RZ-DQPSK FORMAT WITH HIGH SPECTRAL EFFICIENCY AND HIGH ROBUSTNESS TOWARDS FIBER NONLINEARITIES

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Abstract *We propose a simple concept to implement a direct-detection DQPSK transmission to double the transmission rate. The robustness of RZ-DQPSK towards nonlinearities is investigated in a 8x80Gb/s WDM-system over 400km SSMF and compared to 8x40Gb/s RZ-ASK.*

Introduction

Recently, differential binary phase-shift-keying (DBPSK) with return to zero pulse shape (RZ) has been considered as an advantageous modulation format in optical transmission systems to achieve a higher robustness towards nonlinear effects [1,2]. In this work, we propose a simple concept to extend CF-RZ-DPSK to differential quadrature PSK (RZ-DQPSK) to increase the spectral efficiency by a factor of two. RZ-DQPSK transmission is implemented by means of an additional sequential phase modulator and two binary DPSK balanced receivers in parallel. The performance of 8x80Gb/s RZ-DQPSK is compared to 8x40Gb/s conventional On/Off-Keying with RZ pulse shape (RZ-ASK) both at a channel spacing of 100GHz over 400km dispersion compensated SSMF.

Proposal for RZ-DQPSK direct detection

In most DQPSK systems in classical digital communications the four-symbol signal is generated by superposing two bipolar modulated carrier frequencies that exhibit the same frequency but have a 90° phase shift to each other [4]. It is difficult to adapt this concept to optical communications because the required phase shift of 90° has to be guaranteed until the signals are merged by a 3dB coupler. In a recent optical DQPSK proposal [3] this problem is overcome by O/E converting part of the transmitter signal and feeding it to a servo-control loop. We avoid this problem by a DQPSK transmitter setup shown in fig. 1.

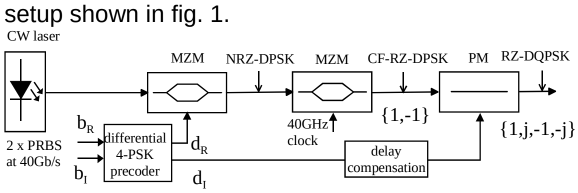

Fig. 1: Transmission setup for RZ-DQPSK

The first two Mach-Zehnder modulators (MZM) form a chirp-free binary DPSK signal with RZ pulse shape (CF-RZ-DPSK [2]). The subsequent phase modulator (PM) with a phase shift of either 90° (d_I=1) or 0° (d_I=0) generates four symbols out of the binary PSK signal, see fig. 2a). This concept requires only electrical tuning of the PM input data within a bit duration by a delay compensation. Fig. 2a) shows that the signal has almost no power during bit transitions and is thus inherently chirp free. This is advantageous considering the effect of group velocity dispersion (GVD). Fig. 1 also shows that for transmitting RZ-DQPSK with a bit rate of 80Gb/s the electronic components only have to operate at the symbol rate of 40GSymb/s.

The differential QPSK precoder [4] is necessary in order to use the simple receiver [3] in fig. 2b) with an optical filter (delay line T_S= 2 x bit duration) and two balanced receivers.

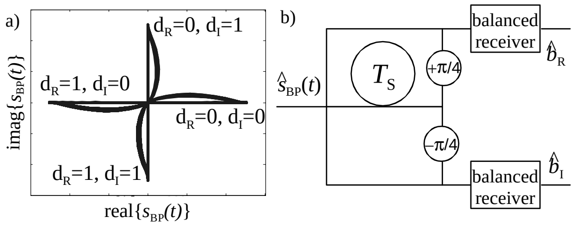

Fig. 2: a) Trajectories of RZ-DQPSK signal constellation in complex plane, b) DQPSK receiver

Experimental verification at 20Gb/s

For experimental use at 20Gb/s, we implemented the transmitter according to fig. 1. For the receiver, the optical filter was realized by means of spliced fiber couplers. The length of the arms are chosen carefully via temperature control. For 20Gb/s BER measurements without precoder, the pulse pattern generator was programmed with a 2^7-1 data sequence that allowed to receive the expected sequence with the bit error tester. We achieve error free transmission in each arm. The measured eye diagram in the upper receiver arm for 20Gb/s is shown in fig. 3.

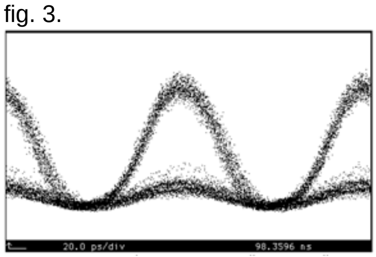

Fig. 3: Measured RZ-DQPSK eye diagram for 20Gb/s data rate using single photo diode

