Experimental study of XPM in 10-Gb/s NRZ precompensated transmission systems

DOI:
10.1109/OFC.2007.4348742

Document status and date:
Published: 01/12/2007

Experimental study of XPM in 10-Gb/s NRZ pre-compensated transmission systems

S. L. Jansen, I. Morita
KDDI R&D Laboratories, Saitama, Japan
email: SL-Jansen@kddilabs.jp

D. van den Borne, G. D. Khoe, H. de Waardt
COBRA institute, Eindhoven University of Technology, The Netherlands
email: D.v.d.Borne@tue.nl

P. M. Krummrich
Siemens Communications, Fixed Networks, Munich, Germany
email: Peter.Krummrich@siemens.com

Abstract: We experimentally assess the nonlinear tolerance of 10-Gb/s NRZ in a pre-compensated dispersion map. It is observed that even for relatively wide 100-GHz channel-spacing, XPM further reduces the nonlinear tolerance in contrast to periodically-compensated maps.

OCIS codes: (060.2330) Fiber optics communications; (060.4510) Optical communications

1. Introduction

Reducing system cost is an important drive for new innovations in long-haul fiber optic transmission systems. Predominantly, system costs could be reduced by finding an alternative for the inline dispersion compensating fiber (DCF) modules. As DCF is a nonlinear medium with a relatively high loss it requires inline amplifiers with mid-stage access. Two technologies are currently being deployed replacing DCF and allowing inline amplifiers without mid-stage access, namely electronic pre-distortion (EPD) [1] and fiber Bragg gratings (FBGs) [2]. The interesting aspect of using EPD is that all chromatic dispersion is pre-compensated at the transmitter. Therefore, no optical inline dispersion compensation is required for this solution, which significantly simplifies the dispersion map.

However, a consequence of systems employing EPD is that the chromatic dispersion accumulates to significantly higher values compared to conventional transmission links with periodic dispersion compensation. It has been shown that the high accumulated dispersion results in a significant increase in peak power and thereby an increased self-phase modulation (SPM) penalty [3]. As a result, significantly lower optical launch powers have to be used in EPD experiments compared to conventional transmission systems in order to reduce the SPM penalty [1, 4]. Several simulations have been reported on the influence of cross-phase modulation (XPM) in 10-Gb/s pre-distorted transmission systems [5, 6].

In this paper the influence of XPM is experimentally assessed for 10-Gb/s NRZ in a pre-distorted dispersion map ("pre-compensated setup") and a conventional system employing periodic dispersion compensation ("inline-compensated setup"). Instead of creating the pre-distorted transmitter with electronics, an ideal linear pre-distorted transmitter is realized in this experiment by placing all DCF of the transmission link at the transmitter [3]. It is shown that the XPM penalty is larger for the pre-compensated transmission system. Even at 100-GHz channel spacing XPM is still a significant impairment in the pre-compensated setup whereas the conventional setup is in this case mainly limited by SPM.

2. Experimental setup

The experimental setup of the pre- and the inline-compensated configurations are depicted in Fig. 1. For both configurations the same transmitter and receiver structure is used. The outputs of five external cavity lasers (ECLs) are multiplexed using a star coupler. Low frequency phase modulation was applied in order to suppress the buildup of SBS in the transmission experiments. The center wavelength is located at 1550.92 nm and the channel spacing is either 50 GHz or 100 GHz. All channels are co-polarized for worst-case interaction. The continuous wave signals are NRZ modulated with 10.7-Gb/s PRBS data (length 2^{31}-1) by a Mach-Zehnder modulator. In the conventional transmission link, a DCF of -517 ps/nm is used as pre-compensation. The transmission line consists of eight standard single-mode fiber (SSMF) spans with an average span loss of 20.5 dB. An inline under-compensation of 83 ps/nm is used. All experiments are conducted with a fixed optical signal-to-noise ratio (OSNR) at the receiver,

©OSA 1-55752-830-6

realized by a noise loading scheme consisting of an attenuator, an Erbium-doped fiber amplifier (EDFA) and a bandpass filter (BPF). The BPF has a full-width at half-maximum of 0.18 nm and is used to remove other wavelength division multiplexed (WDM) channels. After setting the OSNR, the chromatic dispersion is optimized to achieve the minimum bit-error ratio (BER). An EDFA and BPF (1.2 nm FWHM) is then used to amplify the signal and remove access ASE before it is detected using a photodiode and a BER test (BERT) set receiver.

