111-Gb/s POLMUX-RZ-DQPSK Transmission over LEAF: Optical versus Electrical Dispersion Compensation

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Abstract: We investigate the transmission performance of 111-Gb/s POLMUX-RZ-DQPSK modulation using either optical or electrical dispersion compensation. We show that after 2000-km LEAF transmission both link configurations have a comparable nonlinear tolerance.

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1. Introduction

100-Gb/s serial transmission has recently gained an increased interest in the optical telecommunications community. In particular polarization-multiplexed return-to-zero differential quadrature phase shift keying (POLMUX-RZ-DQPSK), combined with coherent detection and digital signal processing, has been considered as a promising candidate [1]. This solution is particularly interesting as it is compatible with a 50-GHz wavelength grid and can tolerate the inter-channel nonlinear impairments generated from co-propagating 10.7-Gb/s and 43-Gb/s channels [2, 3]. However, one of the most significant advantages of a coherent receiver combined with digital signal processing is the capability to compensate fully for chromatic dispersion (CD) [4] and to a large extend for polarization mode dispersion in the electrical domain [1].

Deployed transmission links typically employ (in-line) optical dispersion compensation, realized through dispersion compensating fibers (DCF), in order to reduce the accumulated dispersion at the receiver and to optimize the nonlinear tolerance. The digital signal processing in a coherent receiver negates the necessity of in-line dispersion compensation as the full CD can be compensated in the receiver. This raises the question which configuration results in the optimum transmission performance; in-line optical dispersion compensation or an un-compensated transmission link with subsequent electrical dispersion compensation.

In this paper, we investigate the nonlinear tolerance of 111-Gb/s POLMUX-RZ-DQPSK in two different link configurations. First, we investigate the impact of a transmission link with in-line optical dispersion compensation. We then compare this with a transmission link without in-line optical dispersion compensation, where the CD is compensated electronically by digital signal processing in the coherent receiver. We find that after 2000-km LEAF transmission both link configurations show a comparable nonlinear tolerance.

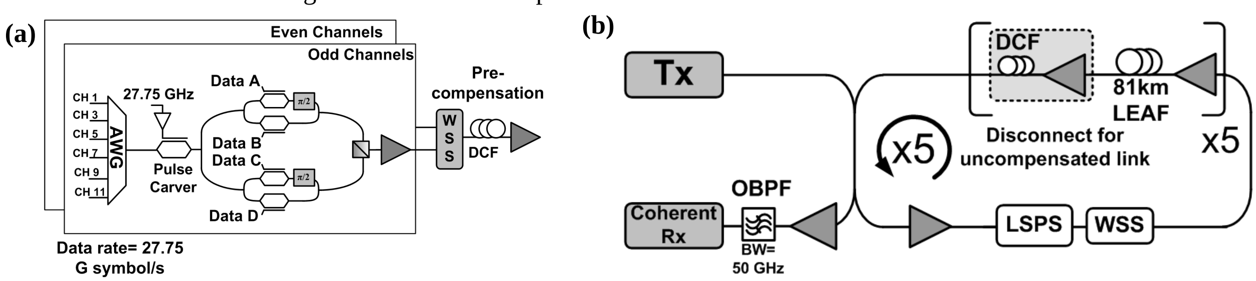

Fig. 1 Experimental setup; (a) transmitter setup, (b) loop setup.

2. Experimental setup

Fig. 1 depicts the experimental setup for the transmitter and the re-circulating loop. At the transmitter (Fig. 1a), 11 external cavity lasers (ECL) are grouped into odd and even channels using two AWGs. The ECL lasers are tuned to the 50-GHz ITU grid between 1548.5 nm and 1552.5 nm. Two separate POLMUX-RZ-DQPSK modulators are used for the odd and even channels. First the signal is pulse-carved using a Mach-Zehnder modulator (MZM) driven with a clock of 27.75 GHz. The signal is then split into two parts using a polarization maintaining coupler and each tributary is DQPSK modulated using a nested-MZM. The drive signal of the nested-MZM consist of a pseudo-random quaternary sequence (PRQS) with length 4^8 [5] and a data rate of 27.75 Gb/s. The two polarizations are interleaved with exactly half a symbol width in order to increase the nonlinearities tolerance [6]. Subsequently both tributaries are combined by means of a polarization beam splitter (PBS) to generate 111-Gb/s POLMUX-RZ-DQPSK modulation. The odd and even WDM channels are then combined by a wavelength selective switch (WSS), which is also used to equalize the spectrum, resulting in the spectra as shown in Fig. 2. Finally, DCF is used for pre-compensation before the signal is fed into the re-circulating loop.

