Impact of Fibre Nonlinearities in Electronic Dispersion Compensation Systems at 40 Gb/s

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Abstract

The impact of intrachannel nonlinearities in 40 Gb/s systems using electronic dispersion precompensation is studied. We found no significant reduction of the nonlinear threshold compared to optical inline dispersion compensation.

Introduction

Electronic pre-distortion (EPD) of chromatic dispersion using digital signal processing and a complex field modulator is a cost-effective alternative to inline dispersion compensating fibre (DCF) modules. After EPD has been proposed and demonstrated with OOK and DPSK at 10 Gb/s [1, 2] it was argued that 10 Gb/s EPD systems are strongly degraded by fibre nonlinearities such as SPM and XPM compared to conventional optically dispersion compensated systems (ODC). Klekamp et al. have analysed the impact of SPM in 10 Gb/s EPD transmission and found that the maximum launch power for a 1-dB required OSNR penalty (the nonlinear threshold – NLT) is reduced by up to 9 dB for OOK signals compared to ODC transmission [3]. While SPM can be pre-distorted using look-up table (LUT) based filters, a study by Essiambre and Winzer has shown a large performance fluctuation in 10 Gb/s EPD systems due to the strong impact of XPM which cannot be compensated for [4]. As a result, the launch power in 10 Gb/s EPD systems needs to be reduced which limits the maximum reach or reduces the OSNR margin. However, at a bit rate of 40 Gb/s the impact of fibre nonlinearities in EPD systems has not been investigated.

In this paper, we numerically analyse the NLT of 10 and 40 Gb/s single-channel EPD systems over 10x80 km SSMF using NRZ-OOK modulation format. The results are compared to ODC systems with optimised dispersion maps.

Complexity of EPD transmitters

The complexity of the EPD transmitter is determined by a number of factors. For assessing the scalability of EPD systems from 10 to 40 Gb/s the memory length of the transmission link plays an important role. The memory length m is defined as the number of optical pulses overlapping and interacting due to chromatic dispersion and fibre nonlinearities. For the case of NRZ-OOK signals with bit rate B it is approximately given by [5]

$$m = CD_{max} B^2 \frac{\lambda^2}{c} + 1, \qquad (1)$$

where CD_{max} is the maximum accumulated dispersion at a position of the link dispersion map with sufficient signal power. In EPD systems CD_{max} is reached at the transmitter and it is given by $CD_{max} = DL$ where D is the fibre dispersion parameter and L is the entire transmission distance. For the 800-km SSMF EPD system analysed in this paper (1) yields a memory length of $m=11$ and $m=165$ for 10 and 40 Gb/s, respectively. The transmitter electronics complexity depends on the physical effect to be predistorted. A combined predistortion of chromatic dispersion and intrachannel nonlinearities requires a nonlinear filter such as a LUT whose size scales exponentially with the memory length (2^m) [1]. This makes clear that EPD of dispersion and nonlinearities at 40 Gb/s is impractical since the required LUT size is too large ($2^{165} \approx 10^{49}$). If only dispersion is predistorted a linear FIR filter may be used whose complexity scales linearly with the memory length of the system. In this case fibre nonlinearities will degrade the performance.
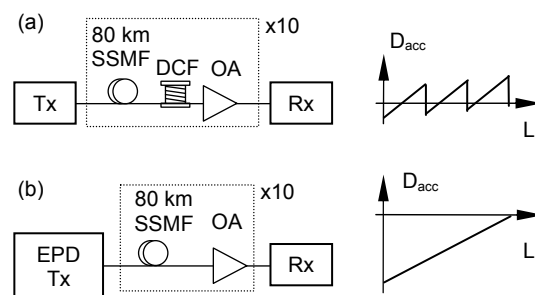

Figure 1: System setup and dispersion map diagram for (a) ODC system and (b) EPD system.

System setups

The two 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 Tab. 1. A singly periodic dispersion map was used for the ODC system (Fig. 1a). It was numerically optimised to obtain minimum transmission penalties at 10 and 40 Gb/s. The optimum parameters are summarised in Tab. 2. In the EPD system the transmitter generates the precompensation for the

entire transmission distance at the transmitter (Fig 1b). No DCF modules are required along the link. For the numerical simulation of EPD ideal dispersion precompensation was assumed using the inverse frequency transfer function of a linear fibre. Therefore, the EPD results present the theoretical maximum neglecting the impact of finite FIR filters, limited D/A conversion and a realistic I-Q modulator. Simulations were carried out using VPI Transmission Maker.

