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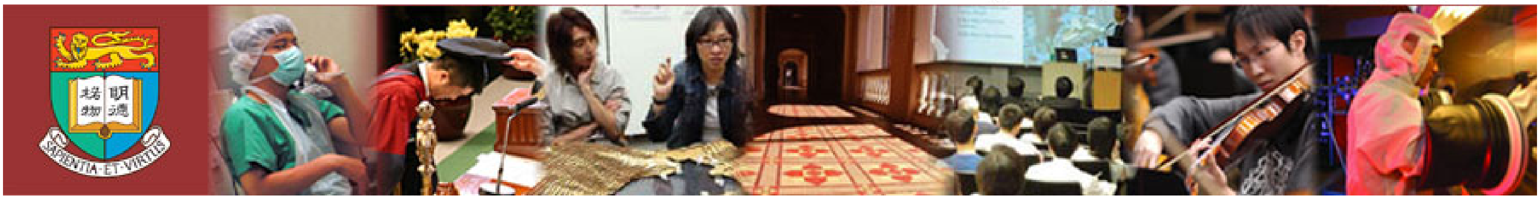

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# Comparison on Crosstalk Tolerance of RZ-DPSK and RZ-OOK Modulation Format in Fiber Optical Parametric Amplifier

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**Abstract** *We investigated crosstalk tolerance of RZ-DPSK and RZ-OOK modulation format in OPA with 100GHz channel spacing. Results show an average of 2.4dB improvement in Q factor by using RZ-DPSK format over RZ-OOK format.*

## Introduction

In modern optical networks, dense wavelength division multiplexing (DWDM) over multiple bands was proven to be an effective way to upgrade the data rate of existing infrastructure. Optical parametric amplifiers (OPAs), which have been shown to be wideband, high gain, low noise [1-3], have received much interest as a promising candidate of next generation WDM link amplifiers. However as reported by previous research, WDM signal amplified by OPA suffers from distortion mainly due to cross gain modulation (XGM) even with unequal channel spacing [4]. Previously, we have compared the crosstalk tolerance of RZ-DPSK and NRZ-OOK modulation format in one-pump OPA with three input channels separated by 2.7 nm in wavelength, and showed improvement in receiver sensitivity by using RZ-DPSK format [5]. However, the robustness of RZ-DPSK format with dense WDM channels has not been testified. In this paper, we will compare the quality of RZ-DPSK and RZ-OOK signals after OPA with dense channel separation of 0.8 nm.

## Experimental Setup

The experimental setup used for this investigation is shown in Fig. 1. The nonlinear medium used for parametric amplification was a spool of 1 km highly nonlinear dispersion shifted fiber (HNL-DSF) with nonlinear coefficient $\gamma \approx 14$ /W/km, zero dispersion wavelength $\lambda_0 \approx 1560$ nm and dispersion slope $dD/d\lambda \approx 0.024$ ps/nm$^2$/km. Eight signal laser sources (SLD1-8) with wavelengths from 1542.9 nm to 1548.5 nm were combined by an arrayed waveguide grating (AWG1) with channel spacing of 100 GHz, and intensity modulated with 10 GHz clock signal at amplitude modulator (MZM1) to generate 10 Gb/s pulse train. The signal pulse trains were then modulated by transmitters shown in Fig. 2. In RZ-DPSK transmitter, The signal waves were combined with the pump wave at 1560.2 nm from a DFB laser source (PLD) and phase modulated with 10Gb/s $2^7$-1 pseudo random binary sequence (PRBS) at phase modulator (PM) for data modulation of signal waves and stimulated Brillouin scattering (SBS) suppression of pump wave. The pulse trains from MZM1 were aligned to the modulating signal fed into PM by a tunable optical delay line (ODL). To remove the pump wave from the signal path, a 50 GHz interleaver (IL) was connected to the signal port of the 50/50 coupler after PM.

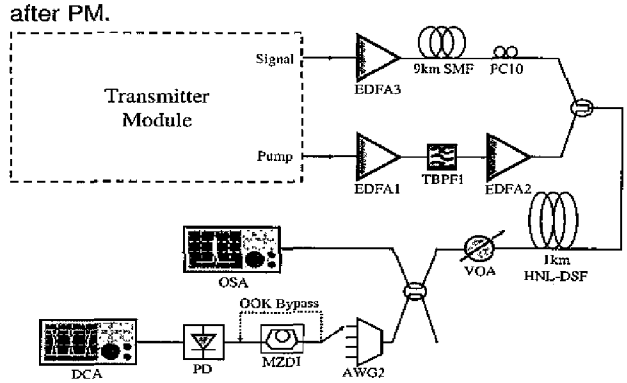


*Fig. 1. One pump OPA with DPSK/OOK input signal. VOA: Variable optical attenuator; OSA: Optical spectrum analyzer; DCA: Digital communication analyzer.*

