

A Novel Pre-Amplifier for WDM Systems Based on a Fiber Optical Parametric Amplifier

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Abstract— We demonstrate a novel scheme to improve receiver sensitivity of using a fiber optical parametric amplifier. The power penalty can be improved by 3.9dB and the receiver sensitivity can achieve -42dBm when BER = 10⁻⁹.

I. INTRODUCTION

Fiber-based optical parametric amplifier (OPA) with femtosecond response time [1], high gain [2] and wide gain bandwidth [3] over several communication bands, has been demonstrated to be a candidate as a receiver pre-amplifier [4], based on the pump depletion effect in OPA. However, the intrinsic pump depletion effect confines its application to a single channel (i.e. signal plus pump). So the OPA-assisted pre-amplifier will be of great significance if it can be extended to WDM systems.

In this paper, we propose and demonstrate a novel pre-amplifier to improve receiver sensitivity by using dual-end detection of OPA for WDM systems.

II. PRINCIPLE AND EXPERIMENTAL SETUP

The principle of pre-amplifier based on OPA is shown in Fig. 1. By launching a weak signal together with a strong pump into nonlinear medium, both the amplification of weak signal and generation of new component called idler will occur by transferring power from the strong pump. As a result, the pattern on signal can be transcribed to idler, while the pump can be depleted simultaneously. By feeding both the amplified signal and idler into a photodetector (PD), constructive superposition can enhance the amplitude of the signal. Therefore, an output electrical signal with higher voltage swing is obtained. Implementing this scheme in each channel of WDM systems, extra amplification can be obtained. Note that previous work focused on combining the depleted pump and signal to enhance the signal swing [4].

The experimental setup is shown in Fig. 2, with part (a) as the pre-amplifier. The nonlinear medium used for OPA is a spool of 1-km highly-nonlinear dispersion-shifted fiber (HNL-DSF) with nonlinear coefficient $\gamma \approx 14 \text{ W}^{-1}\text{km}^{-1}$ and zero-dispersion wavelength $\lambda_0 \approx 1560 \text{ nm}$. The OPA pump is supplied from a tunable laser source (TLS1) with emission wavelength at 1561.1 nm. It is phase-modulated with 10-Gb/s 2³¹-1 pseudo-random binary sequence (PRBS) for stimulated Brillouin scattering (SBS) suppression. The phase-dithered pump is then amplified by two erbium-doped fiber amplifiers (EDFA1 and EDFA2) to 27.7 dBm with a tunable band-pass filter (TBPF1) between them to reduce the amplified spontaneous emission (ASE) noise before entering into

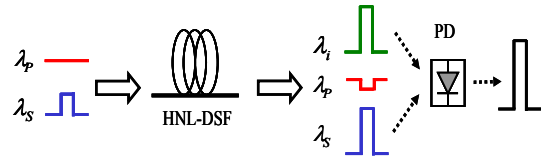


Fig. 1. Principle of proposed pre-amplifier.

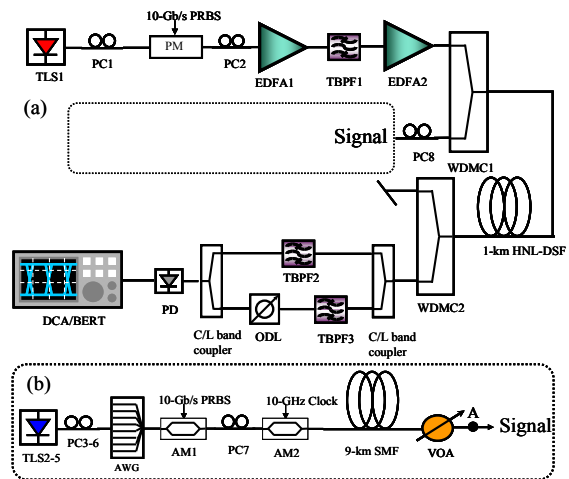


Fig. 2. Experimental setup of (a) pre-amplifier and (b) four WDM channels transmitter.

EDFA2. In Fig. 2(b), the dash line box shows the signal part. Four signal laser sources (TLS2-5) with wavelengths from 1545.3 nm to 1547.8 nm are combined by an arrayed waveguide grating (AWG) with channel spacing of 100 GHz. Then the four lightwaves are intensity-modulated by two Mach-Zehnder intensity modulators (MZ-IM) with 10-Gb/s 2³¹-1 PRBS and 10-GHz clock, respectively. A spool of 9-km single mode fiber (SMF) is used to decorrelate the four channels. The pump and signals are combined using a WDM coupler (WDMC1) and launched into HNL-DSF for parametric amplification. Maximum OPA gain is attained by aligning the state of polarizations (SOPs) of signals and pump through polarization controllers PC2 and PC8. Then the pump is filtered out by WDMC2. The signals and idlers are split by a C/L band coupler, while the corresponding signal and idler are filtered by TBPF2 and TBPF3. And the path length is compensated by optical delay lines (ODL). They are combined again using another C/L band coupler. The output is monitored through digital communication analyzer (DCA) with a 30-GHz bandwidth PD and bit-error rate tester (BERT) with 10-GHz bandwidth PD. The sensitivity of the receiver is defined as the signal power measured at the input port of

