Analysis of Non-Linear Impairments in 40 Gbaud PM DQPSK and D8PSK Transmission

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ABSTRACT

In this paper, 40 Gbaud transmission of single polarization (SP) and Polarization-Multiplexed (PM), RZ-DQPSK and RZ-D8PSK signals is analyzed numerically. The impact of nonlinear crosstalk arising from the presence of neighbouring intensity-modulated channels is analyzed in terms of required OSNR for the BER of 10^{-3} versus launch power.

1. INTRODUCTION

In recent years a lot of research has been carried out for the investigation of efficient multilevel modulation schemes for increasing the spectral efficiency of fiber optical communication systems in terms of b/s/Hz. This includes both direct and coherent detection at the receiver [1]. But the performance of these phase modulated optical communication systems is seriously degraded by nonlinear effects, especially self-phase modulation (SPM) and cross-phase modulation (XPM) [2]. In particular it has been shown that XPM arising from the neighbouring pre-deployed intensity-modulated lower-bit-rate channels is a major source of performance degradation [3], [4].

In this paper we have numerically investigated the performance of SP/PM RZ-DQPSK and SP/PM RZ-D8PSK transmission at 40 Gbaud, in the presence of neighbouring channels modulated by 10 Gb/s NRZ OOK. The transmitter set-up, transmission link and receiver, shown in Figure 1 are modelled according to the experiment set-up presented in [5] (using VPItransmissionMaker®). The impact of nonlinear cross talk from NRZ OOK neighbouring WDM channels on the SP/PM RZ-DxPSK modulated test channel is analyzed in terms of required OSNR for bit error rate (BER) of 10^{-3} as a function of launch power.

2. SIMULATION SETUP

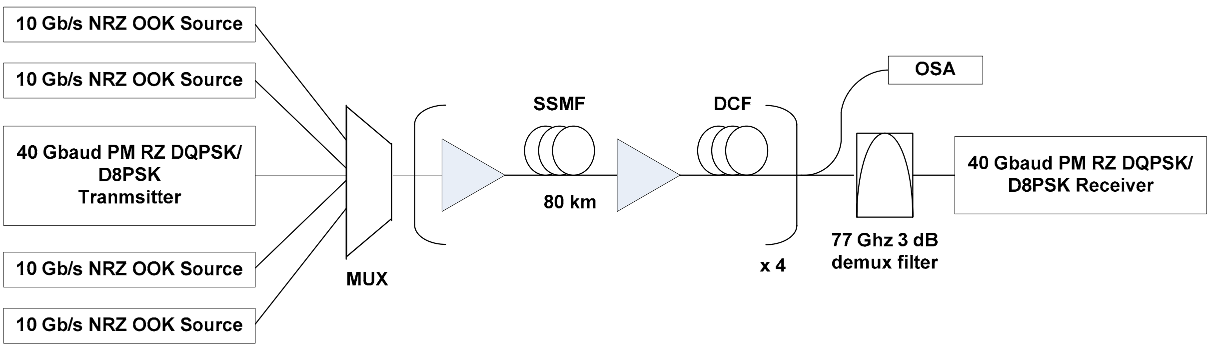

Figure 1. Experimental setup for simulations.

The DQPSK transmitter (see Figure 2) included an ideal laser source (zero line width) at wavelength of 1550 nm. The carrier was then modulated by nested Mach-Zehnder modulators (MZM) which were driven by pre-coded bit sequences of length 2^{13} at a rate of 40 Gbaud. The output signal is then passed through a phase modulator for D8PSK signal generation (with a bandwidth of 35 GHz) and subsequently pulse carved at 50% duty cycle by an extra MZM. Polarization multiplexing is realized by splitting the modulated optical signal by a polarization beam splitter (PBS) and then adding the signal with polarization beam combiner (PBC) with the second stream delayed by 200 symbol periods, i.e. 200×25 picoseconds.

