Nonlinear Penalty Reduction Induced by PMD in 112 Gbit/s WDM PDM-QPSK Coherent Systems

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Abstract *We show by simulation that when linear PMD is fully compensated by the receiver, the presence of DGD along the link reduces the amount of residual nonlinear penalty in 112 Gbit/s PDM-QPSK coherent systems.*

Introduction

Polarization division multiplexing (PDM) of quadrature phase shift keying (QPSK) signals is a very promising solution for deploying wavelength division multiplexed (WDM) systems in 100 Gbit/s networks.[1] Large tolerance to linear impairments such as chromatic dispersion (CD) and polarization mode dispersion (PMD) has been reported in coherent receivers using digital signal processing.[2] However, some residual penalties appear in presence of nonlinear Kerr effects. Experiments[3] and numerical simulations[4] showed that cross-polarization effects (Xpol) and cross-phase modulation (XPM) can limit the performance of PDM receivers.

In this work we focus on the impact of fiber differential group delay (DGD) on nonlinear distortions. We show that, provided the linear PMD is fully compensated at the receiver, the distributed de-correlation introduced by DGD along propagation reduces cross-nonlinear interactions, thus improving the performance.

Transmission System

We tested by simulation the performance of the central of 9 WDM synchronous channels with 112 Gbit/s PDM-QPSK modulation and 50 GHz spacing. All channels were first modulated by random sequences of 256 symbols and then their state of polarization was randomized on the Poincarè sphere. The WDM electric field was propagated in two different optical systems. The first was a single mode fiber (SMF) system without in-line dispersion compensation; the second was a dispersion managed (DM) system, with pre- and line-dispersion compensation, having either non-zero dispersion shifted fiber (NZDSF) or SMF transmission fibers. In the second system the pre-dispersion was chosen as in Frignac et al.,[5] while the in-line residual dispersion was set to 30 ps/nm/span. Both systems were composed of 20×100 km spans, with zero overall cumulated dispersion. The fibers were numerically simulated by solving the coupled nonlinear Schrödinger equation through the split step Fourier algorithm.[6] We emulated PMD by using 50 random waveplates per span. In simulations, the transmission fibers had attenuation 0.2 dB/km, slope 0.057 ps/nm^2/km, nonlinear index 1.5 1/(W·km). Propagation was noiseless, while noise was added before reception, thus neglecting nonlinear phase noise (NLPN), excepts for a few checks, see later. We assumed flat gain amplifiers with 7 dB noise figure. Before reception we assumed perfect optical equalization of linear impairments, i.e. dispersion and PMD. Such an ideal equalization, which replaces CD and PMD electronic compensation,[1] allows us to focus entirely on the extra penalty coming from the interplay of linear and nonlinear distortions along the link. The receiver selected the test channel by a 0.4 nm optical filter, and then demodulated it using a standard coherent receiver, where the carrier phase was estimated by the Viterbi algorithm with 9 taps.[2] We measured the bit error rate (BER) through the Monte Carlo algorithm by counting 100 errors, and then converted the BER in Q factor.

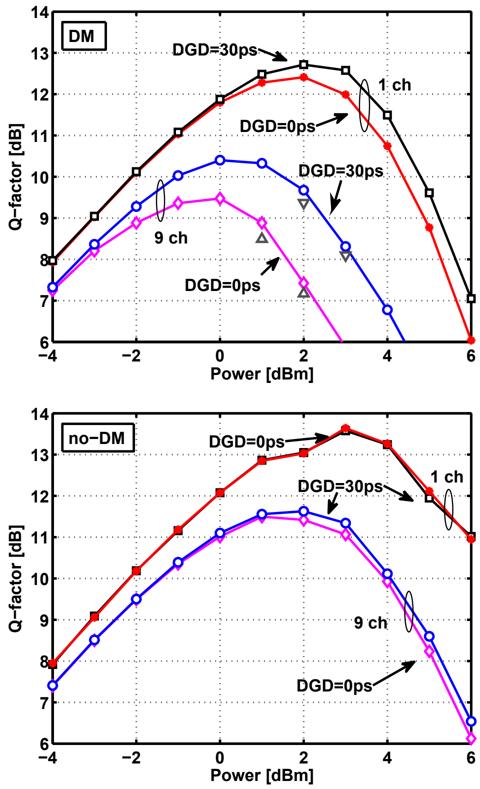

Fig. 1: Comparison between a DM and no-DM 112 Gbit/s PDM-QPSK system. Triangles: simulations with NLPN. SMF fiber.

