Polarization Insensitive Fiber Optic Parametric Amplifier with a Gain Bandwidth of 22 nm in S-Band

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Abstract: We demonstrate a polarization insensitive fiber optic parametric amplifier to provide net gain >10dB and polarization dependent gain <1dB for up to 19 WDM channels in the range 1508– 1530nm. © 2022 The Author(s)

1. Introduction

Wideband optical amplification is a major focus of modern optical communications research in a bid to significantly increase the data transmission capacity. It has been approached via several techniques for example: wideband Raman amplifiers and advanced doped fiber amplifiers extending in E, S, and L-bands. Fiber optic parametric amplifiers (FOPA) have influenced the research community and stand out of the league with multiple unique features. FOPA demonstrates high gain [1], virtually unlimited bandwidth [2], arbitrary wavelength operation [3], and ultra- fast response time [4], to name a few. With its practical implementation, Polarization-insensitive FOPA (PI-FOPA) was demonstrated for amplifying WDM signals in C-Band [5]. Recently, in another advancement, single pump PI-FOPA was shown for bi-directional C+L band amplification of WDM and burst mode signals [6,7]. PI-FOPA in [8] recently was demonstrated for EDFA equivalent gain bandwidth of 35 nm in L-Band. However, experimental demonstrations of FOPA Hybrid parametric amplification in S-band approached have been limited to single-polarization operation, e.g. [9].

In this work, we experimentally demonstrate, for the first time to the best of our knowledge, an S-band polarization-insensitive FOPA (PI-FOPA). We employ the PI-FOPA to simultaneously amplify 42x100 GHz-spaced WDM channels in the range 1491 nm to 1521 nm and a 10 Gbps on-off keying (OOK) signal tuned to one of four wavelengths in the range between 1510 nm and 1530 nm. We consequently demonstrate net gain >10 dB and a polarization dependent gain (PDG) <1 dB across bandwidth of 22 nm between 1508 nm to 1530 nm. We have demonstrated 1.2±0.2 dB received power penalty for the 10G signal amplified by the PI-FOPA.

2. Experimental Setup

Fig. 1 shows an experimental setup to demonstrate PI-FOPA operation in S-Band. The setup consisted of a transmitter section, PI-FOPA, and a receiver section.

The transmitter section generated 42x 100 GHz-spaced WDM channels from 1490 nm to 1521 nm by a wavelength selective switch (WSS) using an amplified spontaneous emission (ASE) noise. The WDM channels were coupled with a tuneable wavelength 10 Gbps OOK signal via a 50% coupler. The 10G signal was used for BER measurements in the range 1510-1521 nm and for gain measurement in the range 1521-1530 nm, where the employed S-Band WSS was not operable. 10 Gbps channel was polarization scrambled (PS) to confirm that the FOPA is able to amplify arbitrarily polarized signals. A variable optical attenuator (VOA) was employed to vary input signal power to PI-FOPA for investigating amplifier performance.

The receiver section consisted of a bandpass filter (BPF) tuned to select the 10 Gbps OOK channel. The received power of the selected signals was measured after the BPF by a power meter connected via a calibrated 1% coupler. A

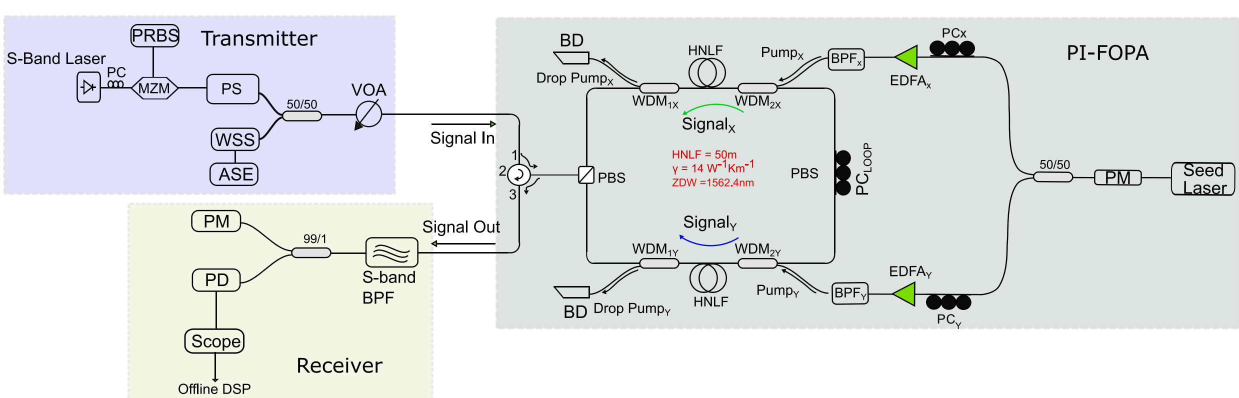

Fig.1 Experimental setup of S-Band polarisation insensitive FOPA

direct detection photodetector with 0.7 AW^{-1} responsivity was employed to perform optical to electrical conversion. A 23 GHz real-time oscilloscope captured traces of electric signal. Further, BER was calculated by an offline digital signal processing (DSP) [4].

