Reduction of Nonlinear Crosstalk in Fiber OPAs

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Abstract: We review different techniques to suppress nonlinear crosstalks due to four-wave mixing (FWM) and cross-gain modulation (XGM) experienced after fiber OPA in WDM system. These techniques should help design high-performance OPAs for use in WDM communication systems.

1. Introduction

Fiber optical parametric amplifiers (OPAs) have recently been demonstrated to be practical amplifiers with high gain [1], large bandwidth [2] and polarization-independence [3]. The quality of signals emerging from OPAs used as signal processors has been investigated by several groups recently, especially with regard to the pump-to-signal RIN transfer [4], cross-phase modulation (XPM) amongst WDM channels [5], etc. However, four-wave mixing (FWM) and cross-gain modulation (XGM) seem to be the fundamental limits for using OPA as WDM amplifier. Previous work has shown that this kind of degradation is already severe with only three WDM channels in one-pump OPA (1P-OPA) system [6]. It was also shown that unequal channel spacing slightly improves the degradation. However, the XGM effect still provides a basic detrimental effect when using OPA in WDM systems, mediated through the depletion of the pump(s) as shown in Fig. 1(a). Similar signal degradation can also be observed in two-pump OPA (2P-OPA), which provides an extra degree of freedom, such that a flattened gain spectrum can be achieved by trading with the gain bandwidth [7]. In this paper, we demonstrate different techniques that would be able to suppress the WDM crosstalks significantly, inherited from both FWM and XGM.

2. Two-orthogonal-pump OPA (2OP-OPA)

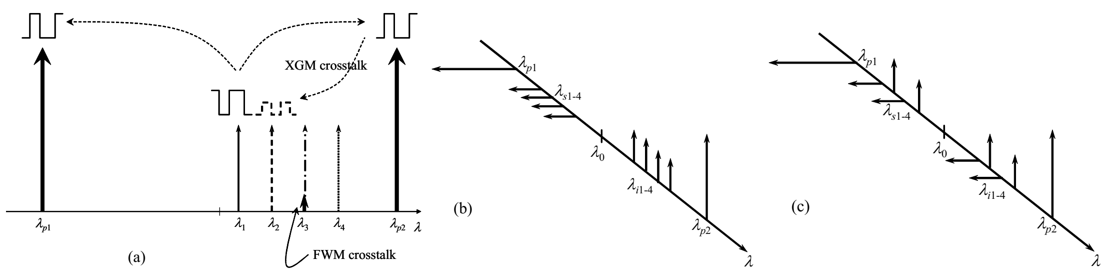

Fig. 1. (a) Illustration of the signal quality degradation of WDM system due to XGM and FWM effects in a 2P-OPA. Schematics of (b) Co-polarized (COPO); (c) polarization-interleaving (POIN) 2OP-OPA system.

2OP-OPA has been demonstrated to be polarization-independent [3]. Preliminary results have also confirmed that it is effective in suppressing nonlinear crosstalks with co-polarized (COPO) WDM channels [8] with the configuration as shown in Fig. 1(b). Furthermore, by using polarization-interleaving (POIN) WDM channels as shown in Fig. 1(c), the signal quality can further be improved [9]. We performed experiments to verify these predictions.

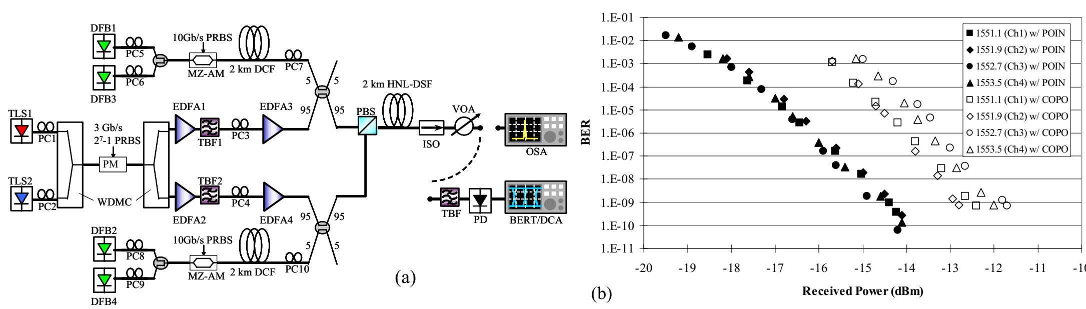

Fig. 2. (a) Typical 2OP-OPA configuration; (b) BER curves for all four channels with POIN and COPO signals.