Setup

The DWDM signal consists of 8 multiplexed channels in RZ-DQPSK and RZ-ASK modulation format with a data rate of 80Gb/s and 40Gb/s per channel, respectively (channel spacing 100GHz, conform to ITU-T G.692). The optical multiplexer is modeled as an Arrayed-Waveguide Grating with a Gaussian shaped transfer function for each channel (B_{3dB}=72GHz). The RZ-DQPSK transmission setup is described in the previous section. The conventional RZ-ASK transmitter consists of two MZM. For RZ-DQPSK and RZ-ASK the 8-channel DWDM signal (PRBS length 2^{10}-1) passes through 4 fiber spans. Each span consists of 100km of a standard single mode fiber followed by a dispersion compensating fiber and a noiseless optical amplifier. The average fiber input power per channel in each span is varied between 0 and 9dBm. The length of the DCF is chosen such that the 4th channel (f_T=193.4THz) is fully compensated. At the receiver side a channel selection filter with a bandwidth of 100GHz filters the signal at a center frequency of 193.4THz. The DQPSK receiver of fig. 2b) is used with the optical filter, two balanced receivers and an electrical lowpass filter (Butterworth, 3rd order, f_{3dB}=28GHz).

Results

In fig. 4 and 5, we show simulation results that are discussed in the next section. To understand the influence of the various nonlinear effects separately, two types of WDM simulation methods are carried out. The first considers linear crosstalk and full Kerr nonlinearity (SPM, XPM and FWM). For the second, we neglected XPM and FWM in our simulation [2]. In fig. 4, we measure the eye opening penalty (EOP) of the 4th channel for both WDM systems respectively normalized to the back-to-back case as a function of the average fiber input power per channel P_{in}.

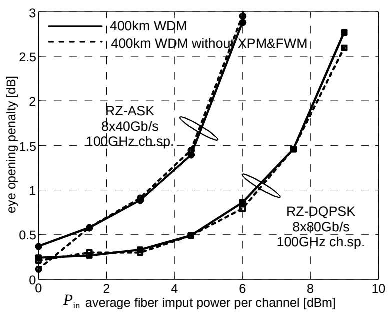

Fig. 4: Eye opening penalty over P_{in} for 8x40Gb/s-RZ-ASK, 8x80-Gb/s-RZ-DQPSK: WDM (lin. Xtalk, SPM, XPM, FWM), WDM without XPM&FWM

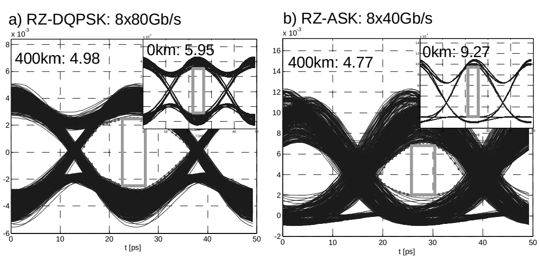

Figure 5: Eye opening of a): 80Gb/s-RZ-DQPSK and b): 40Gb/s-RZ-ASK, P_{in}=6dBm, 400km, 100GHz ch.sp., WDM considering lin. Xtalk, SPM, XPM, FWM

The eye diagrams of the 40Gb/s-RZ-ASK signal and the 80Gb/s-RZ-DQPSK signal at 193.4THz and for 6dBm average fiber input power in case of full Kerr nonlinearities are shown in fig. 5 in comparison to the back-to-back eye diagrams.

Discussion

Our simulation results (fig. 4 and 5) indicate that RZ-DQPSK with a spectral efficiency of 0.8b/s/Hz tolerates even higher input powers than RZ-ASK with just 0.4b/s/Hz spectral efficiency.

Fig. 4 shows that in the case of the considered WDM-system for an EOP of 1dB RZ-DQPSK tolerates approx. 3dB more input power compared to RZ-ASK. This indicates that the advantageous properties of binary DPSK that are shown in e.g. [1,2] can be transferred to (quadrature) RZ-DQPSK. By comparing the simulation methods with (i) full Kerr nonlinearity (solid line) and (ii) neglecting XPM and FWM (dashed line) in fig. 4, it can be noticed that for RZ-ASK and RZ-DQPSK the most important impairment is SPM in agreement with [5]. Nearly no additional degradation through XPM and FWM can be seen.

Further simulations indicated, that 80Gb/s RZ-DQPSK and 40Gb/s RZ-ASK reveal the same amount of dispersion tolerance although the bit-rate is doubled. Comparing on equal bit rate, this means that for the QPSK format the uncompensated length can be quadrupled.

Conclusions

We propose an RZ-DQPSK approach to double the transmission rate in optical direct detection systems with standard equipment. Compared to RZ-ASK a differential quaternary precoder, a subsequent phase modulator and a simple optical filter in front of two balanced receivers is needed. We could experimentally prove the feasibility of this concept at a data rate of 20Gb/s. By means of RZ-DQPSK, we achieve a spectral efficiency of 0.8B/s/Hz without polarization multiplexing. Our simulations show that in spite of the doubled transmission rate (8x80Gb/s) RZ-DQPSK is even more robust against fiber nonlinearities than RZ-ASK with just half the bit rate (8x40Gb/s), both having a channel spacing of 100GHz. By means of this it is possible not only to double the transmission rate but also to extend the optical transparent length through increased robustness towards fiber nonlinearities.

References

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