The optical fiber link consists of four spans of 80 km standard single mode fiber (SSMF) amplified by erbium doped fiber amplifiers (EDFAs). The dispersion was fully compensated in each span by dispersion compensating fibers (DCFs). The attenuation in each SSMF and DCF was 18 dB and 12 dB, respectively. For the WDM system the neighbouring channels were NRZ OOK modulated by 10 Gb/s de-Bruijn bit sequences

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(DBBS) sequences of length 2^{11}. The optical amplifiers are modelled as ideal noise-free EDFAs and all optical noise is added at the receiver. Cross-polarization nonlinear effects were included according to the Manakov model [6][1] and PMD effects were neglected.

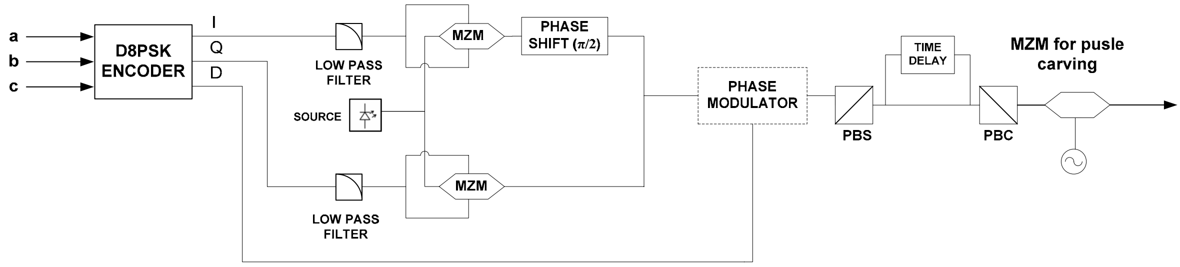
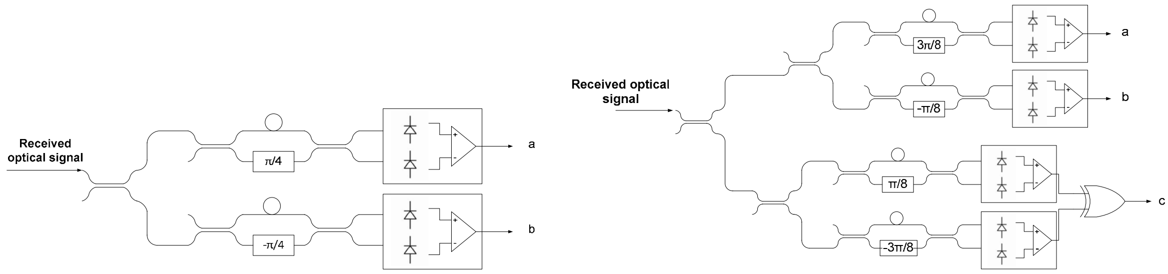


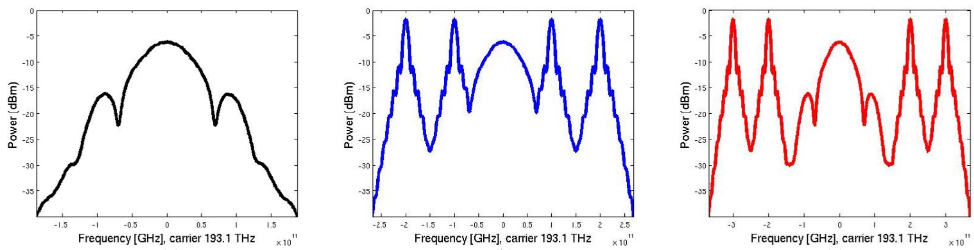
Figure 2. Schematic diagram of DQPSK/D8PSK transmitter.



(a) (b)

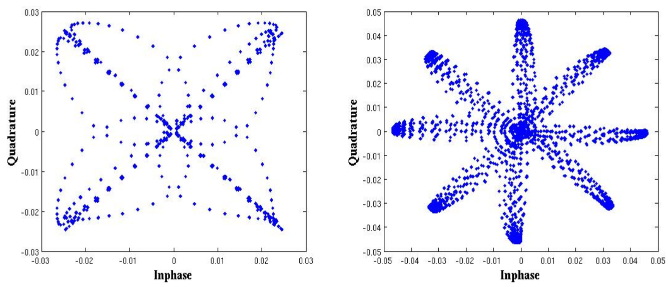
Figure 3. Schematic diagram of DQPSK (a)/D8PSK (b) Receiver.

