A Systematic Approach to Investigate the Tolerance of 53.5 GBaud 33%-RZ-DQPSK towards Optical Filtering and Residual Chromatic Dispersion based on Experiments

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Abstract: We experimentally investigate 107 Gb/s 33%-RZ-DQPSK to explore its tolerance towards chromatic dispersion and narrow-band optical filtering. The results indicate that dispersion tolerance can be increased by the use of appropriate filters.

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1. Introduction

During the last years 100 Gb/s optical transmission per channel has been shown in several ways. DP-QPSK (dual polarization quadrature phase shift keying) at 25-28 GBaud with coherent detection has become the modulation of choice to achieve this data rate without significantly increasing the channel's requirements of bandwidth [1]. In our paper we concentrate on the next higher symbol rate, i.e. 50-56 GBaud for two reasons: (i) for next generation coherent systems, this symbol rate will be used, probably together with higher modulation levels, to achieve data rates beyond 100 Gb/s [2]. (ii) using a reduced complexity receiver without local oscillator and digital signal processing and without polarization multiplexing (polmux) this symbol rate is required to achieve 100 Gb/s with a less complex receiver structure based on DQPSK [3-7]. Field tests partially with live traffic have been demonstrated in [4, 7]. However, most of the experiments aim to show the feasibility of increasing transmission capacity in realistic setups, reducing the requirements for amplification [6], increasing span lengths [5] or investigating the influence of co-propagating neighbor channels [4, 7]. Transmission impairments such as narrow-band optical filtering in WDM interleavers and de-interleavers have been investigated for the specific setup [4], but not in general.

In this paper, the aim is slightly different. The general requirements of the DQPSK signal regarding chromatic dispersion and bandwidth (limited by network elements such as interleavers in reconfigurable optical add drop multiplexers (ROADMs)) are to be explored systematically. With the knowledge of the numbers of narrow-band filters and possible variations in center frequencies the "real" bandwidth of a system can be estimated. By knowing the filter requirements of DQPSK, the penalty due to this filtering can be assessed. Another issue where the knowledge of filtering properties is necessary is in WDM transmission with narrow channel spacing where the signals should be pre-filtered to prevent linear crosstalk [4]. Moreover, transmission setups might include channelized FBGs (fiber Bragg gratings) for inline or residual dispersion compensation which also band-limit the signal. For our investigation we choose 33% duty cycle RZ (return-to-zero) pulse shaping, whereas all the other publications use 50%-, 66%-RZ and NRZ (non-return-to-zero).

Chromatic dispersion is the other issue addressed here. In a realistic WDM network the residual dispersion might not be ideally compensated. The knowledge of the tolerable chromatic dispersion of DQPSK is an important design parameter. Finally, since the influence of chromatic dispersion depends on the signal bandwidth, we show that filtering can increase the tolerance towards chromatic dispersion up to a certain amount.

2. Experimental setup

Figure 1 shows the experimental setup. The 1550.11 nm continuous wave laser light is passed through a Mach-Zehnder modulator (MZM) which is driven by a 26.75 GHz clock to produce a 33%-RZ optical pulse train. An IQ-MZM which consists of two parallel MZMs with a $\pi/2$ phase shift is driven by two 53.5 Gb/s binary data sequences from a 53.5 Gb/s pulse pattern generator (PPG), where the inverse data output is shifted by 35 bit. After a booster EDFA (erbium doped fiber amplifier) we insert a bandwidth tunable filter with flat-top characteristics. It is followed by a variable optical attenuator (VOA) and a tunable dispersion device, which consists of small fiber pieces which can be arbitrarily connected to achieve the desired amount of dispersion with a step size of 10 ps/nm. The reason to choose this device and not a tunable FBG is that channelized FBGs also introduce filtering which might influence the results. To prevent fiber nonlinearity impact, the input power to the fiber device is kept below -3 dBm. Another VOA and a second EDFA are used to adjust the receiver input OSNR which is measured by an optical spectrum analyzer (OSA). To noise-limit the received signal, a 250 GHz bandpass filter is introduced. After a third EDFA with low noise figure the signal is passed through an 18.7-ps-delay interferometer (DI) and a balanced receiver. The bit error ratio (BER) of the demodulated signal is measured by a 53.5 Gb/s bit error rate tester (BERT). I and Q tributaries are measured one after the other. Since no DQPSK pre-coder is available, the BERT is programmed to the expected data pattern. The sent data is a pseudo random binary sequence (PRBS) of length 2^{11}-1, since this is the longest possible sequence for programmed patterns.

