# Experimental Investigation of Asymmetrical Filtered 43 Gb/s RZ-DQPSK

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***Abstract*-We experimentally investigate the impact of centre frequency drift of either laser source or optical bandpass filters for 43 Gb/s RZ-DQPSK We show by Monte-Carlo simulations that frequency drifts of 40 GHz result in only 3.6 dB OSNR penalty.**

## I. Introduction

Network operators are interested in robust and high spectral efficient dense wavelength division multiplexing (WDM) transmission systems. Recently, it was shown that multi-level modulation formats like RZ-DQPSK (Return-to-Zero Differential Quaternary Phase-Shift Keying) are promising methods for increasing the spectral efficiency of WDM systems [1-4]. Furthermore, the spectral efficiency can be increased by narrowband optical filtering in combination with reduced channel spacing [5]. However, reduced channel spacing requires high laser and filter frequency stability. Since these parameters can change, for example due to temperature fluctuations, network operators demand robust modulation formats also against frequency drifting.

In this contribution we investigate the impact of asymmetrical filtering inducted centre frequency drift of the laser or optical bandpass filters for the RZ-DQPSK modulation format both with experimental investigations and Monte-Carlo simulations. From Monte-Carlo simulations at 40 Gb/s we notice a high tolerance towards filter detuning of up to 40 GHz resulting in only 3.6 dB optical signal to noise ratio (OSNR) penalty. The robustness of RZ-DQPSK towards filter detuning was further confirmed experimentally at 43 Gb/s by using a flat top filter with steep slopes. For 20 GHz filter offset we determined a 2.6 dB OSNR penalty.

## II. Experimental setup

The experimental setup is shown in Fig. 1. A RZ-DQPSK transmitter (Tx) similar to [1] generated a 43 Gb/s (21.5 Gbaud) signal with 50% duty cycle using pseudo random binary sequences with length of $2^{15}$-1 bits. The 43 Gb/s RZ-DQPSK signal passed a tuneable optical bandpass filter with a full width half maximum optical bandwidth of 50 GHz. The centre frequency of the filter corresponded to the distributed feedback laser frequency of 194.6 THz and was then detuned by 10 GHz, 20 GHz and 25 GHz in order to emulate filter drift or detuned laser centre frequency. Then, the filtered signal was noise loaded and received by a DQPSK receiver (Rx) which consisted of a Mach-Zehnder delay interferometer and balanced receiver with 18 GHz electrical bandwidth. The OSNR was measured by an optical spectrum analyser (OSA) with 0.5 nm resolution bandwidth. Precoding was omitted since we used a programmable bit error ratio (BER) tester. The BER for the in-phase and quadrature part were measured one after another.

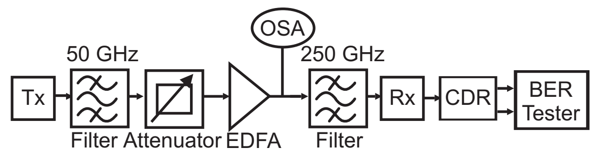


Fig. 1. Simplified block diagram of the experimental RZ-DQPSK setup.

The numerical setup was similar to the measurement setup. However, we used in our Monte-Carlo simulations a data rate of 40 Gb/s and the 50 GHz optical filter was modelled as a 1st order Gaussian filter. The filter bandwidth of the 3rd order electrical Butterworth filter was 22 GHz.

## III. Results and Discussion

Results from the Monte-Carlo simulations are presented in Fig. 2 as BER versus OSNR (0.1 nm reference bandwidth) for several filter centre frequency offsets from 0 GHz to 40 GHz for both RZ-DQPSK tributaries. From the BER curves we notice that in-phase and quadrature part show the same performance and we notice that with increasing filter shift the OSNR penalty is increasing. However, the slope of the curves is not affected by asymmetrical filtering. For a 10 GHz and 20 GHz shift we observe a small penalty of 0.2 dB and 0.8 dB, respectively. For 30 GHz and 40 GHz the penalty is increased to 1.9 dB and 3.6 dB, respectively. Thus, even for strong asymmetry with an offset of 40 GHz, the OSNR penalty is still below 4 dB although the lower sideband of the RZ-DQPSK power spectrum density (PSD) is nearly removed (compare PSD of the filtered RZ-DQPSK signal in Fig. 3). Thus, we notice that asymmetrical filtering results only in reduced eye amplitudes and widened crossing points, but not in distorted eye diagrams (compare eye diagram of the filtered RZ-DQPSK signal in Fig. 3).

In order to confirm the robustness with respect to asymmetrical filtering we conducted experimental investigations. In Fig. 4 we plot the experimentally determined required OSNR (0.1 nm reference bandwidth) vs. BER for a back to back transmission using a 50 GHz flat top filter with and without filter shift. We used a flat top filter since an arrayed waveguide grating (AWG) multiplexer with Gaussian characteristics was not available.