No. of spans	10
Span length	80 km
Attenuation	0.2 dB/km
SSMF dispersion	16 ps/nm/km
NL coefficient	1.31 (W×km) $^{-1}$

Table 1: System parameters for both EPD and ODC.

Bit rate	10 Gb/s	40 Gb/s
D_{pre}	−1000 ps/nm	−300 ps/nm
D_{res}	100 ps/nm	20 ps/nm
D_{post}	150 ps/nm	0 ps/nm

Table 2: Dispersion map parameters for the ODC systems at 10 and 40 Gb/s, respectively. Parameters are optimised to minimise the impact of nonlinearities.

Results and discussion

The OSNR required for a BER of 10^{-4} versus the average launch power was simulated for the 10 Gb/s system using a DeBruijn binary sequence (DBBS) of order 10 and 13 corresponding to 1024 and 8192 bits, respectively. The results (Fig. 2) show that the EPD system reaches the 1-dB OSNR penalty at approximately −2 dBm launch power whereas the ODC system's NLT is larger than 10 dBm. This results in a NLT difference between ODC and EPD of over 12 dB. Using a longer DBBS sequence does not change this behaviour confirming that the impact of intrachannel nonlinearities is accurately captured by these simulations.

The numerical or experimental characterisation of a transmission system with an accumulated dispersion as large as 12,800 ps/nm at 40 Gb/s is challenging since according to (1) accurately capturing the intrachannel nonlinear effects requires a DBBS of order 165 and length 2^{165}. Nevertheless, Fig. 3 shows the results for various DBBS length increasing from 10 to 15. A remarkable result of Fig. 3 is that the large NLT difference between ODC and EPD observed in the 10 Gb/s systems does not exist in the 40 Gb/s system.

The NLT of the 40 Gb/s EPD system is less than 1 dB smaller than that of the ODC system. Although the required OSNR curve of the EPD system depends on the DBBS sequence the difference remains relatively small up to the 1-dB penalty point. Hence, there is

good reason to expect that the NLT will not be severely affected by further increasing the DBBS length.

In addition to the single channel analysis, preliminary results for EPD in a WDM system (not shown here) indicate that 40 Gb/s transmission is also less sensitive to XPM induced burst errors compared to 10 Gb/s, as reported in [4].
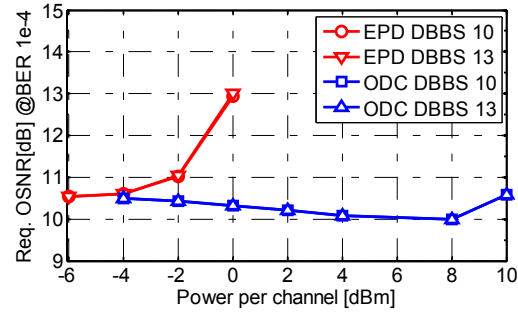

*Figure 2: Required OSNR for a BER of 10^{-4} versus the average launch power for the 10x80 km SSMF system at **10 Gb/s** using EPD and ODC with different DBBS sequence lengths.*
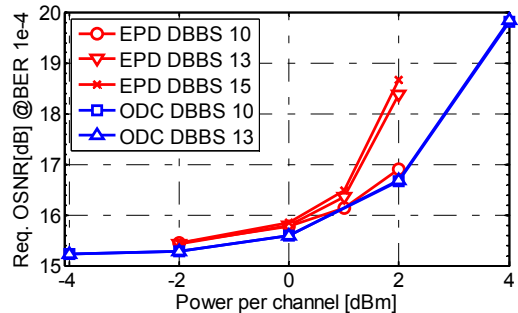

*Figure 3: Required OSNR for a BER of 10^{-4} versus the average launch power for the 10x80 km SSMF system at **40 Gb/s** using EPD and ODC with different DBBS sequence lengths.*

Conclusions

We have shown that the strong nonlinear threshold reduction due to intrachannel nonlinearities observed in 10 Gb/s electronic dispersion precompensation systems is not existent in 40 Gb/s transmission. At 40 Gb/s there is only a small nonlinear threshold difference of less than 1 dB between idealised electronic predistortion and conventional optical inline dispersion compensated systems. Hence, 40 Gb/s EPD systems are expected to have the same maximum reach and OSNR budget as ODC systems.

References

1. Killey et al, Proc. OFC 2005, paper OThJ2
2. McGhan et al, Proc. OFC 2005, paper PDP27
3. Klekamp et al, Proc. OFC 2006, paper OWR1
4. Essiambre et al, Proc. ECOC 2005, paper Tu3.2.2
5. Wickham et al, Photon. Technol. Lett., 16 (2004), pp. 1591-1593