Fibre Nonlinearities in 10 and 40 Gb/s Electronically Dispersion Precompensated WDM Transmission

Christian Weber, Christian-Alexander Bunge, Marcus Winter, Klaus Petermann
Fachgebiet Hochfrequenztechnik, Technische Universität Berlin, 10587 Berlin, Germany
christian.weber@tu-berlin.de

Abstract: Fiber nonlinearities in WDM systems using linear electronic dispersion precompensation are studied at high bit rates. In contrast to 10 Gb/s systems, only a small performance degradation due to nonlinearities was found at 40 Gb/s.

OCIS codes: (060.2330) Fiber optics communications; (060.4080) Modulation

1. Introduction

Electronic predistortion (EPD) of chromatic dispersion using digital signal processing is a potentially cost-effective alternative to conventional optical dispersion compensation (ODC) using inline dispersion compensating fiber modules (DCF). The inline dispersion compensation in ODC systems is replaced by an EPD transmitter that pre-compensates the individual WDM channels for the chromatic dispersion of the entire transmission distance. EPD has been experimentally demonstrated at a channel bit rate of 10 Gb/s in a single channel system and a WDM system [1, 2].

While EPD significantly simplifies the dispersion map by saving DCF modules and allowing for amplifiers without mid-stage access it leads to higher values of accumulated dispersion compared to ODC systems with periodic inline dispersion compensation. Numerical simulations [3, 4] and lab experiments [5, 6] have shown that 10 Gb/s EPD systems are stronger degraded by fiber nonlinearities such as SPM and XPM than ODC systems due to the large accumulated dispersion, which is far from the optimum dispersion map. While SPM and chromatic dispersion can be electronically predistorted simultaneously using a combination of linear filters and nonlinear filters based on look-up tables, a numerical investigation has shown large performance degradation in electronic predistorted 10 Gb/s NRZ-OOK WDM systems due to XPM which cannot be compensated for [3]. As a consequence, 10 Gb/s EPD systems operate at reduced launch power values compared to ODC systems leading to reduced system reach or reduced margins.

The use of the EPD technique at higher bit rates such as 40 Gb/s requires increased complexity of the EPD transmitter. The channel memory of nonlinear pulse interactions scales with the square of the bit rate. Hence, if only linear EPD is considered the filter length, i.e. the number of FIR filter taps, is expected to increase by a factor of 16 which may become practical in the future. However, using combined EPD of chromatic dispersion and intrachannel nonlinearities would lead to an exponential complexity growth due to the required nonlinear filtering using, e.g., look-up table filters. As a consequence, at 40 Gb/s and higher, only linear EPD of dispersion is considered practical.

In such systems, intra- and interchannel nonlinearities will limit the performance. Numerical simulations of 40 Gb/s NRZ-OOK single channel EPD systems have shown that there is no significant difference between the impact of intra-channel nonlinearities in EPD and ODC systems, quite in contrast to the situation at 10 Gb/s [7]. However, these simulations did not take into account interchannel nonlinearities that occur in WDM systems.

In this paper, EPD is studied in 10 and 40 Gb/s WDM systems with five individually predistorted channels to assess the impact of XPM in EPD systems operating at higher bit rates.

2. System setup

The investigated WDM system setups are shown in Fig. 1 together with their dispersion map diagrams. The system parameters for the EPD and ODC systems are given in Table 1. The five WDM channels are co-polarized. For the ODC system, a periodic dispersion map was used, Fig. 1(a). The impact of nonlinearities in ODC systems can be reduced by optimizing the precompensation at the transmitter D_{pre}, the residual dispersion per span D_{res} and the postcompensation at the receiver D_{post}. The optimum parameters have been found using numerical simulations to obtain minimum transmission penalties at 10 and 40 Gb/s and are given in Table 1. The DCFs were assumed lossless and linear.

OTuD2.pdf

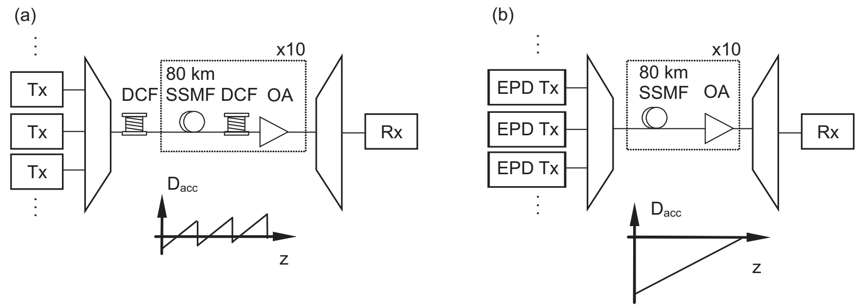

Fig. 1. WDM system setup and dispersion map for (a) ODC system and (b) EPD system.