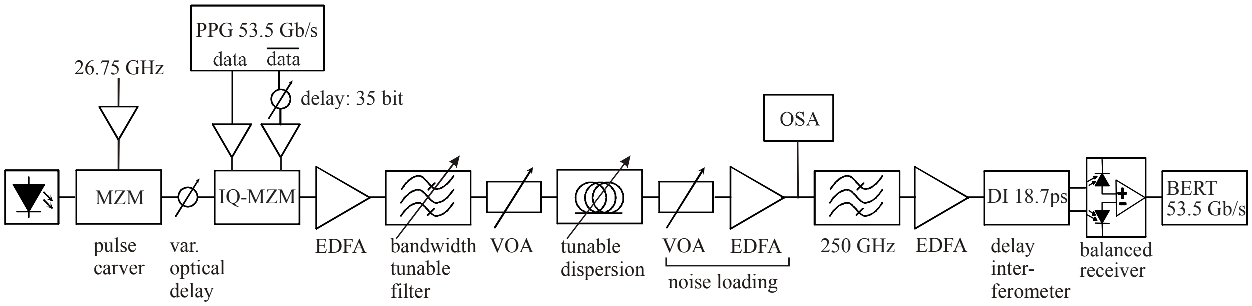

Fig. 1: Experimental setup for 33%-RZ-DQPSK at 107 Gb/s with tunable bandpass filter (emulating cascaded ROADMs) and tunable dispersion (emulating residual dispersion).

3. Results and discussion

Figure 2 shows measured eye diagrams and optical spectra (resolution bandwidth 0.01 nm) without and with 80 GHz and 55 GHz filtering. While the unfiltered eye looks absolutely clear and the narrow-pulse RZ shape is clearly visible, the filtering degrades the signal and converts it into an NRZ-like shape. For 55 GHz every second bit is distorted more severely. This effect results from an imperfect sine wave for the pulse carving. The upper and the lower half-wave of the sine are not identical, which leads to a lower carving amplitude in every second pulse. However, this effect is only visible for the narrow band filtered signal.

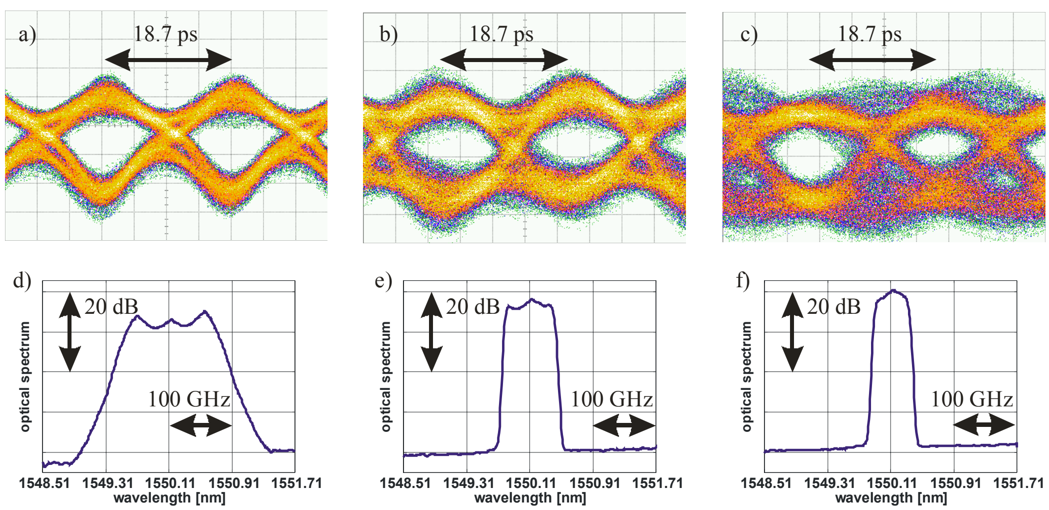

Fig. 2: Spectra and eye diagrams for narrowband filtered 33%-RZ-DQPSK: (a), (d) unfiltered signal, (b), (e) signal filtered with 80 GHz, (c), (f) signal filtered with 55 GHz. Asymmetric eye distortion in c) results from non-ideal pulse carving sine wave. This effect is only visible in strong filtered signal, but present for other signals as well. Spectra measured with resolution bandwidth of 0.01 nm.