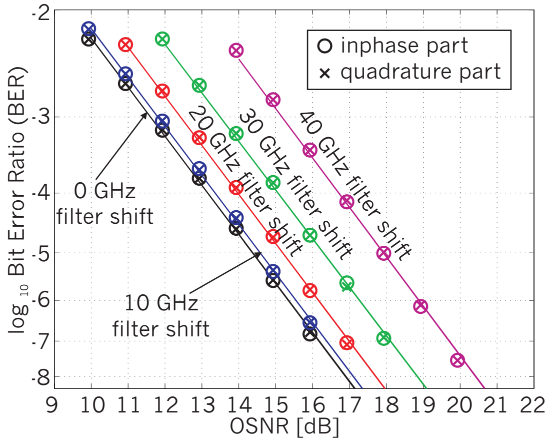


Fig. 2. Simulated BER vs. OSNR for 50 GHz optical filter with 0 GHz, 10 GHz, 20 GHz, 30 GHz and 40 GHz offset from centre frequency.

First, we notice that the required OSNR for the back to back curve without filter drift conforms to [6]. Furthermore, the in-phase and quadrature tributaries are in agreement for all measurements. Thus, even if the signal is strongly asymmetrically filtered, there is no difference in the performance of the in-phase and quadrature tributaries. This was also confirmed by the numerical results.

Next, we determine the OSNR penalty due to asymmetrical filtering. For a 10 GHz offset from the centre frequency there is no penalty observable near the FEC threshold at a BER of $10^{-4}$. At a BER of $10^{-9}$ the penalty is approximately 1 dB. For strong detuned filter centre frequencies of 20 GHz a penalty of 2.6 dB is noticeable at a BER of $10^{-4}$. However, for better BERs we notice an error floor resulting in an increased OSNR penalty of 6 dB at $10^{-9}$. If the filter is further detuned to 25 GHz we notice an error floor of around BER=$10^{-5}$. Even with increased OSNR a BER better than $10^{-5}$ was not obtainable. Nevertheless, error free operation after FEC correction can be expected. We explain these error floors due to the flat top filter shape with steep filter flanks. Since we used a Gaussian filter for the numerical investigations, a one to one comparison between numerical and experimental results is not possible. However, the robustness of RZ-DQPSK

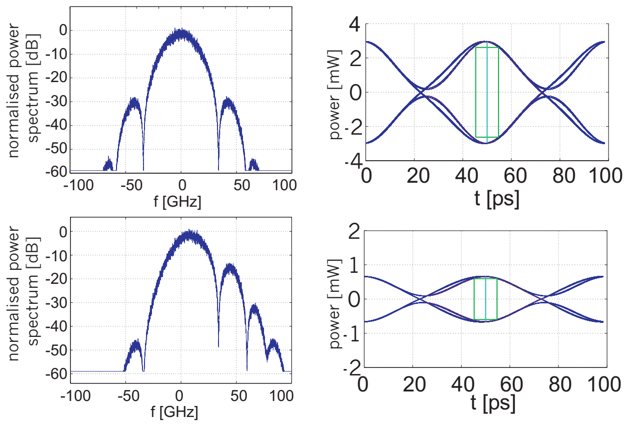


Fig. 3. Normalised PSD (left) and eye diagrams (right) of a 50 GHz Gaussian filtered RZ-DQPSK signal. Top: symmetrical filtered, Bottom asymmetrical filtered with 40 GHz offset from the centre frequency.

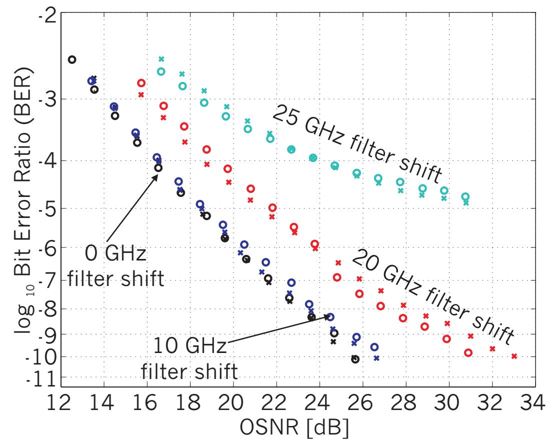


Fig. 4. Measured BER vs. OSNR for 50 GHz optical filter with 0 GHz, 10 GHz, 20 GHz and 25 GHz offset from centre frequency.

towards asymmetrical filtering with filter detuning of up to 20 GHz was confirmed.

## IV. Conclusions

We have investigated the impact of asymmetrical optical bandpass filtering for 40 Gb/s RZ-DQPSK. Monte-Carlo simulations using Gaussian 1st order bandpass filters show a tolerance up to 40 GHz detuning for 3.6 dB OSNR penalty. Experimental investigations on 43 Gb/s RZ-DQPSK demonstrated up to 20 GHz detuning tolerance for a 2.6 dB OSNR penalty, even when using flat top filter with steep slopes.


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