal power, the minimum distance between the transmitted symbols in the complex plane is reduced by a factor of square root of 2. Thus, to achieve the same minimum symbol distance for DQPSK the power has to be increased by 3dB. In addition, in [4] it is shown, that autocorrelation detection compared to coherent detection induces an additional penalty. For binary DPSK, this additional penalty is negligible for good values of the BER, while for quaternary transmission a penalty of approximately 2dB is obtained as shown theoretically in [4].

As a result, a sensitivity difference of at least 5dB is expected. We measure 7dB and attribute the remaining difference of 2dB to the accumulation of several minor impairments. For example, for the transmitter phase modulator the amplitude of the driving voltage must be set carefully to ensure exact orthogonality of real and imaginary part to avoid ISI. In the same way, for the receiver MZI any derivation from the phase shift of +45° and –45° introduces ISI as well.

5. Conclusions

For RZ-DQPSK at 20Gb/s as well as for RZ-DPSK at 10Gb/s we experimentally measured an improvement of 3.5dB in receiver sensitivity by using balanced detection in comparison to single-ended detection. Doubling the data rate by making the transition from RZ-DPSK towards RZ-DQPSK, a power penalty of 7dB was measured, which, due to some degrading implementation effects, is close to the theoretically achievable value of 5dB inherently obtained for autocorrelation detection.

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