Polarization- insensitive fibre optic parametric amplifier with gain bandwidth of 35 nm in L-band

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Abstract: We experimentally demonstrate a polarisation-insensitive fibre optic parametric amplifier (PI-FOPA) with the record wide gain bandwidth of 35 nm. We employ the PI-FOPA to amplify the full C- band equivalent 42x100GHz-spaced channels with net gain >10 dB and polarisation-dependent gain <0.5 dB in the wavelength range between 1580 nm and 1615 nm.

Introduction

Fibre optical parametric amplifiers (FOPA) are center of research interest due to their capabilities to provide ultrawide gain bandwidth [1] and unconstrained wavelength operation [2]. In addition, FOPA demonstrate exclusive features like ultra-fast response, very large gain (>70 dB), and gain on arbitrary wavelengths [3]-[5]. Recently, polarization-insensitive FOPA (PI-FOPA) was demonstrated to amplify counter propagating WDM channels in bi-directional C and L band signal transmission [6,7] confirming FOPA amplification for multiband WDM applications.

Applications in fibre-optic communications require amplifiers to have polarisation-insensitive gain. However, PI-FOPAs have been limited to <20nm gain bandwidth due to complexity of polarisation-diversity schemes [8,9]. In this work we double the record PI-FOPA gain bandwidth and amplify a 40 nm wide band of WDM channels using a single PI-FOPA in the L band.

Additionally, capacity crunch in current optical fiber communications systems is inevitable with utilization of complete C-band [10]. Therefore, exploring optical transmission development in L- band is justified. In lieu with that, robust optical amplification techniques are required for outside C-band operations. Conventional, optical fiber amplifiers including erbium doped fibre amplifier (EDFA) and Raman amplifiers are available in L-band operations [11,12]. However, EDFA and Raman amplifiers are limited with small signal gain bandwidth with non-flat gain shape and requirements of multiple pumps for signal amplification [13,14]. Therefore, a robust optical amplification technique is required in L- band to provide large signal gain and bandwidth.

In this paper, we experimentally demonstrate polarization-insensitive amplification by FOPA of the record wide signal band comprising 48 x 100- GHz-spaced WDM channels between 1580 nm to 1620 nm with >10dB signal gain. Within this range we demonstrate polarization dependent gain (PDG) of <0.5 dB across 35 nm range. Additionally, we demonstrate peak polarization insensitive gain of ~20 dB. This result demonstrates PI-FOPA allows for signal amplification across >4.1THz band in the L band.

Experimental Setup

Figure 1 shows the experimental setup for L- band polarization insensitive FOPA. The setup consisted of a WDM transmitter, a polarization insensitive FOPA and a coherent receiver for signal detection.

The WDM transmitter produced 48x100 GHz- spaced channels in the wavelengths range from 1580 nm to 1620 nm. An

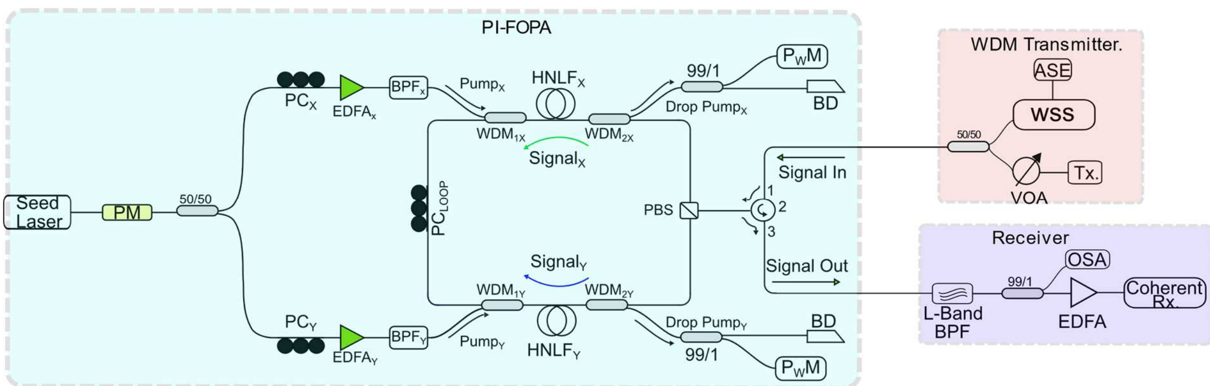

Fig. 1: Experimental setup of L-band polarization insensitive FOPA with WDM transmitter and coherent receiver