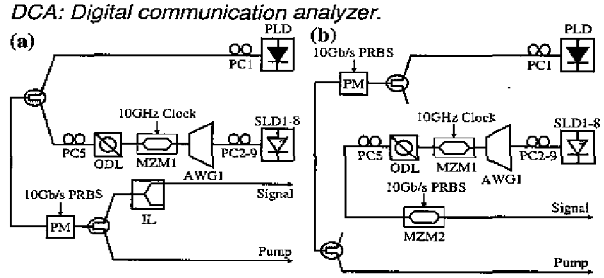


*Fig. 2. Transmitter modules for (a) RZ-DPSK and (b) RZ-OOK format.*

In RZ-OOK transmitter, the signal pulse trains after MZM1 were intensity modulated with 10Gb/s $2^7$-1 PRBS by another amplitude modulator MZM2 for data modulation, while the pump wave was phase modulated at PM for SBS suppression. The pump wave was amplified subsequently by two stages of erbium-doped fiber amplifiers (EDFA1 and EDFA2) to 31dBm, with a tunable bandpass filter (TBF1) inserted in between to filter out signal waves and suppress amplified spontaneous emission (ASE) level. On the other hand, the signal waves were boosted to total power of 7dBm by EDFA3 and de-correlated using 9 km SMF-28 fiber. The amplified pump and signals were then combined by a 50/50 coupler and launched into HNL-DSF for parametric amplification. The states of polarization (SOP) of signals were aligned to that of the pump wave by using polarization controller PC10. The signal gain attained was 15dB at 1548.8 nm. After parametric amplification, the signals were filtered using AWG2 and directly detected by photodetector (PD) for RZ-OOK signal, or demodulated and detected by Mach-Zehnder delay interferometer (MZDI) and PD for RZ-DPSK signal.

## Results and Discussions

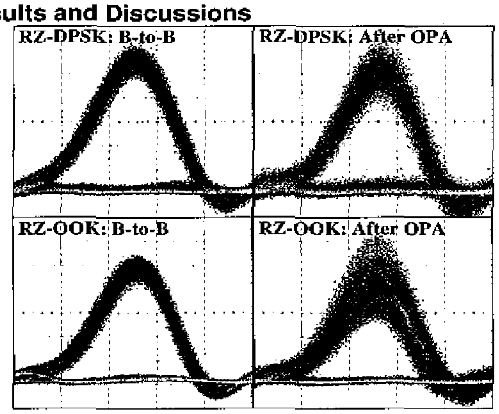


*Fig. 3. Eye diagrams for RZ-DPSK (top) and RZ-OOK (bottom) signals before and after OPA.*

The eye diagrams of RZ-DPSK and RZ-OOK signals before and after OPA are shown in Fig. 3. As observed from the eye diagrams, RZ-OOK signal suffered from strong XGM induced crosstalk as indicated by multiple mark level feature, and also FWM induced crosstalk as shown by the noisy mark level. On the other hand, clear eye opening was still observed for the post-OPA RZ-DPSK signal. Fig. 4. shows the Q factor penalty for RZ-DPSK and RZ-OOK signals. On average, the Q factor penalty for RZ-DPSK signal was 2.4dB less than that for RZ-OOK signal. The higher Q factor penalty of channel 1 signals observed from the plot was mainly due to lower signal power launched at channel 1 to equalize the channel power after signal EDFA, and higher ASE noise from pump EDFA at shorter wavelength regime. Also, the data point for channel 5 RZ-OOK signal was dropped from the plot as the Q factor of post-OPA signal was not measurable as the strong XGM effect rendered the mark level undefined for this channel.

To quantify the robustness of RZ-DPSK modulation format with multiple channels coexisting at the input to OPA, we have also measured the Q factor penalty at channel 1, 4 and 8 versus number of input channels and the results are shown in Fig. 5. As from the plot, the variation of Q factor with different number of channels for RZ-DPSK signals was significantly less than the variation for RZ-OOK signals. From this result it can be deduced that the crosstalk between RZ-DPSK modulated channels was reduced as compared with RZ-OOK signals. Moreover, as the penalty for RZ-DPSK signal was essentially the same for single channel and multiple channel inputs, it is believed that the penalty was mainly caused by the additional phase noise contributed by ASE noise from pump EDFA.

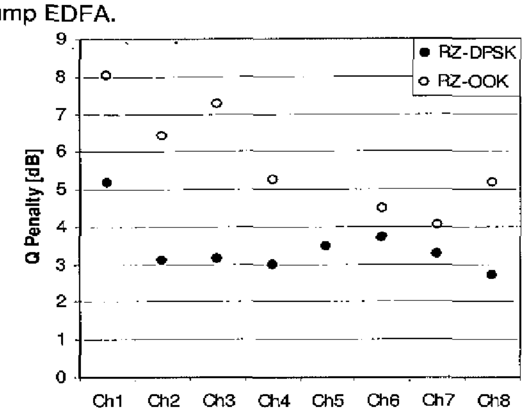


*Fig. 4. Q factor penalty of RZ-DPSK and RZ-OOK signals at different channel.*

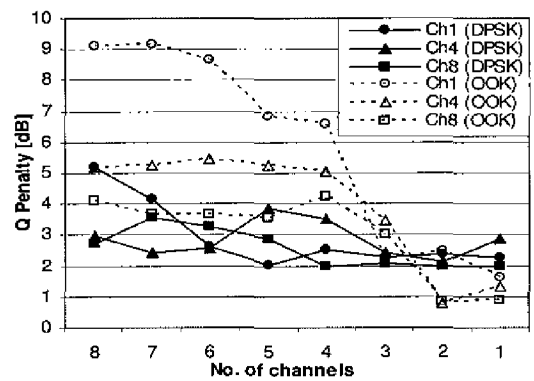


*Fig. 5. Q factor penalty of RZ-DPSK and RZ-OOK signals vs. number of channels.*

## Conclusions

We have investigated experimentally the crosstalk tolerance of RZ-DPSK and RZ-OOK modulation format in OPA. Results show an average of 2.4dB improvement in Q factor by using RZ-DPSK format over RZ-OOK format, and confirmed that crosstalk level of RZ-DPSK signals were greatly reduced as compared with RZ-OOK signal.

## Acknowledgment

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