In the EPD system, the transmitter generates the precompensation for the entire transmission distance at the transmitter, Fig. 1(b). No DCF modules are required along the link. For the numerical simulation of EPD, ideal dispersion precompensation of 12,800 ps/nm was assumed, modeled by the inverse frequency transfer function of a linear fiber without attenuation and without nonlinearity. Therefore, the EPD results represent the theoretical maximum neglecting the impact of finite FIR filters, limited D/A conversion and I-Q modulator. No compensation of nonlinearities is considered for the EPD system. Simulations were carried out using the VPItransmissionMaker software.

Table 1. System parameters for 10 and 40 Gb/s system simulations.

Modulation format	NRZ-OOK
Number of spans	10
Number of WDM channels	5
Span length	80 km
Attenuation	0.2 dB/km
SSMF dispersion	16 ps/nm/km
Nonlinear coefficient	1.31 $W^{-1}km^{-1}$

Bit rate	10 Gb/s	40 Gb/s
Channel spacing	50 GHz	100 GHz
Optical demux filter	30 GHz	44 GHz
Electrical low pass filter	7 GHz	28 GHz
D_{pre}	-1000 ps/nm	-300 ps/nm
D_{res}	100 ps/nm	20 ps/nm
D_{post}	150 ps/nm	0 ps/nm

3. Results and discussion

The impact of XPM is assessed using a simulation technique first described in [3]. It is based on the fact that XPM depends on the intensity of neighboring WDM channels and that a wide range of temporal waveform alignments between WDM channels is required to accurately capture the effect of XPM. Using this technique, each system has been simulated 100 times using random time delays between WDM channels over a range of launch powers. In each run, the OSNR required for a BER of 10^{-4} of the central channel was calculated using a 2^{10} DeBruijn binary sequence (DBBS). From the resulting histograms of the required OSNR, the 10th and 90th percentile is calculated and plotted versus the launch power. In this case, the P-th percentile is the required OSNR value below which fall P percent of the calculated required OSNR values. The larger the difference between the 10th and 90th percentile the stronger is the impact of XPM.

The results for the ODC and EPD system at a channel bit rate of 10 Gb/s are shown in Fig. 2(a). At low launch powers around -4 dBm, there is almost no difference between the 10th and 90th percentile in both EPD and ODC indicating a negligible impact of XPM. Increasing the launch power per channel to -2 and 0 dBm leads to a spreading of the required OSNR for the EPD system as indicated by the shaded area in Fig. 2(a), a phenomenon already found in [3] at a single launch power. The maximum launch power before significant spreading occurs is about -2 dBm in the EPD system whereas the ODC system does not show large fluctuations of the required OSNR below 8 dBm launch power. The difference in maximum launch power is more than 10 dB. In the ODC system, XPM is suppressed by the choice of the dispersion map.

Fig. 2(b) summarizes the results of the required OSNR versus the launch power for the 40 Gb/s EPD and ODC systems. The ODC curves shows only a small spreading of the required OSNR for all simulated launch powers. This confirms the well-known fact that, in this transmission regime, intrachannel nonlinerities are the dominant limiting effect and XPM has negligible effect. For the EPD system, the 10th and 90th percentile curves start to diverge as the launch power increases above 0 dBm indicating that the required OSNR fluctuates due to XPM. However, the effect

