Experimental Investigation of RZ-8DPSK at 3x 10.7Gb/s

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Abstract: We experimentally determine the required OSNR and dispersion tolerance of RZ-8DPSK at 32.1Gb/s. We show a 1dB dispersion tolerance of 600ps/nm and an OSNR penalty of 6.7dB compared to RZ-DQPSK at the same symbol rate.

Introduction:
It is well known that the advanced return to zero (RZ) optical differential quadrature phase shift keying (DQPSK) modulation is transmitting two bits by each symbol and is thus advantageous for increasing the spectral efficiency by maintaining a high robustness towards non-linear fibre effects [1]. Increasing the transmitted bits per symbol can be achieved by using additional symbol states in the complex plane constellation using additional amplitude (AM) or phase modulation (PM). In [2] and [3] the RZ-DQPSK format was combined with a binary and quaternary AM resulting in 8 and 16 possible states and thus in 3 and 4 transmitted bits per symbol, respectively. Increasing the DQPSK phase states by a factor of two results in the 8DPSK modulation format. A coherent reception of 8DPSK was presented in [4]. However, according to our knowledge non-coherent reception of 8DPSK was only investigated by numerical simulations using different receiver methods with multi-level or binary reception techniques [5-9]. In this contribution we investigate experimentally the noise and chromatic dispersion tolerance of the 8DPSK modulation format at a symbol rate of 10.7 GSymbols/s and investigate which receiver structure is feasible for a non-coherent reception of the 8DPSK modulation format.

Transmitter set-up:
To measure the required optical signal to noise ratio (OSNR) of RZ-8DPSK a 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 a Mach-Zehnder modulator (MZM) for generating a 10.7GHz RZ-pulse train with 50 % duty cycle. The optical RZ-signal was coupled into two MZM arranged within a Mach-Zehnder super-structure resulting in an 21.4Gb/s RZ-DQPSK modulated signal. A subsequent phase modulator (PM) generated an additional phase shift of 45° or 0° depending on the logical level of the drive signal data 3 resulting in an optical RZ-8DPSK signal at 10.7GSymbols/s or 32.1Gb/s, respectivily. The three data modulators were driven with delayed and thus decorrelated pseudo random bit sequences (PRBS) with a length of 2^7-1. The optical path difference between the Mach-Zehnder super structure and the PM was approximatily 18ns which ensured additional decorrelation of the data streams.

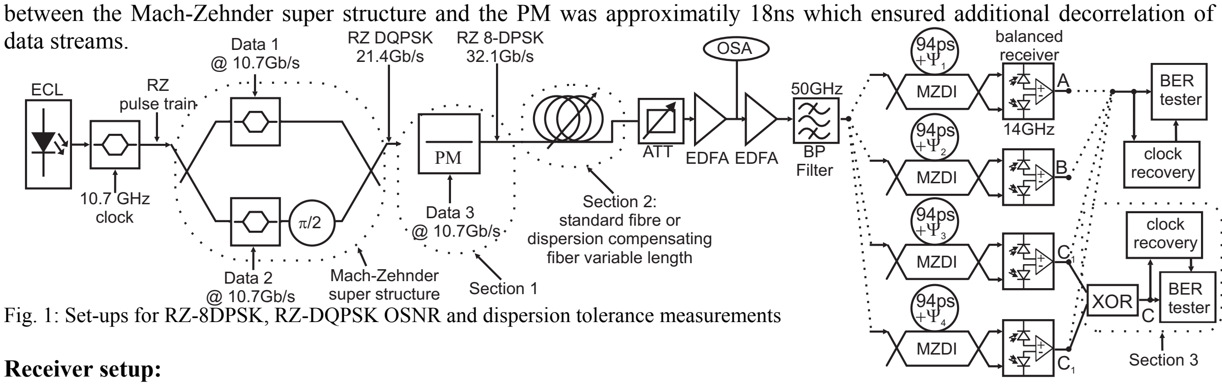

Fig. 1: Set-ups for RZ-8DPSK, RZ-DQPSK OSNR and dispersion tolerance measurements