The typical experimental configuration is shown Fig. 2 (a). The parametric gain medium consisted of 2 km of HNL-DSF (OFS Ltd.) with a nominal zero-dispersion wavelength λ_0 of 1543.4 nm, and a dispersion slope of 0.019 ps/nm^{2}km. The fiber nonlinear coefficient γ was 10.4 W^{-1}km^{-1}. Two tunable laser sources, TLS1 and TLS2, set at

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1529.45 nm and 1556.8 nm, respectively, serve as the pump sources, with the average wavelength approximately equal to λ_0. The CW pumps were phase-modulated (PM) by 3 Gb/s 2^7-1 pseudo-random bit sequence (PRBS) to suppress stimulated Brillouin scattering (SBS). The polarization controllers, PC1 and PC2, align the pump SOP's with PM, which helps to reduce the insertion loss. Pumps #1 and #2 were then amplified by two separate EDFAs, with maximum output power of 21 dBm each, and they are combined with odd (#1, #3) and even (#2, #4) channels by 95/5 couplers, respectively. The two branches are then combined with a polarization beam-splitter (PBS). Furthermore, polarization controllers (PC3 and PC4) are used to ensure that the two pumps incident on the HNL-DSF are orthogonal. Similarly, PC7 and PC10 are used to maintain orthogonal SOPs between odd and even channels. We used 4 WDM channels (DFB1-4, with odd and even channels orthogonal to each other) with spacing of 100 GHz, as signals to determine the signal quality degradation. Each signal is intensity-modulated by a 10 Gb/s PRBS. They are de-correlated by 2 km of dispersion-compensating fiber (DCF). We measured the eye diagrams and bit-error rate (BER) using the digital communication analyzer (DCA) and BER tester at the output of HNL-DSF. The results are shown in Fig. 2 (b), which showed about 2dB improvement in sensitivity of the case POIN signals.

3. Modulation format in OPA

Besides pursuing pumps configuration to suppress nonlinear crosstalk, reduction by using different modulation formats has also been shown to be effective. For example, return-to-zero differential phase-shift keying (RZ-DPSK) modulation format, which the signal power level is constant, should be effective in suppressing XGM-induced crosstalk. The typical experimental setup is similar to the one shown in Fig. 2 (a) except that the modulation part has to be modified, depending on the modulation format. The eye diagrams of RZ-DPSK and OOK signals before and after OPA amplification are shown in Fig. 3(a)–(d). As depicted from the eye diagrams, the OPA amplified RZ-DPSK signal remained almost undistorted while OOK signal suffered from severe distortion after OPA amplification. The reduced eye opening of received RZ-DPSK signal could be accounted by slight phase modulation to intensity modulation (PM-IM) conversion of pump due to the drift of pump laser center wavelength from the center wavelength of band-pass filter TBPF1, and ASE noise. Besides distortion due to PM-IM conversion of pump and ASE noise, XGM caused the most severe distortion in OPA amplified OOK signals, which resulted in multiple mark levels of signal as shown in the Fig. 3(d). The BER of back-to-back transmitted and OPA amplified WDM signals were measured and are shown in Fig. 3(e) and (f). As from the BER plots, the power penalty of RZ-DPSK signal after OPA was about 0.8dB, while the power penalty for OOK counterpart was approximately 3dB. Therefore it is clear that using RZ-DPSK modulation format in OPA amplified links helps to relax receiver sensitivity by more than 2dB due to reduction of signal distortion.

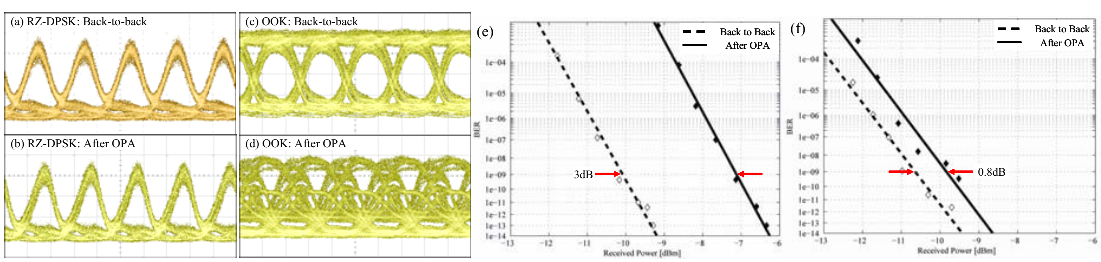

Fig. 3. (a) – (d) Eye diagrams of de-multiplexed WDM signal before and after OPA. BER plots for OOK (e) and RZ-DPSK (f) signal.

4. Conclusion

We review different techniques to suppress nonlinear crosstalks due to four-wave mixing (FWM) and cross-gain modulation (XGM) experienced in WDM system with fiber OPA. These techniques should help design high-performance OPAs for use in WDM communication systems.

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