The PI-FOPA employed for signal amplification was based on a polarization-diversity loop with two gain fibers arranged in "Loss-Gain" configuration for reduced nonlinear crosstalk [10]. The gain fibers were 50 m long dispersion stable highly nonlinear fibers (HNLFs) with zero dispersion wavelength (ZDW) at 1562.4 nm and nonlinearity of 14 $W^{-1}km^{-1}$. The pump was sourced from a 100 kHz linewidth laser at 1563.6 nm and was phase modulated to mitigate stimulated Brillouin scattering. Two high-power EDFAs amplified the pump at 8.2 W. Polarisation controllers were employed to minimize and control polarisation drifts of signals and pumps in the diversity loop. Calibrated tap couplers and an optical spectrum analyzer have been used to measure net gain and PDG. The net gain is averaged across both polarizations. The PDG is the gain difference between the X and Y arms of the FOPA.

3. Results and discussion

Fig. 2(a) shows an overlay of optical power spectra at the input and output of the PI-FOPA in four scenarios. In each scenario the PI-FOPA input comprised 42x WDM channels and a 10 Gbps OOK channel tuned to one of four wavelengths. OSA resolution was 0.1 nm. The total power of the WDM channels at the PI-FOPA input was -5 dBm. Powers of the individual channels at the input and output of the PI-FOPA were -22 dBm and up to -10 dBm respectively. Fig. 2(a) shows that FOPA gain rolls off at shorter wavelengths rapidly and reaches negative values below ~1500 nm. This is due to negative Raman gain affecting signals in both gain fibers due to its bidirectional nature and thus having double impact as compared to FOPAs employing a single gain fiber [11].

Fig. 2(b) shows the key PI-FOPA characteristics: net gain and polarization dependent gain (PDG). The results are shown for the wavelength range (1508 – 1530 nm) where net gain >10 dB and PDG <1 dB can be achieved. Results of four measurements are shown: each measurement has been performed with the fixed WDM channels and a signal tuned to one of four wavelengths: 1523 nm, 1525 nm, 1527 nm, and 1530 nm. Therefore, we demonstrate net gain >10 dB and PDG < 1 dB for 18 channels out of 42 in the range 1508 – 1521 nm and for a tuneable channel in the range 1521 – 1530 nm at the same time, which amounts to a total of 19 channels.

Fig. 3(a) shows averaged BER measured against received power for varied attenuation by setting VOA. Three 10 Gbps OOK channels were selected to measure BER across S-band as: 1510.3 nm, 1514.9 nm and 1520.3 nm. BER was measured for: back to back (B2B) configuration by excluding PI-FOPA directly connecting the transmitter to the receiver and including PI-FOPA. The signal was filtered by a BPF tuned to its wavelengths before detection. All three signal wavelengths were firstly configured in B2B to measure BER. The difference of received power in B2B case was observed to be <1 dB at the BER level of 10^{-3}. For extreme two signal wavelengths of WDM at 1510.3 nm and 1520.3 nm, the difference between received power was 0.7 dB. Received power difference between 1514.9 nm and 1520.3 nm of 0.4 dB. The difference of received power in B2B could incur due to the non-optimized modulator functioning in S-Band. Further, the BER was measured, including PI-FOPA for signal performance after parametric amplification. BER measured for FOPA amplified signals demonstrated almost similar performance as B2B with received power difference ~1.0 dB for all three channels. Similar to B2B case power difference increased to 1.0 dB for signals at 1510.3 nm and 1520.3 nm after PI-FOPA. 0.5 dB of power difference was measured between 1514.9 nm and 1520.3 nm signals. The increase in received power difference between the extreme wavelength channels incur due to different PDG change from 0 dB. In Fig. 3(b), we measure the received power penalty at BER level of 10^{-3}, at selected 10 Gbps signal wavelengths.