Results

We first studied the impact of PMD by varying the signal power. We analyzed the test channel both in the WDM case and in the single channel case to assess the role of nonlinear PMD in self and cross nonlineari-

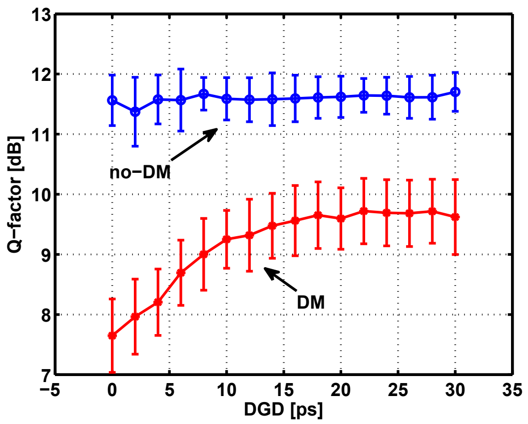

Fig. 2: Q factor vs. DGD in the DM and no-DM case. SMF fiber.

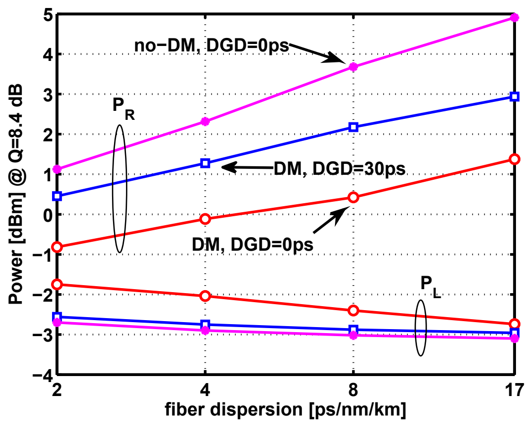

Fig. 3: Power @ Q=8.4 dB vs. Tx fiber dispersion.

ties. In both cases we measured the Q factor with average DGD equal to 0 ps or 30 ps. The stochastic nature of PMD was taken into account by averaging over 40 different random realizations of fiber waveplates, the same for any setup for a fair comparison.

Fig. 1(top) shows the average Q factor vs. signal power with in-line DM. The ascending and descending sections of the Q factor are related to optical noise and nonlinear impairments, respectively. It is worth noting that the presence of DGD improves the performance in both the single channel and the WDM cases. While in the single channel case the best Q factor increases by 0.4 dB, in the WDM case we have a larger improvement of 1 dB. The reason of the improvement in presence of DGD in the nonlinear regime is that both intrachannel interactions between the X and Y components, and interchannel Xpol distortions are reduced by the walk-off and depolarizing effect of PMD. Note that at small powers DGD does not impact since all linear impairments are exactly compensated. For some powers in the nonlinear region of the 9 channel case we repeated the simulations by including NLPN (triangles in the figure) finding a negligible impact of NLPN in this setup.

In Fig. 1(bottom) we show the same curves for the non-compensated case (no-DM). Here the DGD impact is totally masked by the large dispersion cumulated along the link. Note that the non-compensated case yields larger Q factors than the DM one, and thus becomes a better option when its use is possible, in agreement with what observed in.[4,7]

In a second test we fixed the power to 2 dBm and varied the average DGD in the range 0 to 30 ps. The corresponding Q factor vs. DGD is shown in Fig. 2. The error bars indicate fluctuation within one standard deviation among the 40 PMD realizations, and give information about the PMD-induced randomness of the nonlinear interaction. We observe that in the DM case the Q factor saturates at DGD values larger than 18 ps, while in the no-DM case it appears independent of the DGD value, as expected.

In a final test we checked the dependence of the DGD-smoothed nonlinearities from the fiber dispersion. To this aim, we measured the power that gives a specific Q factor, here equal to $\overline{Q} = 8.4$ dB, for fiber dispersions varying in the range 2 to 17 ps/nm/km. When such a power exists, we have two possible solutions: one in the linear regime (i.e. ascending region of Q vs. power) and one in the nonlinear regime (descending region). We label the first power P_L and the second P_R. Their difference is the power budget for the system designer. Hence, a system with power P such that $P_L < P < P_R$ has $Q > \overline{Q}$. Such powers are depicted in Fig. 3 vs. transmission fiber dispersion shown in a log scale. The best performance is still achieved by the no-DM case, even if the no-DM improvement is lower for smaller dispersions. In any DM case we always observe that DGD enlarges the power budget $P_R - P_L$. The worst performance is with D=2 ps/nm/km fibers which experience larger cross-nonlinear effects. However, we observe that the improvement introduced by the DGD on P_R is almost independent of the fiber dispersion.

Conclusions

We investigated the impact of PMD in 112 Gbit/s PDM-QPSK systems showing that DGD helps reducing the nonlinear penalty, provided that linear PMD is fully compensated by the receiver. Hence PDM-QPSK turns out to be a good option for high PMD links not only for its tolerance to linear PMD, but also because it takes advantage of the DGD-induced tolerance to nonlinearities.

References

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