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# Record PMD Mitigation of 11 ps for 43 Gb/s RZ-DPSK by Distributed Polarisation Scrambling

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## Abstract

We experimentally demonstrate a record mean DGD tolerance improvement of 220% to 11ps for 43Gb/s RZ-DPSK by a cascade of 5 distributed polarisation scramblers and UFEC. This tolerance for RZ exceeds the NRZ value by 2ps.

## Introduction

Polarization mode dispersion (PMD) is considered as serious limitation for implementation of data rates of 43 Gb/s per channel and beyond in optical long-haul communication systems. For 10 Gb/s PMD mitigation by polarization scrambling at the transmitter only [1] or distributed fast polarization scrambling was proposed by numerical evaluations [2,3]. The basic principle of these schemes is that the scramblers accelerate the PMD statistics of the transmission fiber down to sub FEC frame duration (e.g. 12µs for OTU 2 FEC). Hence PMD-induced outage times are transformed to short error bursts and can be corrected by the FEC. Improvement by distributed fast scrambling was experimentally demonstrated with FEC at 10.7 Gb/s [4] in a loop experiment emulating 16 cascaded scramblers. Recently successful operation at 42.7 Gb/s [5] was shown in a straight-line experiment with 5 cascaded scramblers.

Here, we experimentally investigate the mean DGD tolerance at 43 Gb/s RZ-DPSK modulation format by using 5 fast polarization scramblers and compare the results with NRZ-DPSK. A scrambling speed of 50MHz allowed to investigate the performance of FEC's potential burst error correction capability.

## Experimental set-up

Fig. 1 depicts the experimental set up for the measurement. At the transmitter the RZ-DPSK signal is generated by a $LiNbO_3$ Mach Zehnder modulator driven by a 43Gb/s DPSK pre-coder followed by an RZ carver for RZ-50% with bias at 3dB point and 2xV$\pi$/2 modulation with 43.08 GHz. The data signal of one of the four 10Gb/s tributaries is obtained by FEC encoding and decoding of a $2^{23}$-1 PRBS sequence (UFEC with net coding gain of 8.6 dB). The other three 10.7Gb/s tributaries are loaded with $2^{23}$-1 PRBS sequence.

To emulate the transmission over a fiber link loaded with slowly drifting PMD, the 43Gb/s signal was sent over 5 differential group delay (DGD) elements, as illustrated in Fig.1. The first of the 5 DGD elements was a tunable DGD emulator and the other 4 elements were polarization maintaining fibres (PMF) of fixed length (e.g. 3.44 ps, 3.44 ps, 3.0 ps, and 2.5 ps).

Each fast scrambler (SCR) consists of a $LiNbO_3$ polarization modulator with 3 sections of 3 differently oriented waveplates (see inset in Fig.1). The retardation of the waveplates is modulated via 3 electrodes. They are driven at slightly different frequencies of *f*, *f*+0.2 MHz, and *f*+0.4 MHz. The first two scramblers could only be operated at 1 MHz, whereas the last three scramblers were driven at 50 MHz. It was proven by simulation that PMD induced distortion dynamics i.e. jitter and eye-opening penalty (EOP), is dominated by the fastest scrambling frequency in the line [5]. The frequency offset of 0.2 MHz was chosen to be faster than the FEC frame rate (approx. 85 kHz). In front of the tunable DGD-emulator a slow mechanical SCR is used to ensure worst case measurements of PMD effects. Receiver OSNR was varied by an attenuator and 1dB OSNR penalty is generally measured with respect to back-to-back.

In the case of DPSK the signal was also sent over a straight line of 4 spans of 80 km SMF as described in [5]. However, no impact of the fiber (SMF) on the mean DGD tolerance was observed and therefore the RZ measurements were performed without fiber link.

The receiver comprises a 1-bit delay interferometer to demodulate the DPSK signal and a balanced detector in front of a SFI5 deserialiser chip. The 4 tributaries of at the deserialiser outputs which belong to the 10.7Gb/s FEC channel were multiplexed and launched into the FEC decoder. The measurements at post FEC-BER were generally performed over several minutes and some samples (at the 1 dB limit) were also measured over longer periods (up to 2 hours) to ensure no occurrence of uncorrectable error bursts.

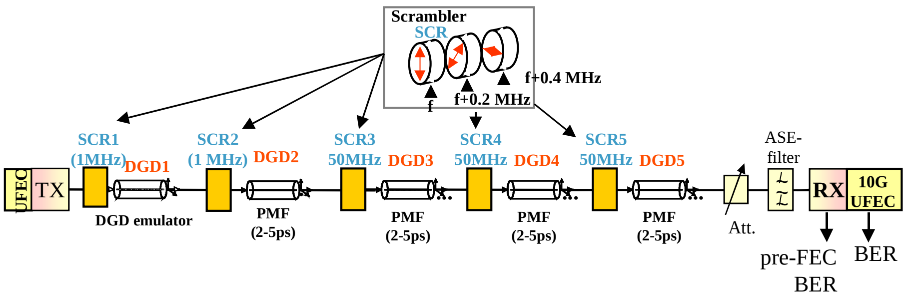


Fig. 1: Lab set-up of 43Gb/s DPSK-NRZ/RZ transmission link with 5 fast pol. scramblers, 5 DGD emulators and enhanced FEC on one 10.7Gb/s tributary.