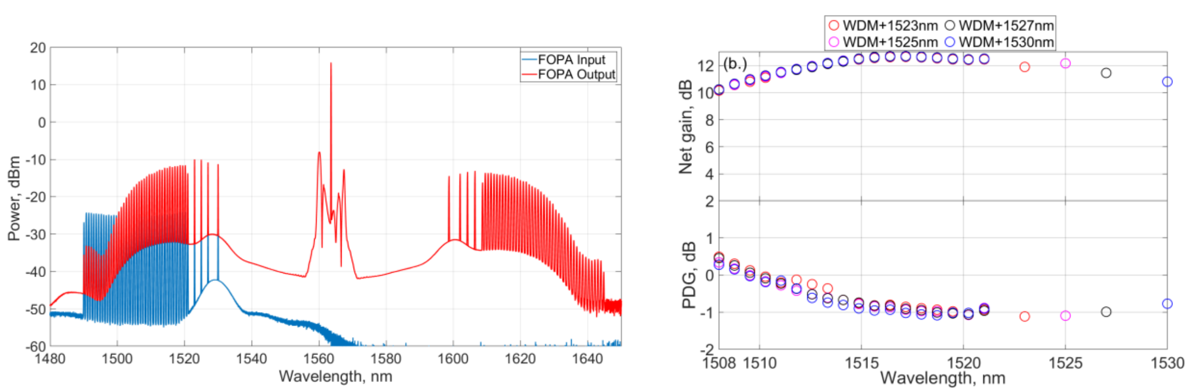

Fig. 2. (a) Optical power spectra at the FOPA input and output. (b) FOPA net gain and polarisation dependent

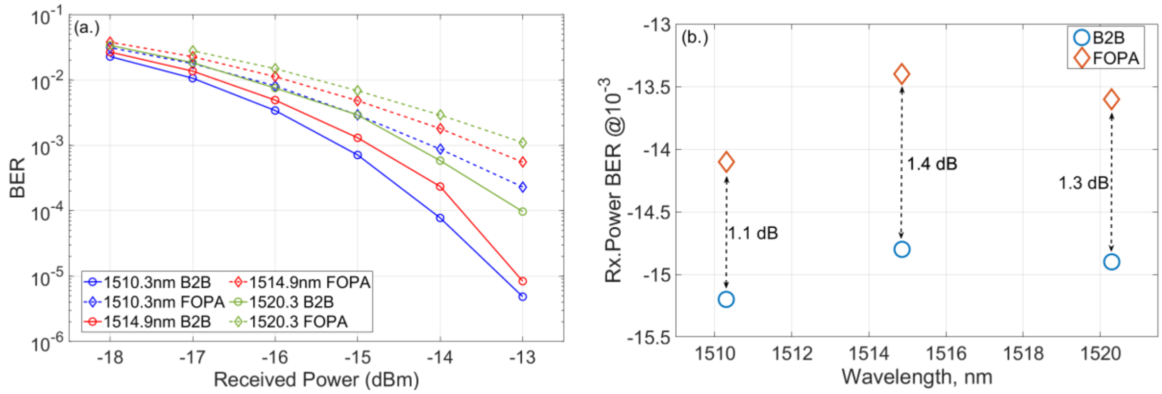

Fig. 3(a) BER vs received power with and without FOPA for 3x 10 Gbps OOK S-Band channels at 1510.3 nm,1514.9 nm and 1520.3 nm (b) Penalty measured at BER of 10^{-3} for received power against wavelength

The received power penalty at signal 1510.3 nm between B2B and FOPA was 1.1 dB. When signal wavelength was changed to 1514.9 nm, the penalty increased to 1.4 dB. Further, at the signal wavelength of 1520.3 nm, received power penalty at 10^{-3} was ~1.3 dB. It was observed that the received power penalty was increased for a longer wavelength. This is due to higher parametric gain at these wavelengths and hence higher attenuation implemented at the PI-FOPA input to achieve the same received power. The signal gain was 1 dB lower than the other two signal wavelengths of 1514.9 nm and 1520.3 nm.

4. Conclusions

We have demonstrated a PI-FOPA amplification of 42x 100 GHz-spaced WDM channels and a tuneable 10 Gbps OOK channels in S-Band, achieving a net gain >10 dB and PDG <1 dB for 18 channels and a tuneable channel in the range 1508 – 1530 nm. For the first time of our knowledge, we demonstrate a PI-FOPA to amplify WDM channels in the S-Band. Additionally, we show BER performance of 10 Gbps OOK signal with less than <1.4 dB received power penalty from B2B at BER level of 10^{-3}. Overall, this work demonstrates the capability of multi-band PI-FOPA with wide gain bandwidths.

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