Receiver setup:
In [5-9] different receiver structures for the 8DPSK modulation format were investigated. All of these receivers require a differential precoder at the transmitter side and two sets of MZDI and balanced receivers with electrical components operating at the symbol rate at the receiver side. The outputs of these receivers are electrical multi-level signals which require additional concurrent analogue or digital post processing [5-10]. However, in this contribution we used a receiver technique with binary detection schemes according to [7-9] which exhibits 3dB lower OSNR requirements [7] compared to the receivers with multi level detection schemes. This receiver requires four sets of MZDI (with phase differences of $\Psi_1=3\pi/8$, $\Psi_2=-\pi/8$, $\Psi_3=+\pi/8$ and $\Psi_4=-3\pi/8$) and balanced receivers and an additional logical XOR- gate in order to receive all three tributaries (A-C) of the 8DPSK signal. This receiver allowed us to measure the BERs of the three data tributaries one after another. For our measurements we could omit the XOR gate from section 3 because the BER of the third data tributary C is in the worst case the BER of the signal C_1 plus the BER of signal C_2. Thus the complete BER of RZ-8DPSK can be calculated by $BER_{RZ\text{-}8DPSK}=1/3*(BER(A) + BER(B) + BER(C_1) + BER(C_2))$.

Measurement set-up:
In order to measure the required OSNR for RZ-8DPSK and RZ-DQPSK we used the setup according to figure 1. In section two we used standard single-mode fibre or dispersion compensation fibre of different lengths. Section 2 was omitted for back-to-back measurements. The resolution bandwidth of the optical spectrum analyser (OSA) was set to 0.1nm. For measurements with the RZ-DQPSK modulation format we omitted section 1 and 3 and measured the two data tributaries one after another by adjusting a

phase difference of $\Psi_1=\pi/4$ and $\Psi_2=-\pi/4$ inside the MZDI. For all experiments differential precoding was omitted by programming the bit error ratio (BER) tester with the expected bits. The complete BER for RZ-DQPSK can be calculated by $BER_{RZ\text{-}DQPSK}= ½*(BER(A)+BER(B))$.

Results and discussion:

In figure 2 we plot the measured (2a) and simulated (2b) eye diagram of the multi-level electrical RZ-8DPSK signal after the balanced receiver for a phase difference inside the MZDI of $\pi/8$. We notice from the measurement that the upper and lower eye opening is already distorted. We think that these distortions are due to unavoidable implementation imperfections at the transmitter and receiver side. For example: In order to achieve an exact phase shift of 45º by the phase modulator at the transmitter side a driver amplifier and phase modulator with high linearity is required. At the receiver side a balanced receiver with same optical input power into both arms and an exact phase difference of Ψ inside the MZDI is desirable [9]. From our measured eye diagrams we conclude that a practical implementation of other receiver techniques [5-10] which requires multi-level electrical signal detection is more complicated.

Next we plot the required OSNR for 21.4Gb/s RZ-DQPSK and 32.1Gb/s RZ-8DPSK at the same symbol rate of 10.7GSymbols/s for all 10.7Gb/s tributaries in figure 2c. We notice that the difference between the two RZ-DQPSK tributaries is within measurement tolerance of 0.5dB. By comparing the four measured RZ-8DPSK data tributaries we see that three are in a good agreement. However, the forth tributary exhibits an OSNR penalty at a BER of 10^{-9} of approximately 1.75dB if compared to the other three tributaries. We think that these differences are due to imperfect receiver implementations, measurement tolerances. If we compare the worst RZ-DQPSK with the worst RZ-8DPSK tributary at a BER of 10^{-8} we obtain a penalty of 6.7dB. This can be explained with the narrower distance in the complex plane between adjacent symbols. In [7] we find an OSNR difference of 4dB which was numerically determined between RZ-DQPSK and RZ-8DPSK for a fixed data rate of 40Gb/s at a BER of 10^{-8}. At the same symbol rate we expect a 1.5 times (1.8dB) higher OSNR difference, thus 5.8dB. Our measurements are thus in good agreement with the numerical results from [7].