At the receiver white Gaussian optical noise is added to the signal (in order to vary the OSNR), before being demultiplexed using a flat top filter having a bandwidth of 77 GHz. The differential demodulation was done by using delay line interferometers (DLI) having free spectral range (FSR) of 40 GHz. The demodulated signal was detected by balanced detectors having 28 GHz bandwidth. The architecture of DQPSK/D8PSK demodulator [7] is shown in Figure 3a and Figure 3b. OSNR measurement was done at 0.1 nm. Figure 4 shows the spectrum of the signal in the single channel as well as WDM scenarios. Figure 5 shows the constellation diagrams of the single channel and single polarization RZ-DQPSK and RZ-D8PSK signal at transmitter.



(a) (b) (c)

Figure 4. Spectrum of transmitted signal. Single channel (a), 100 GHz spaced WDM with (b) 100 GHz, and (c) 200 GHz separation from the nearest neighbour.



(a) (b)

Figure 5. Constellation diagram of (a) DQPSK and (b) D8PSK transmitted signal.

[1] This was obtained by using the *VectorPMD* fiber model in VPItransmissionMaker® and by setting the birefringence step size to the fiber length and by using an identity matrix as the fiber rotation matrix.

3. SIMULATION RESULTS and DISCUSSION

The back-to-back performance is studied first in *Figure 6* which shows the required OSNR to obtain BER = 10^{-3} is around 16 dB and 22.5 dB for single-polarization RZ-DQPSK and RZ-D8PSK respectively, and 19 dB and 25.5 dB for PM RZ-DQPSK and PM RZ-D8PSK respectively. The difference in required OSNR when moving from 4-level to 8-level modulation, is at around 6.5 dB in both the cases of single and dual polarization systems, which is close to the theoretical value of 6.3 dB for DQPSK and D8PSK perturbed by Gaussian white noise [8].

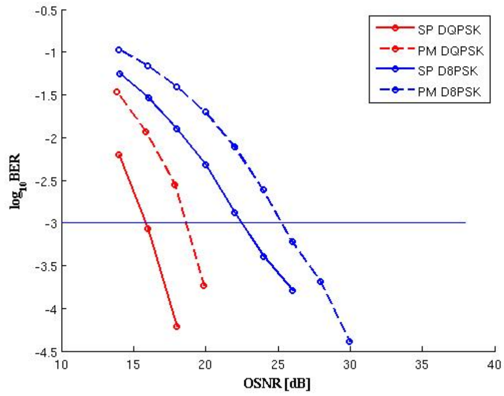


Figure 6. BER as a function of OSNR for back to back transmission of single channel, single polarization (solid), polarization multiplexed (dashed),40 Gbaud RZ-DQPSK (red)/ RZ-D8PSK (blue).

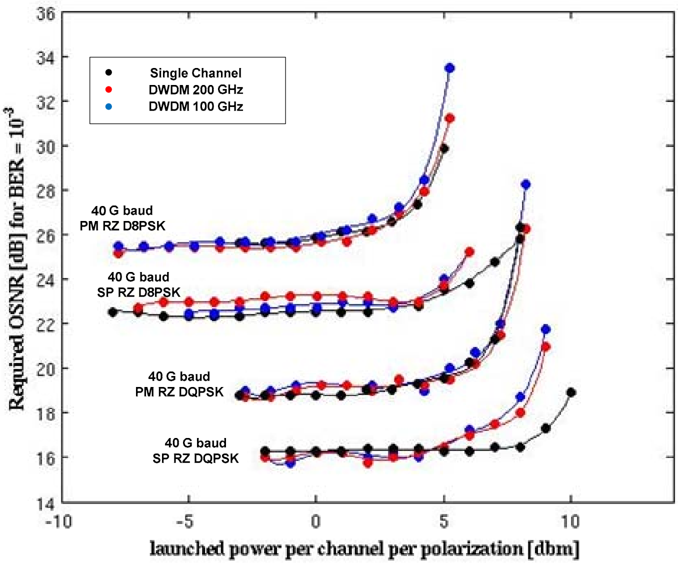


Figure 7. Required OSNR versus launch power per channel per polarization for SP/PM RZ-DQPSK and SP/PM RZ-D8PSK.

