PARAMETRIC GAIN IMPAIRMENTS IN 10 Gb/s CODED OPTICAL SYSTEMS WORKING AT LOW SIGNAL-TO-NOISE RATIOS

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Abstract *We show that parametric gain may force the use of more powerful forward error correction codes than planned when ignoring such effect in 10 Gb/s dispersion-managed transmission systems.*

Introduction

Parametric gain (PG) is a nonlinear effect in which a signal exchanges energy with the amplified spontaneous emission (ASE) white noise through a four wave mixing (FWM) process. As a result, the received ASE power spectral density (PSD) ceases to be white. It was recently shown [1] that in the strongly nonlinear regime, and at low signal-to-noise ratios (OSNR), a power threshold due to PG exists beyond which the ASE PSD inflates well above the prediction of the standard PG small-signal model [2], thus strongly degrading system performance. In this paper, we show that PG can introduce substantial OSNR penalty in an ultra-long dispersion optimized transmission system working at very low OSNR with forward error correction coding (FEC), which can readily exceed one dB for low dispersion transmission fibres when the power approaches the PG threshold. Such penalty implies either the use of a more powerful FEC than planned if ignoring PG, or the use of less noisy amplifiers.

Transmission System

It has recently been shown that the performance of single channel optimized dispersion mapped systems, ignoring PG, only depends on the cumulated nonlinear phase $\Phi_{NL} = \gamma\langle P\rangle L_{eff} N$, being $\langle P\rangle$ the average power, γ the nonlinearity coefficient, L_{eff} the effective length, and N the number of spans [3]. Moreover, it was shown in [1] that the effect of PG essentially depends on Φ_{NL} and the fibre type only, when using full in-line compensation. Hence, to speed up our simulations, instead of selecting an ultra-long haul system, we studied a 5-span single channel 10 Gb/s system whose set-up is shown in Fig. 1. The transmission fibre was either NZDSF$^+$ (Non-zero dispersion shift fibre, D=2.9 [ps/nm/km], γ=2.1 [$W^{-1}km^{-1}$]), or TeraLight^{TM} (D=8 [ps/nm/km], γ=1.7 [$W^{-1}km^{-1}$]), or SMF (single-mode fibre, D=17 [ps/nm/km], γ=1.4 [$W^{-1}km^{-1}$]). The dispersion of each span is 100% compensated by a DCF fibre, working in the linear regime. Before and after the transmission line, pre- and post- compensation fibres were optimized to have the best performance at each transmitted power. We used a Gaussian optical filter of bandwidth 28.75 GHz, and an electrical 2nd-order Butterworth filter of bandwidth 6.5 GHz. The OSNR was uniformly degraded along the line to get an end-line OSNR of 16 dB over 0.1 nm, so that the bit error rate (BER) could be changed by varying the preamplifier noise figure through a variable attenuator, and thus the received OSNR. The system BER was evaluated with an accurate Karhunen-Loéve method, as described in [1].

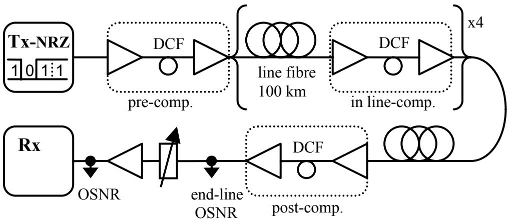

Fig.1. System set-up.

Results

Fig. 2 shows the BER vs. the received OSNR for NZDSF$^+$ (top), TeraLight^{TM} (centre) and SMF (bottom) transmission fibre. Since the end-line OSNR is fixed to 16 dB, the x-axis is limited to such level. The filled symbols refer to the curves in presence of SPM and neglecting PG (i.e. using white ASE), while the corresponding open symbols refer to computations with both SPM and PG. The inset shows the nonlinear phase values for each curve. For decreasing Φ_{NL} the curves eventually coincide with those of linear propagation (no SPM).

From the figure, we learn that very little change in BER occurs when varying the nonlinear phase within the shown range if PG is ignored. The realistic inclusion of PG, instead, shows an evident dependence of BER on nonlinear phase. The curves indicated by diamonds have been obtained by using the PG threshold value of the nonlinear phase calculated as in [1]. It is clear that, as the nonlinear phase approaches such value, the BER curves very rapidly depart from the linear propagation curve.