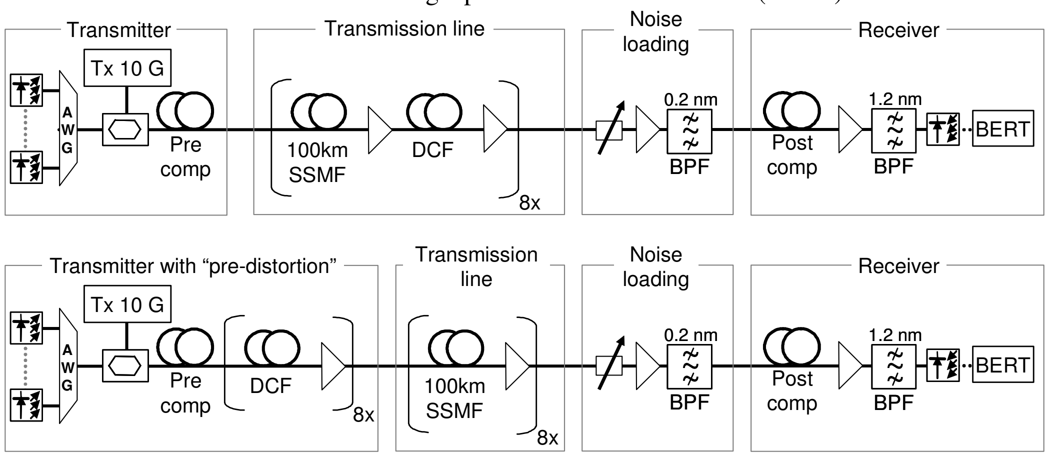

Fig. 1: Experimental setup of the pre- and the inline-compensated setup.

In the pre-compensated setup, all eight inline DCF modules are placed together with their amplifier before the transmission link. The same 800-km link of SSMF is used for transmission. For convenience a small amount of DCF is kept at the receiver for the optimization of the BER. Note that when EPD is used for dispersion compensation, the extra DCF at the receiver would not be required. However, as the amount of post-compensation is relatively low (<300 ps/nm), keeping it at the receiver end will not significantly affect the transmission performance.

2. Experimental results

In the pre-compensated setup it was found that when the same DCF input powers are used as in the conventional transmission system, the nonlinear impairments that occur in the DCF at the transmitter had a detrimental influence on the performance of the transmission system. When the pre-compensated signal is generated electronically, these nonlinearities would not occur and therefore it is crucial for a realistic comparison that the nonlinearities in the pre-compensating DCF are negligible. This was achieved by reducing the input power into the DCF to -12 dBm/channel. At this input power, no penalty with respect to back-to-back was measured. Because of the low input power into the DCF, the OSNR after transmission is significantly reduced. However, as the BER is assessed at a constant received OSNR, the OSNR degradation of the low input power into the DCF does not affect the performance for the NRZ modulation format. On the other hand, this method limited us to ASK modulation formats, because for phase modulated modulation formats (such as DPSK) additional penalties would arise along the transmission link because of nonlinear phase noise [7].

The nonlinear tolerance towards SPM is taken as a reference for the measurements. This nonlinear tolerance is assessed by transmitting a single channel and varying the SSMF launch power while measuring the BER at a fixed received OSNR. All measurements are conducted with a fixed OSNR of 13 dB for which a Q-factor of 13.3 dB (BER of $1.9*10^{-6}$) is measured in the back-to-back configuration. Fig. 2 shows the obtained BER curves as a function of the launch power, in which the back-to-back performance is represented as a dashed line. At low input powers, the influence of nonlinear impairments is small and therefore the BER performances of the pre- and periodic compensated schemes are equal to the back-to-back performance. When a single channel is transmitted, the performance of the periodic compensated scheme allows significantly higher launch powers. For a Q-factor of 10 dB (BER of $7.8*10^{-4}$) the maximum launch power is 8.1 dBm in the pre-compensated scheme. When the periodic compensated scheme is used, the launch power can be increased by 6 dB to 14.1 dBm before a similar penalty occurs. It can thus be concluded that similar to [3] a relatively large SPM penalty is observed in the pre-compensated setup. In the periodic compensated scheme, a small improvement in BER with respect to the back-to-back BER is observed for launch powers between 8 dBm and 11 dBm. This improvement in BER results from the interaction of GVD and SPM, which changes the pulse shape of the NRZ signal into an RZ like signal. The RZ shaping is clearly observed in the eye diagram after transmission with a launch power of 10 dBm, depicted in the inset of Fig. 2.

The influence of XPM is measured by transmitting five WDM channels at 100-GHz and 50-GHz channel spacing. In this configuration, the BER of the center channel, experiencing most XPM, is assessed. At 100-GHz channel spacing a Q-factor of 10 dB is obtained in the pre-distorted transmission system at an input power of 6.5 dBm. At this point, the XPM penalty is 2 dB with respect to single channel. For the periodic configuration a Q-factor of 10 dB is obtained at 13.9 dBm launch power, where unlike the pre-distorted transmission system only a minor Q-factor of 0.3 dB is observed. It can thus be concluded that XPM is more significant in the pre-compensated setup whereas for the periodic dispersion map the performance is mainly limited by SPM.