Next the results for transmission simulations are shown in Figure 7 which plots the required OSNR for BER = 10^{-3} versus launch power per channel per polarization. The total launch power during the simulations was adjusted so that the each channel in every polarization and wavelength has equal average launch power.

he impact of nonlinearities is apparent in all the cases for DQPSK and D8PSK, since as the launch power increases the required OSNR also increase in a nonlinear fashion. For each scenario launch power is increased until BER = 10^{-3} is no longer achievable even in the absence of noise.

The required OSNR when going from SP to PM increased by 3 dB in both cases of DQPSK and D8PSK which is consistent with the back to back simulation results. The required OSNR in moving from 4-level DQPSK to 8-level D8PSK is in both the case of SP and PM is 6.3 dB which is also consistent with the back to back transmission results.

Figure 8 shows the nonlinear threshold (NLT) – defined as the launch power for which the required OSNR is increased by 2 dB compared to back-to-back – for all the cases in Figure 7. We observe that the difference in NLT between SP RZ-DQPSK and SP RZ-D8PSK is around 3 dB, which is explained by the fact that the phase difference between neighbouring symbols in a D8PSK constellation is half that of a DQPSK constellation.

Next we observe that in the case of single polarization DQPSK and D8PSK the NLT is degraded considerably (between 1 dB and 2 dB) when adding neighbouring WDM channels, due to XPM. However even greater penalty is caused by adding an orthogonal-polarization channel (3 dB NLT degradation going from SP to PM DQPSK Single Channel and 2.3 dB NLT degradation going from SP to PM D8PSK Single Channel), suggesting that cross-polarization phase modulation (XPolM) is dominant over XPM. And indeed, it can be seen that adding WDM neighbours to a PM channel does not degrade NLT significantly. We also observe that introducing a guard band (i.e. leaving one channel space empty at each side of the 40 Gbaud channel) does not have a significant impact on the magnitude of non-linear cross-talk.

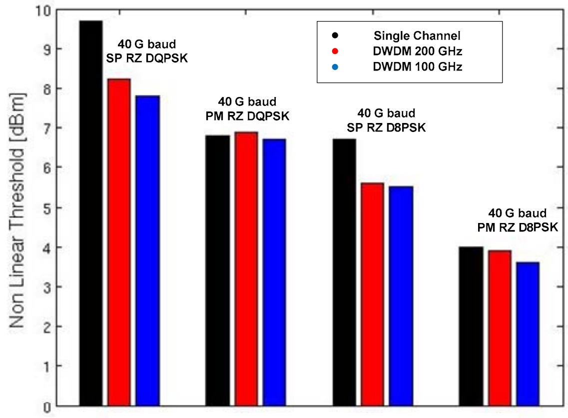


Figure 8. Nonlinear threshold for all cases in Figure 7.

4. CONCLUSIONS

We studied the impact of nonlinearities on 40 Gbaud DQPSK and D8PSK transmission at 40 Gbaud. We observed that D8PSK has a 6.5 dB OSNR sensitivity penalty compared to DQPSK and a worse tolerance to intra- and inter-channel nonlinearities than DQPSK, in both single and polarization multiplexed scenarios. We also found that polarization multiplexed DQPSK and D8PSK are strongly impacted by XPolM, which seems to be dominating over the XPM arising from four neighbouring channels modulated by RZ-OOK at 10 Gb/s.

ACKNOWLEDGEMENT

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