## Results and discussion

Fig. 2 displays the OSNR penalty versus mean DGD (mean DGD = $\sqrt{(DGD1^2+...+DGD5^2)}$) measured at the pre-FEC BER of $10^{-3}$ (Fig. 2a, error free after FEC) and at post-FEC-BER $10^{-9}$ (Fig. 2b) for 5 scramblers running at 50MHz. The mean DGD tolerance converges to the upper limit of the fiber PMD tolerance for distributed scrambling [6]. Since recent measurements [5] revealed that for the current set-up a pre-FEC BER of $10^{-3}$ is already a sufficient criteria for error-free post-FEC operations even for fast polarisation scrambling, OSNR penalty measurements at this pre-FEC BER give a good picture of the mean DGD tolerance and are shown in Fig. 2a).

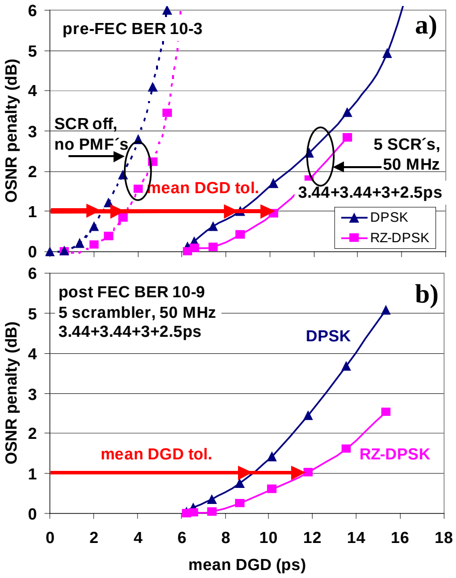


Fig.2: OSNR penalty vs. mean DGD for DPSK and RZ-DPSK. 2a): Measurement at pre-FEC-BER $10^{-3}$ with 5 scrambler at 50 MHz scrambling frequency and with scramblers off. 2b): Measurement at post FEC-BER $10^{-9}$.

By using a set of 4 PM fibers of 3.44 ps, 3.44 ps, 3 ps, and 2.5 ps and varying the DGD emulator after the first scrambler between 0 and 12 ps, the OSNR penalty versus mean DGD was measured and is drawn for NRZ-DPSK (triangles) and RZ-DPSK (boxes) in Fig. 2a), solid lines.

For comparison the dotted lines - labeled by "scrambler off" – show the mean DGD values for both formats without scrambling gained by rescaling the measured first order PMD tolerance to the appropriate mean DGD value by the commonly used rule-of-thumb of DGD/3, resulting in a mean DGD tolerance of 1 dB, 2.5 ps and 3.5 ps for NRZ and RZ, resp., when providing 1 dB OSNR margin.

Comparison of both pairs of curves clearly demonstrate that pol. scrambling increases the mean DGD tolerance by more than a factor of 3 to 8.6 ps and 10.2 ps, respectively (corresponding to 37% and 44% of the bit period). Consequently, the higher robustness to DGD of RZ-formats compared to NRZ also holds for distributed polarization scrambling.

In order to (1) confirm that no error bursts are present which cannot be handled by the FEC and (2) to determine the additional improvement [5] which might be attributed to the FEC's burst error correction capability at a high scrambling speed [4] of 50 MHz, the DGD tolerance was measured by observing the post FEC BER (FEC-BER) and keeping it at $10^{-9}$. Fig 2b shows the corresponding penalty curves for NRZ-DPSK (triangles) and RZ-DPSK (boxes). As compared to the results for constant pre-FEC BER (Fig. 2a) a further improvement by 13-18% is observed leading to a mean DGD tolerance of 9.2 ps (NRZ-DPSK) and 11.8 ps (RZ-DPSK), which corresponds to 40% and 47% of the bit period, resp. This moderate additional improvement of less than 20% underlines the explanation, that if the scrambling period is beyond the FEC frame duration the dominating effect is a randomization of the errors by scrambling and FEC interleaver [6].

Measurements at different configurations of PMF´s were also performed to investigate the impact of different DGD sets on the mean DGD tolerance. In Fig. 3 two additional DGD configurations (triangles, circles and rectangles) are added to the RZ-DPSK curve of Fig. 2b (boxes). The worst-case set for a mean DGD of 11 ps is represented by the circles: all DGD´s exhibit nearly the same value of about 5 ps. This corresponds to a maximum spreading of the DGD values seen by the receiver during a FEC frame.

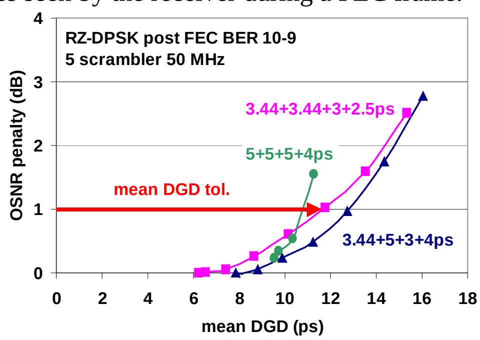


Fig.3: OSNR penalty vs. mean DGD for RZ-DPSK at FEC-BER $10^{-9}$, 50 MHz scr. freq. and with different configurations of PMF´s.

## Summary

A record PMD mitigation of 11 ps (47% of the bit period) by distributed fast polarization scrambling and forward error correction has been demonstrated for the modulation format RZ-DPSK at a bit-rate of 43Gb/s. This is an increase in mean PMD tolerance by a factor of 3.2 compared to the case without scrambling. Measurements with pre-FEC BER indicate that a FEC without burst error correction can achieve a mean DGD tolerance of 10.2 ps for RZ-DPSK.

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## References


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