Next we show the dispersion tolerance of RZ-8DPSK for a fixed BER of 10^{-9} by plotting the residual dispersion versus the OSNR penalty at a BER of 10^{-9} compared to a back-to-back measurement for one tributary in figure 2d. We notice that the dispersion tolerance for the 32.1Gb/s RZ-8DPSK modulation format is approximately 600ps/nm. We explain this high dispersion tolerance with the small spectral width of the modulated signal. In [7] we find a simulated dispersion tolerance for 1dB OSNR penalty at a BER of 10^{-12} of 260ps/nm for RZ-DQPSK and 480ps/nm for RZ-D8PSK at the same data rate of 40Gb/s. If a symbol rate of 10Gsymbols/s is considered we estimate a 1dB dispersion tolerance of 1040ps/nm ($260ps/nm*2^2$) for RZ-DQPSK and 853.3ps/nm ($480ps/nm*1.33^2$) for RZ-8DPSK. Our measurements are in a similar range and thus in agreement with the numerical results from [7]. Considering this for our measurements we expect for RZ-DQPSK a dispersion tolerance of 730ps/nm.

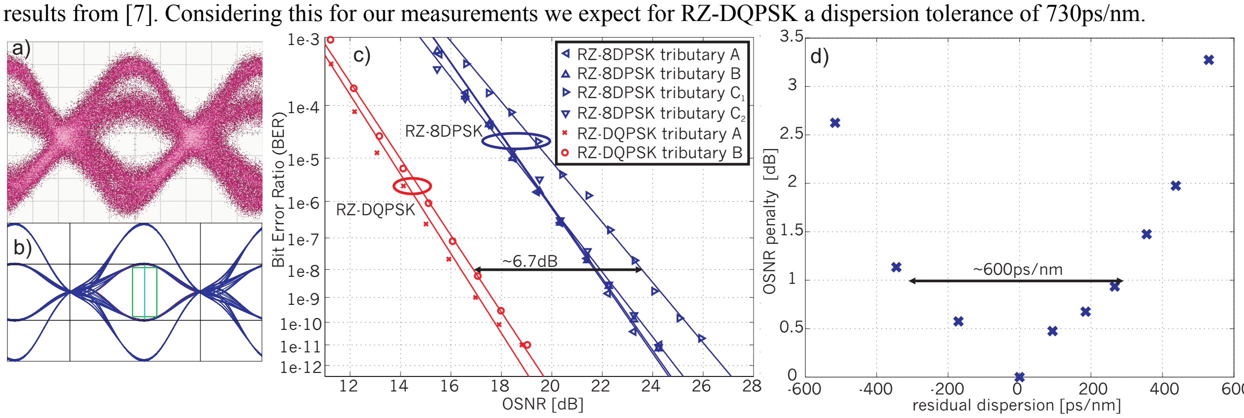

Fig. 2: a) Measured eye diagram for RZ-8DPSK; b) simulated eye diagram after 14GHz Butterworth low pass filter; c) BER curves for 10.7Gsymbols RZ-DQPSK and RZ-8DPSK; d) OSNR penalty vs. residual dispersion for one RZ-8DPSK tributary.

Conclusions:

In this contribution we investigated a non-coherent RZ-8DPSK receiver setup by determining the required OSNR at a data rate of 32.1Gb/s. We compared the OSNR requirement with RZ-DQPSK at same symbol rate and measured an OSNR penalty of 6.7dB which is in agreement with numerical results. In addition to that we showed also that the RZ-8DPSK modulation format exhibits a high dispersion tolerance. For 32.1Gb/s we measured a dispersion tolerance of 600ps/nm.

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