BER vs. OSNR results are displayed in Figure 3. The back-to-back (b2b) OSNR performance of the setup is shown in Figure 3 (a) for I and Q tributaries separately. It is well comparable to the results in the references, but it must be noted that only 50%, 66% and NRZ are reported there. The performance for low BERs could be probably improved by using a narrower noise limiting filter which was not available in our case. Having adjusted the b2b setup, we measured the BER vs. OSNR curves for different filter bandwidths. The BER is determined by taking the mean of the results for I and Q. Results are displayed in Figure 3 (b) for bandwidths of 80 GHz down to 55 GHz in small steps and without filtering. It can be seen that 80 GHz already introduces a penalty of 2-3 dB, but no significant error floor compared to b2b is visible. The results for 70 and 65 GHz are very similar. If the OSNR is increased beyond the 30 dB plotted here, error free transmission is possible. However, for 60 GHz a severe degradation starts and 55 GHz shows a significant error floor. Figure 3 (c) shows the OSNR penalty (compared to b2b) due to filtering at a BER of 10^{-3}. The smallest bandwidth for which a BER of 10^{-3} can be achieved, 53.7 GHz, is included in Figure 3 (c) as well.

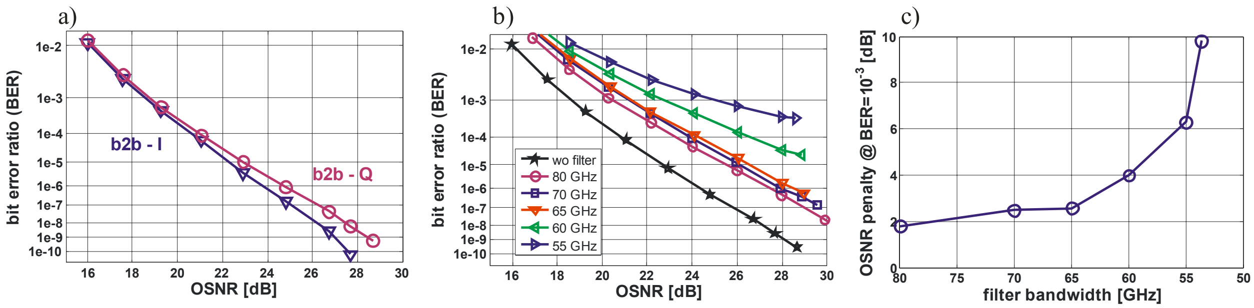

Fig. 3: Filter influence on 107 Gb/s 33%-RZ-DQPSK. (a) I and Q tributary separately, b2b case, (b) BER vs. OSNR for narrow band filtering at 55 to 80 GHz, (c) OSNR penalty (compared to b2b) due to filtering at a BER of 10^{-3}.

Finally, we determined chromatic dispersion tolerance of the 33%-RZ-DQPSK signal. Full BER curves are measured, but for simplicity we only show the required OSNR at a BER of 10^{-3}. Since the influence of chromatic dispersion depends on the bandwidth of the signal, we also measure dispersion tolerance for the 70 GHz and the 80 GHz filtered signals. Figure 4 show that narrow-band filtering improves the dispersion tolerance of 33%-RZ-DQPSK to a certain amount, e.g. ~5 dB at 20 ps/nm. For 30 ps/nm 70 GHz and 80 GHz filtering yield similar results with ~5 dB penalty compared to b2b case.

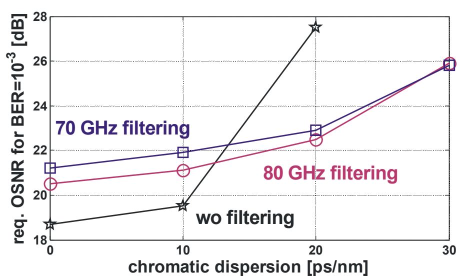

Fig. 4: Dispersion tolerance of 107 Gb/s 33%-RZ-DQPSK, unfiltered and filtered with 80 GHz and 70 GHz bandpass filter.

5. Conclusion

We experimentally investigated the tolerance of 107 Gb/s 33%-RZ-DQPSK towards narrow band optical filtering and chromatic dispersion in a systematical approach. The results show that filtering has a severe impact on the signal, especially if the filter bandwidth lies below 65 GHz. Moreover, we show that narrowband optical filtering can significantly increase the robustness towards chromatic dispersion.

6. Acknowledgement

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7. References

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