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L-band 112Gbps polarization multiplexed QPSK (PM-QPSK) channel was sourced from a QPSK transmitter with tunable wavelength source emitting in L-band wavelengths. ASE shaped WDM 100 GHz spaced channel were emulated using a wavelength wave shaper (WSS) shaped from 1580 nm to 1620 nm wavelength in L-band. The 100 Gbps PM- QPSK data channel was coupled with WDM signals using 3 dB (50% tap) coupler in a WDM transmitter section. A variable optical attenuator was connected after QPSK signal to match the – 30 dBm per channel power of the emulated channels. The total signal power at the input to the PI-FOPA was -13 dBm.

Signals from the WDM transmitter were amplified with a PI-FOPA employed a polarisation diversity loop in the "Loss – Gain" configuration [15,16]. An optical circulator was employed for coupling/decoupling input and output signals before and after PI-FOPA amplification. A polarisation beam splitter (PBS) split input signal into single polarisation components. The signal components were independently and equally amplified in corresponding gain fibres by co-propagating pumps. The amplified signal components were recombined by a PBS after making a full loop.

The pumps were sourced from a 100 kHz linewidth laser tuned at 1564.3 nm and was phase modulated for SBS mitigation. Two high power EDFAs were employed to optically pump parametric gain fibers reaching pump power of ~8W. The gain fibres were two 50 m lengths of dispersion-stable highly non-linear fiber (HNLFs) with zero dispersion wavelength of ~1562nm and nonlinear coefficient of ~14 $W^{-1}km^{-1}$.

A polarization controller (PC_{LOOP}) was employed to tune signal polarisation inside the loop. Two more polarization controllers (PC_X, PC_Y) were employed before the pump EDFAs to control pump polarisations. Nevertheless, the FOPA is indeed polarization-insensitive because it can amplify polarisation diverse signals and arbitrarily polarized signals with low PDG, whereas tuning of these polarization controllers is independent of input signal polarization, and only compensates for slow polarization drifts within the loop. Moreover, these polarisation controllers can be fully automated [16] or removed if polarisation maintaining fibres are employed [15].

Signal receiver section consisted of a variable optical attenuator (VOA) to control input power to the receiver, set to 0 dB attenuation. Signal after VOA was filtered through a tunable band pass filter (BPF) tuned to the signal wavelengths at 1607 nm,1600 nm,1590 nm and 1580 nm. A 99/1% optical tap was connected after the BPF to monitor filtered signal at OSA using 1% coupler port. A pre-amplifier L-band EDFA was connected after BPF to, amplify signal set at fixed output power of 5 dBm with input power to the EDFA was -20 dBm. Employed coherent detector was tuned to the signal wavelengths working at a fixed signal input power of 5 dBm.

Transmitted signal was mixed with an 100kHz local oscillator and corresponding traced were captured using 80 GSa/sec 36 GHz real time scope. Further processed with offline DSP to calculate bit error ratio and Q factor values.

Result and Discussion

Fig. 2 shows power spectra and net gain with polarization dependent gain (PDG) measured for PI- FOPA amplified WDM signals. Fig 2(a.) demonstrates power spectrum measured against signal wavelengths at OSA resolution of 0.1 nm. 100 GHz-spaced WDM channels were launched as an input to the PI-FOPA with per channel input