The re-circulation loop (Fig. 1b) consists of 5 spans of 81 km LEAF with an average CD of 4 ps/nm/km and an average span loss of 17.5 dB. EDFA-only amplification is employed, and the launch power into the LEAF is varied between -4 and +3 dBm. Two different dispersion maps are used for comparison; an uncompensated dispersion map without any in-line DCFs and a double periodic dispersion map with a per-span under-compensation of 170 ps/nm and a per-loop under-compensation of 260 ps/nm (at 1550 nm) [7]. Inside the re-circulating loop a WSS is used to emulate the narrowband optical filtering of a 50 GHz ROADM, which is simultaneously used for gain equalization. A loop synchronized polarization scrambler (LSPS) is used to reduce loop-induced polarization effects.

At the receiver side, an optical band pass filter (OBPF) is used to extract the center channel at 1550.5 nm. A QPSK mixer consisting of two polarization beam splitters and two 90° hybrids is used to mix the signal with a free running ECL laser that has a linewidth of 100 kHz. The four outputs of the QPSK-mixer are detected using four single ended PIN/TIA photodiodes (PD). After the PDs, a digital storage scope samples the four tributaries at a sampling rate of 50 Gsamples/s and stores $2x10^6$ samples from each tributary. In each measurement, 5 sets of data at different time instants are stored to obtain a total of $2x10^7$ bits. The samples are processed using off-line processing on a desktop computer. First of all, the samples are re-sampled to 2 samples/bit and subsequently equalized using an FIR filter in a butterfly structure [1]. After the equalizer, a carrier phase estimator (CPE) using Viterbi & Viterbi algorithm [8] is implemented to remove the frequency offset between the LO and the transmitter laser. The CPE uses an averaging interval of 9 symbols.

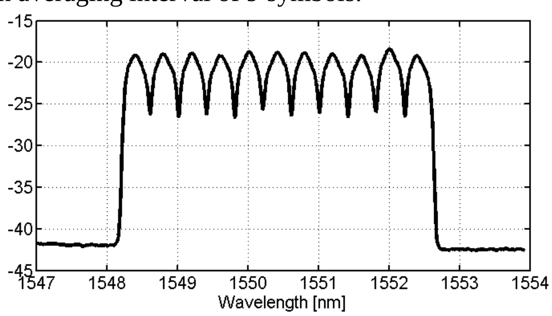

Fig. 2: Optical spectrum of 11x111-Gb/s channels on a 50-GHz grid

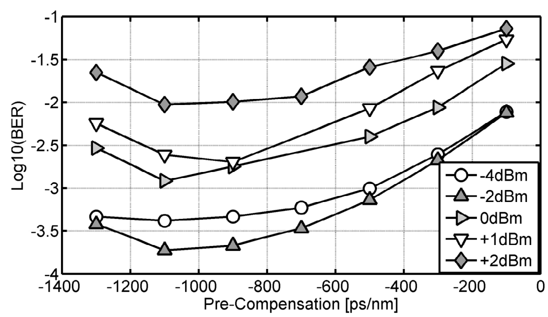

Fig. 3: Effect of pre-compensation in the compensated link

3. Experimental results

The 111-Gb/s POLMUX-RZ-DQPSK signal propagates 5 times around the re-circulating in the loop, resulting in a total transmission distance of 2000 km. First of all, a double periodic dispersion map as described in Section 2 is considered. Fig. 3 shows the BER as a function of the pre-compensation for several launch powers. In this experiment, the pre-compensation is varied between -1300 ps/nm and -100 ps/nm (at 1550.5-nm) with a tunable dispersion compensation module (TDCM). Afterwards, the nonlinear tolerance of the double-periodic dispersion map is examined by varying the launch power between -4 dBm and +3 dBm at the optimum pre-compensation value. The launch power into the DCFs is set to 6 dB below the launch power into the transmission fiber. The optimum BER performance is obtained for a launch power of -2 dBm and a pre-compensation of -1100 ps/nm.

To investigate the impact of un-compensated transmission, all of the DCF modules are removed from the re-circulating loop. The pre-compensation DCM is now varied between 0 and -4000 ps/nm, which is half of the total accumulated CD for a 2000-km transmission distance. To realize such high pre-compensation value, SSMF slope-matched DCF is used. The slope mismatch between the SSMF-DCFs and LEAF transmission fiber is compensated at the coherent receiver, and therefore does not impact the performance. Fig. 4a shows that the optimum pre-compensation is approximately -4000 ps/nm. The launch power into the transmission fiber is then again varied between -4 and +3 dBm. Similar to the un-compensated link, the optimum pre-compensation is used in the launch power variation. Fig. 5a compares the nonlinear tolerance of the transmission with and without dispersion compensation. It has been shown that for symbol rates below 12 Gbaud, the XPM penalty is lower for an un-compensated transmission link compared to the compensated link [9]. However, Fig. 5a indicates that for a symbol rate of around 27 Gbaud, there is only a slight advantage in nonlinear tolerance for the un-compensated transmission link compared to the configuration with periodic dispersion compensation. However, this advantage can be attributed to a reduction of SPM in the un-compensated link rather than a reduction in XPM.