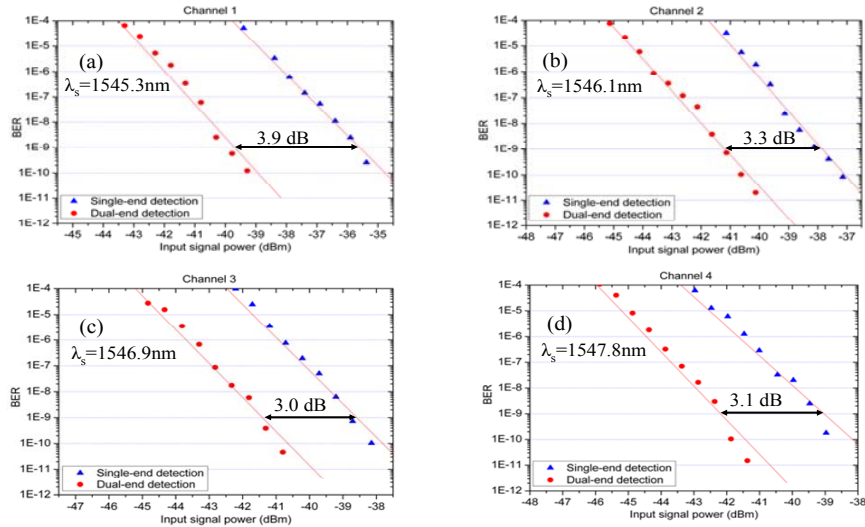


Fig.3. BER plots of (a) channel1, (b) channel 2, (c) channel 3, and (d) channel 4.

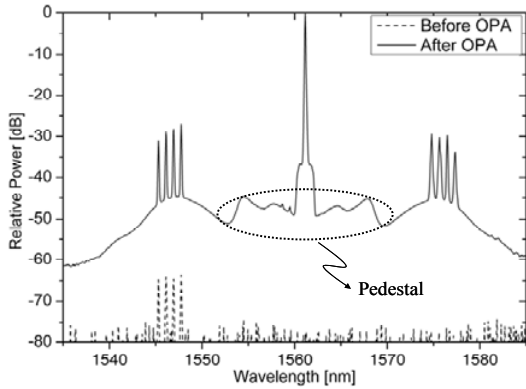


Fig. 4. Spectra before and after OPA at the output of HNL-DSF.

WDMC1 (denoted as point A in Fig. 2), which is controlled by a variable optical attenuator (VOA).

III. RESULTS AND DISCUSSION

In order to quantify the benefit of dual-end detection, bit-error rate (BER) of single- and dual-end detection schemes for four WDM channels are measured and shown in Fig. 3. From channel 1 to 4 at wavelength from 1545.3 nm to 1547.8 nm with spacing of 100 GHz, receiver sensitivities at $\text{BER} = 10^{-9}$ can reach -35.6 dBm, -37.8 dBm, -38.5 dBm and -39 dBm by single-end detection only using amplified signals. Their difference can be explained by the different parametric gain experienced by each channel as shown in Fig. 4, which shows the spectra at the output of the 1-km HNL-DSF. The dash line represents the four 10-Gb/s signals; while the solid line corresponds to the amplified signals. The parametric gains experienced by the four channels are 33 dB, 35 dB, 37 dB and 37 dB, respectively, which can be measured from the spectra as shown in Fig. 4. The channel in high-gain region can achieve lower sensitivity. Note that the pedestal of pump is caused by the WDMC1. Using dual-end detection scheme, the receiver sensitivities can be improved by 3.9 dB, 3.3 dB, 3.0 dB, and 3.1 dB, respectively. The improvement is contributed

by the increase in signal swing from idlers. The output signals of pre-amplifier can obtain extra power from idlers while input signal power remains the same.

IV. CONCLUSION

We demonstrated a novel receiver sensitivity improvement scheme for 10-Gb/s RZ-OOK signal using constructive superposition of signals and idlers in OPA for WDM systems by dual-end detection. Low receiver sensitivity down to -42 dBm was realized and power penalties were improved by more than 3 dB in all channels compared to the single-end counterpart through signal swing enhancement. This scheme would be useful for improving performance of OPA-assisted receiver in WDM systems.

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