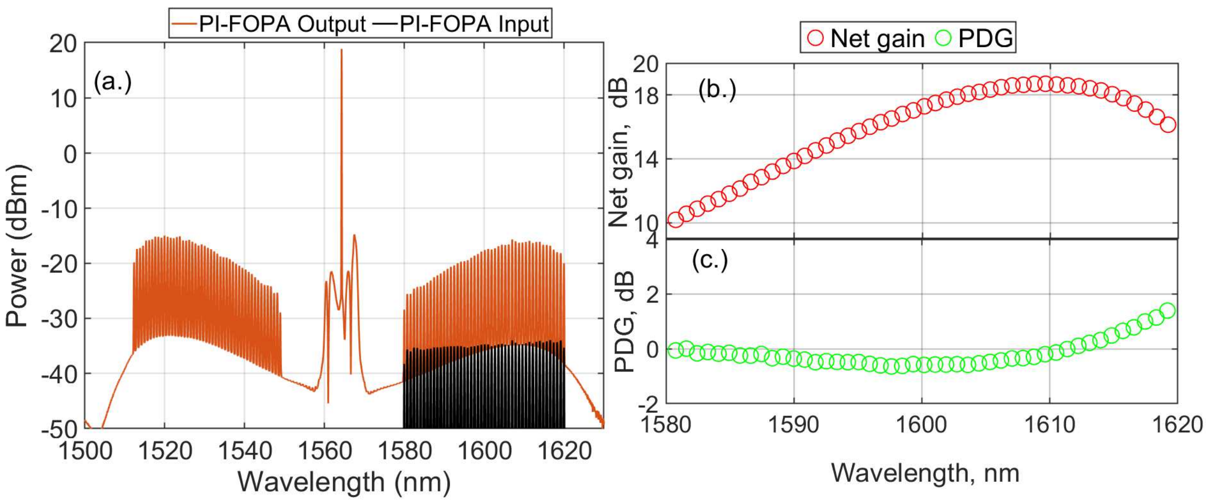

Fig.2 (a.) Power spectra of PI-FOPA amplified 48X100GHz-spaced WDM channels measured at PI-FOPA input and output (b.) Net gain >10 dB measured for each WDM signal from 1580 nm to 1620 nm with and (c.) PDG across 40 nm bandwidth with <0.5 dB PDG over 35 nm L-band signal bandwidth

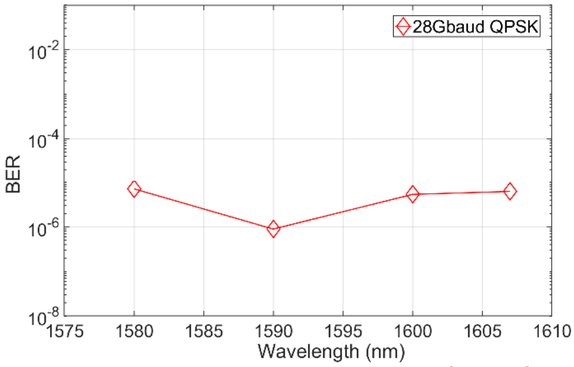

Fig. 3: BER against varied signal wavelengths for 100 Gbps QPSK channel

power of -30 dBm at total signal input power of - 13 dBm. PI-FOPA amplified WDM signals observed overall >10 dB net gain. 112 Gbps PM- QPSK channel have input signal power to FOPA as -30.0 dBm observe maximum output power of – 16.0 dBm after PI-FOPA amplification. In Fig. 2(a.) parametrically generated idlers on C- band wavelength and residual pump are also located within the spectra. It is too be noted that, large residual pump was ~20 dBm was not detrimental in this experiment to the signal and was not detrimental. Residual pump could be suppressed further with an additional pump filter if required.

Fig 2 (b).and (c.) demonstrate PDG and net gain measured against signal wavelengths for the same scenarios as Fig.2(a). The net gain across 40 nm from 1580 nm to 1620 nm was >10dB with maximum signal of ~19 dBm at 1609 nm. Overall, gain bandwidth achieved was ~4.7 THz presenting broadband L-band PI- FOPA. PDG across 35 nm signals from 1580 nm to 1615 nm was <0.5 dB. However, PDG reaching up 1.4 dB was observed for channels at longer wavelength >1615 nm. We predict increase in PDG over broad gain spectrum due limited polarization control over broad gain bandwidth region.

Fig.3 demonstrate measured BER at varied signal wavelengths of 1580 nm to 1600 nm with 10 nm step and 1607 nm. We were unable to detect wavelength >1607 nm due to limitation of receiver L-band EDFA amplification. BER was obtained via offline DSP averaged over ten captured 28 Gbaud signal traces. Almost stable performance was observed for PI-FOPA amplified signals with BER level of 10^{-6} at all measured signal wavelengths with BER reaching up to 10^{-7} at signal wavelength of 1590 nm.

Conclusions

In this work we demonstrate a L-band PI-FOPA with 35 nm gain bandwidth with >10 dB net gain. We also report <0.5 dB polarization dependent gain for 42x100 GHz-spaced WDM signals. This experimental work presents FOPA unique features of high net gain of ~20 dB, low PDG of <0.5 dB and large gain bandwidth of 35 nm in L- band. Additionally, we obtained stable BER performance for chosen signal wavelengths 10 nm apart from 1580 nm to 1607 nm. This experimental work provides confidence in wide band fiber optic parametric amplifiers in real telecom applications.

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