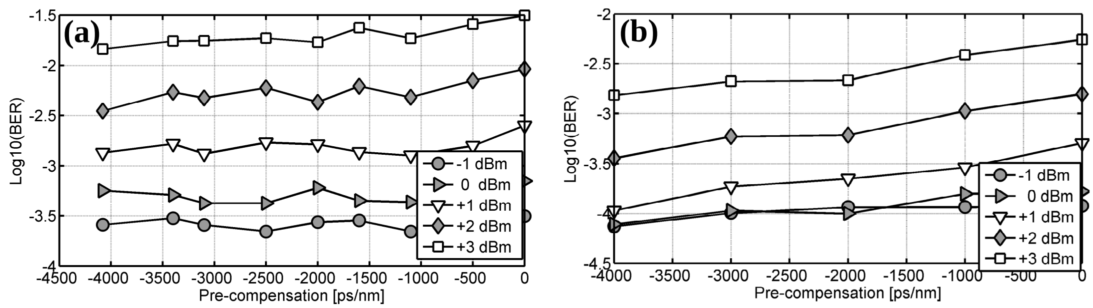

Fig. 4: Effect of pre-compensation in a link with no dispersion compensation, neighbors at: (a) 50-GHz and (b) 200-GHz spacing.

To confirm that the difference between the dispersion un-compensated and the dispersion compensated link configurations is due to a reduction in SPM, we investigate quasi-single channel transmission. Therefore, the direct three neighboring channels from each side of the central channel are turned off at the transmitter. The remaining four channels, at a minimum of 200-GHz spacing from the centre channel, are kept to stabilize the EDFAs. Similar to the results obtained at 50-GHz channel spacing, the optimum pre-compensation is found to be -4000 ps/nm (Fig. 4b). Fig. 5b compares the SPM tolerance of the 111-Gb/s signal in the configuration with and without in-line dispersion compensation. This shows that the SPM tolerance of the uncompensated link, using the optimum pre-compensation, is somewhat higher than observed for the dispersion-compensated link. This indicates that the improvement in nonlinear tolerance observed in Fig. 5a is due to an increase in SPM tolerance, while no advantage in XPM tolerance is noticed for the dispersion un-compensated configuration.

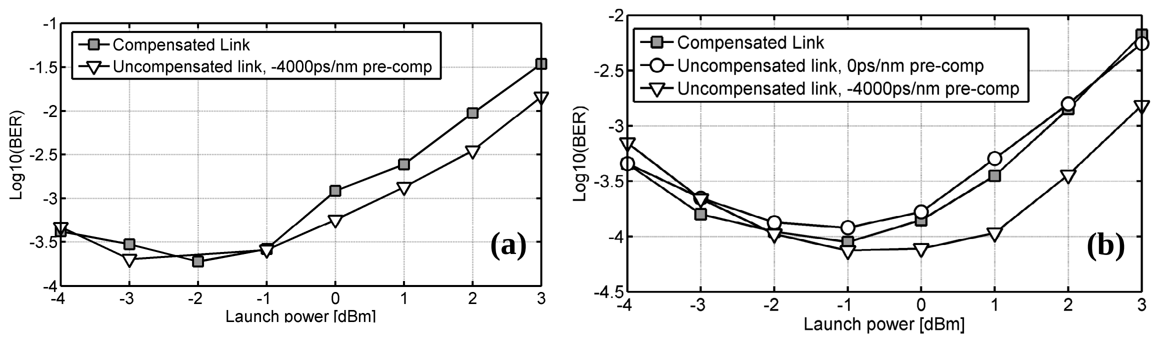

Fig. 5: Transmission performance w/ and wo/ optical dispersion compensation, neighbors at: (a) 50-GHz and (b) 200-GHz spacing.

4. Conclusion

We experimentally compared the nonlinearities tolerance of 111-Gb/s POLMUX-RZ-DQPSK in a link with either (in-line) optical or electrical chromatic dispersion compensation. When transmission is (partially) limited by XPM, almost no difference between the compensated and un-compensated links can be observed. For a transmission link limited by SPM, a slight advantage can be realized using no in-line dispersion compensation, providing an optimized pre-compensation is used.

5. References

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