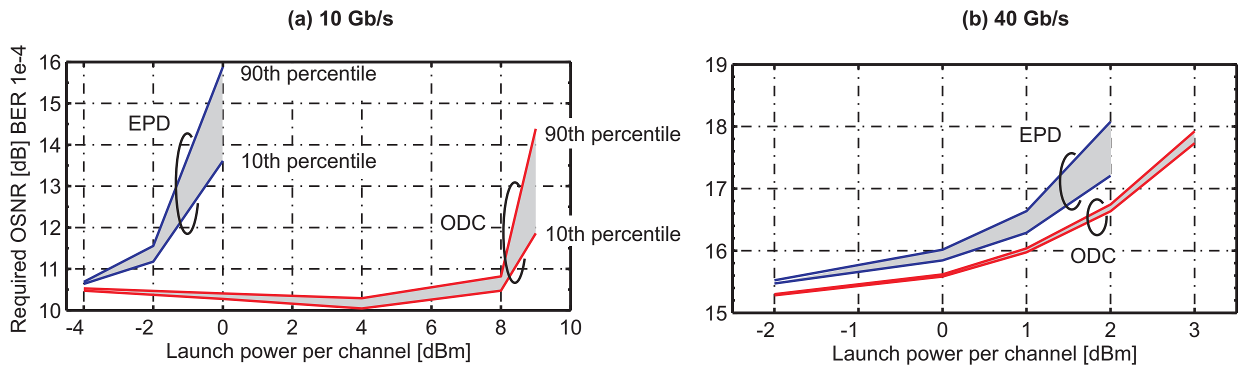

Fig. 2. Distribution of the required OSNR of the central channel as a function of the launch power per channel for ODC and EPD system (a) in a 5x10 Gb/s WDM system with 0.2 b/s/Hz spectral efficiency and (b) in a 5x40 Gb/s WDM system with 0.4 b/s/Hz spectral efficiency. The 10th and 90th percentile of the required OSNR distributions are shown as a result of 100 realizations of random time delays between WDM channels.

is less pronounced than at 10 Gb/s despite using a higher spectral efficiency of 0.4 b/s/Hz at 40 Gb/s than at 10 Gb/s where 0.2 b/s/Hz were used. The maximum launch power before strong spreading occurs is about 0 dBm in the EPD system and 2 dBm in the ODC system. The large performance difference between the ODC and EPD system at 10 Gb/s cannot be observed at 40 Gb/s. This shows that nonlinearities are less critical in EPD systems operating at a channel bit rate of 40 Gb/s. No significant nonlinearity-induced degradation of the EPD system compared to the ODC system could be observed. Considering that EPD systems may achieve a higher OSNR at the receiver since lossy DCFs are removed from the link, EPD systems have the potential to outperform ODC.

4. Conclusion

The impact of nonlinearities in 10 and 40 Gb/s NRZ-OOK WDM systems using linear electronic dispersion precompensation was investigated. While XPM severely degrades the performance of EPD systems at 10 Gb/s compared to conventional inline compensated ODC systems, it is shown that this performance degradation is less pronounced at 40 Gb/s. The difference in maximum allowable launch power between EPD and ODC is more than 10 dB at 10 Gb/s and only about 2 dB at 40 Gb/s. These results suggest that EPD may become more attractive at higher bit rates since limitations due to nonlinearities are less critical.

References

1. D. McGhan, C. Laperle, A. Savchenko, C. Li, G. Mak, and M. O’Sullivan, “5120-km RZ-DPSK transmission over G.652 fiber at 10 Gb/s with no optical dispersion compensation,” in *Proc. Conference Optical Fiber Communications (OFC 2005)*, Anaheim, CA, paper PDP27.
2. M. Birk, X. Zhou, M. Boroditsky, S. H. Foo, D. Bownass, M. Moyer, and M. O’Sullivan, “Wdm technical trial with complete electronic dispersion compensation,” in *Proc. European Conference on Optical Communication (ECOC 2006)*, Cannes, France, 2006, paper Th.2.5.6.
3. R. J. Essiambre and P. J. Winzer, “Fibre nonlinearities in electronically pre-distorted transmission,” in *Proc. European Conference on Optical Communication (ECOC 2005), Glasgow, UK*, Glasgow, UK, 2005, paper Tu3.2.2.
4. A. Klekamp, F. Buchali, M. Audoin, and H. Bulow, “Nonlinear limitations of electronic dispersion pre-compensation by intrachannel effects,” in *Proc. Conference Optical Fiber Communications (OFC 2006)*, Anaheim, CA, 2006, paper OWR1.
5. S. Chandrasekhar, C. Doerr, and L. Buhl, “Demonstration of 100dwdm transmission over 1280 km of ssmf with no inline dispersion compensation using interconnected recirculating loops,” *Photonics Technology Letters, IEEE*, vol. 18, no. 1, pp. 256–258, 2006.
6. S. L. Jansen, I. Morita, D. van den Borne, G. D. Khoe, H. de Waardt, and P. M. Krummrich, “Experimental study of XPM in 10-Gb/s NRZ precompensated transmission systems,” in *Proc. Conference Optical Fiber Communications (OFC 2007)*, Anaheim, CA, paper OThS6.
7. C. Weber and K. Petermann, “Impact of fibre nonlinearities in electronic dispersion compensation systems at 40 Gb/s,” in *Proc. European Conference on Optical Communication (ECOC 2008)*, Brussels, Belgium, 2008, paper P.4.10.