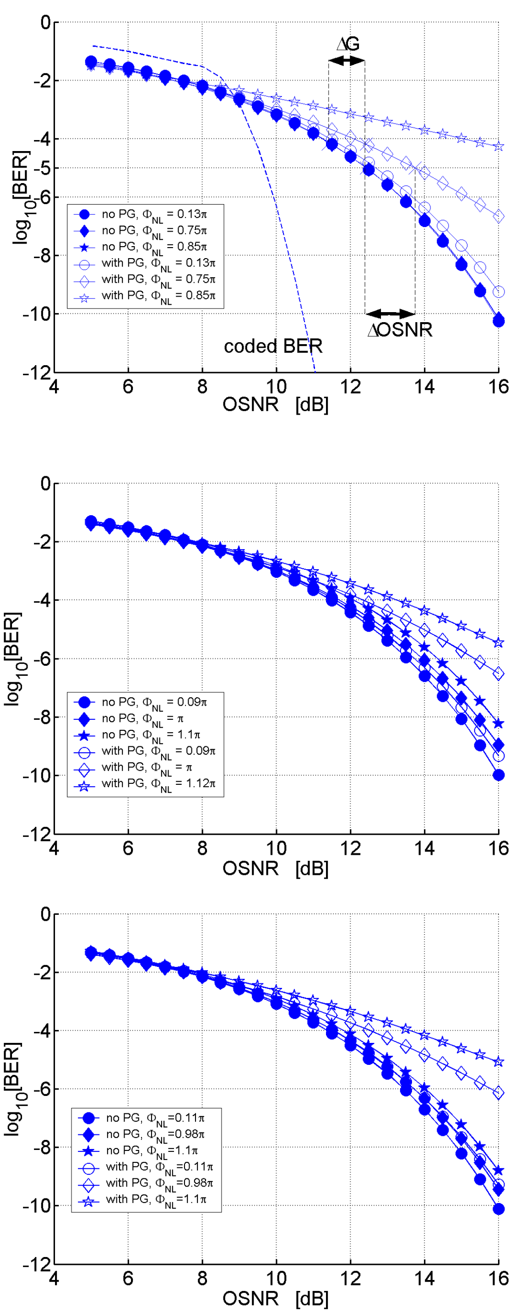

Fig. 2. Uncoded BER vs. received OSNR for a NZDSF$^+$ (top), TeraLight^{TM} (centre) and SMF (bottom) map. End-line OSNR = 16 dB. Open symbols: SPM+PG; filled symbols: SPM+white noise.

We also observe from the three figures that the PG impact is largest for the NZDSF$^+$, because the FWM process that inflates the ASE noise is better phase matched by its lower chromatic dispersion.

In Fig. 2 (top) we also show the coded BER curve [4], for a standard (255,239) Reed Solomon code, corresponding to the uncoded filled-symbols BER curves, i.e., ignoring PG. Suppose now, for instance, that we wish to operate our system at an uncoded BER of 10^{-5}, corresponding to a coded BER of about 10^{-22} . Then, when neglecting PG, we find from the filled-symbols curve that we should use an OSNR=12.4 dB. However PG worsens the BER to about 10^{-4} in the diamond curve case, leading to a coded BER of 10^{-13}. Such degradation can be compensated in two alternative ways. First, by working at the same OSNR and using a more powerful code, whose additional gain should equal ΔG~1 dB in this case, as indicated in Fig. 2 (top). Second, by keeping the same FEC, but increasing the OSNR by ΔOSNR~1.5 dB so as to leave the uncoded BER at 10^{-5}. Note that much larger penalties are incurred when operating the system beyond the nonlinear phase threshold.

Conclusions

We investigated the impact of parametric gain in 10 Gb/s optimized dispersion mapped systems working at low signal-to-noise ratios by means of forward error correction codes. We showed that in such regime the parametric gain of ASE can substantially degrade the BER. The additional penalty introduced by the parametric gain rapidly grows up after a nonlinear phase threshold, thus requiring either much more powerful FECs or larger OSNRs than planned when ignoring the parametric gain.

References

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