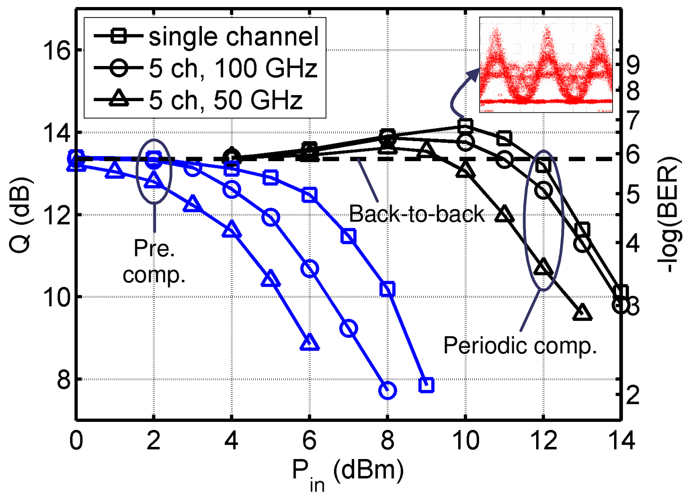

Fig 2: Single channel and WDM nonlinear tolerances of the pre-compensated (blue) and the periodically compensated (black) dispersion map, measured at a fixed received OSNR of 13 dB.

When the channel spacing is reduced from 100 GHz to 50 GHz, a strong impact due to XPM is seen for both configurations. In the pre-distorted transmission system, a Q-factor of 10 dB is obtained at a launch power of 5.3 dBm. The XPM penalty with respect to single channel increases in this case to 2.8 dB, which almost equals the total Q-factor penalty with respect to the back-to-back configuration (3.3 dB). In the periodically compensated configuration, the XPM penalty is 2.1 dB. Consider now the XPM penalty, expressed as the reduction in allowable launch power to obtain a 10-dB Q-factor. We then find for the pre- and the periodically compensated configuration a 2.8 dB and 1.5 dB penalty with respect to the single channel configuration, respectively.

Apart from chromatic dispersion EPD can be used as well for the compensation of single channel impairments such as SPM. Therefore, it is expected that using EPD the nonlinear tolerance of the single channel configuration can be significantly increased. However due to the significant XPM impairments in the WDM configuration (for both periodic and EPD dispersion maps) the usefulness of compensating for SPM with nonlinear EPD is questionable.

A larger nonlinear tolerance is expected in transmission systems where intra-channel nonlinear impairments dominate over inter-channel nonlinear impairments. Therefore, an interesting application would be to use EPD for future 40-Gbit/s transmission systems using differential quadrature phase shift keying (DQPSK). These transmission systems operate at a symbol rate of 20 GS/s and enable transmission over long-haul distances with high accumulated inline dispersion provided that the intra-channel nonlinear impairments are compensated for [8]. However, the implementation of a pre-compensated transmission system at 20 GS/s is not straightforward as it requires further development in high speed D/A converter design.

4. Conclusions

In this paper the influence of XPM is assessed for the dispersion map of pre-compensated transmission systems. It is shown that for 100-GHz spaced WDM channels XPM causes a significant penalty whereas the transmission system with a periodic dispersion map is mostly limited by SPM. When the channel spacing is reduced to 50 GHz, both configurations are impaired by XPM, although the total penalty with respect to back-to-back is lower in the conventional transmission system compared to the pre-compensated one.

5. References

[1] M. Birk et al., "WDM technical trial complete electronic dispersion compensation", ECOC 2006, Th2.5.6.

[2] Y. Painchaud et al., "Low-penalty cascade of low-ripple FBG-based dispersion compensators", ECOC 2006, Th4.2.7.

[3] S. Chandrasekhar et al., "Demonstration of 100% precompensated DWDM transmission over 1280 km of SSMF with no inline dispersion compensation using interconnected recirculating loops", PTL, vol. 18, pp. 256-258, 2006.

[4] D. McGhan et al., "5120 km RZ-DPSK transmission over G652 fiber at 10 Gb/s with no optical dispersion compensation", OFC 2005, PDP 27.

[5] R. I. Killey et al., "Electronic precompensation techniques to combat dispersion and nonlinearities in optical transmission", ECOC 2005, Tu4.2.1.

[6] R.-J. Essiambre et al., "Fibre nonlinearities in electronically pre-distorted transmission", ECOC 2005, Tu3.2.2.

[7] H. Kim et al., "Experimental Investigation of the Performance Limitation of DPSK Systems Due to Nonlinear Phase Noise," PTL, vol. 15, pp. 320-322, 2003.

[8] S.L. Jansen et al., "26x42.8-Gbit/s DQPSK Transmission with 0.8-bit/s/Hz Spectral Efficiency over 4,500-km SSMF using Optical Phase Conjugation", ECOC 2005, Th4.1.5.