Effect of Dispersion Fluctuations on Longitudinal Gain Evolution in Phase-Sensitive Parametric Amplifiers

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Abstract: A Brillouin probing method is proposed to extract the distribution of signal power along phase-sensitive parametric amplifiers. Operation near the zero-dispersion-wavelength shows enhanced sensitivity to dispersion fluctuations, allowing effective extraction of the dispersion map.

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1. Introduction

Phase-sensitive fiber optic parametric amplifiers (PS-FOPA) have recently drawn a great interest. With their unique phase-sensitive amplification ability and ultralow noise figure, they have been successfully used for multilevel phase coded data regeneration and amplification [1]. These appealing properties are all subject to the condition that the fiber is considered ideally uniform. However, like their phase insensitive counterpart, any longitudinal imperfections, such as zero dispersion wavelength (ZDW) fluctuations, alter the ideal performance of PS-FOPA based devices [2]. Furthermore, with end-to-end power measurements, the distributed signal evolution leading to the overall gain/loss of the PS-FOPA cannot be resolved, while such information could find interesting applications for design purposes. Actually similar end-to-end characteristics can be the result of diverse signal evolutions along the fiber since the PS-FOPA supports a variety of signal power distributions depending on the initial phase mismatch [3]. Knowledge of these diverse signal evolutions, while being an interesting insight in the phenomenon, can also be used to optimize the design of the amplifier. Longitudinal power measurements of a PS-FOPA can therefore be extremely insightful. In this paper, a modified version of a Brillouin optical time domain analysis (BOTDA) scheme is utilized to derive the signal power evolution along a PS-FOPA, for diverse wavelengths of the parametric pump. Different amplification/de-amplification evolutions along a PS-FOPA are reported and the altering effect of ZDW fluctuations is observed. The enhanced sensitivity to ZDW fluctuations is then exploited to extract the unknown dispersion map along the fiber.

2. Experimental setup

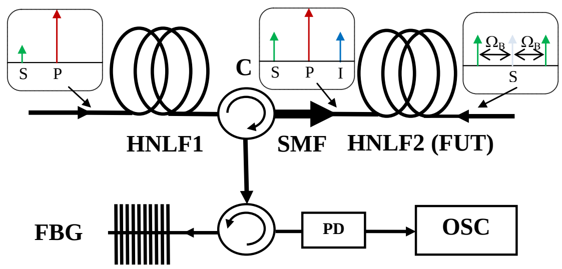

Fig.1: Experimental setup. FUT: fiber under test, PD: photo-detector

The schematic of the setup is depicted in Fig. 1. The BOTDA sub-system is similar to the double sideband probe scheme implemented in [4], used to record power evolutions in phase insensitive FOPAs. For the phase sensitive case, two spools of highly nonlinear fibers (HNLF) are connected by a piece of single-mode fiber (SMF). Both HNLFs have similar given ZDW around 1550 nm (+/- 5 nm) and are 500 m long. A continuous wave (CW) tunable laser (TL_1) is phase modulated to suppress amplified spontaneous Brillouin backscattering, and subsequently amplified to pump the FOPA. Another CW tunable laser (TL_2) is used for the generation of both the signal and probe sidebands. The signal light is pulsed by passing through a gated semiconductor optical amplifier (SOA) delivering 100 ns optical pulses. The pulsed signal and pump are then coupled using a wavelength-division multiplexer (WDM) and sent through the first HNLF (HNLF1). At the output of HNLF1, the pump, signal and generated idler are directly launched into the PS-FOPA through a circulator (C). The twin probes are generated from a tapped portion of the TL_2 by carrier-suppressed amplitude modulation at the Brillouin frequency. Two successive measurements are realized using an orthogonal polarization switch on the probe to compensate fluctuations due to random birefringence along the second HNLF. After counter propagation, the probes are directed to the remaining port of C and sent to a fiber Bragg grating (FBG) which selects only one probe spectral line. The time trace of the selected probe is then acquired by an oscilloscope (OSC).

3. Results and discussion

To extract the PS-FOPA gains from the raw experimental data, standard BOTDA measurements [4] are first carried out and used to normalize the pre-existing Brillouin gain fluctuations in the probe traces. The parametric pump is then initially positioned at 1557 nm, far from the ZDW, while still inducing a strong parametric gain in both HNLFs. Different initial phase mismatches are realized by tuning the signal wavelength [5]. Figure 2 shows the experimentally retrieved gain distribution for five signal wavelengths, corresponding to the five shorter wavelengths of the inset of Fig. 2. These gains are fitted to the analytical expression giving the PS-FOPA gain [5] assuming uniform dispersion. For these pump wavelengths (located far from the ZDW), a good match is obtained, as any residual dispersion fluctuation would be dominated by the large continuous background.

Different amplification paths, including pure amplification, pure de-amplification or de-amplification followed by amplification, are all correctly predicted by the analytical expression.

The pump is then positioned closer to the ZDW, at 1553.1 nm, and the signal is once again tuned to lie within the amplification bandwidth of both FOPAs. The experimentally derived gain distribution for two distinct signal wavelengths are shown in Fig. 3(a). The gains calculated from the uniform dispersion previously evaluated and expanded by a Taylor series are plotted as dotted blue lines. Interestingly, the gain distribution for the 1573.3 nm signal shows a trend significantly different from the uniform dispersion fit. Actually, the unusual amplification path consisting of first amplification followed by de-amplification can never be obtained from the PS-FOPA gain solution under constant dispersion values. To find the dispersion profile, an optimization routine has been applied to the FOPA equations. The dispersion profiles obtained from two gain measurements, one in the forward and one in the backward direction of HNLF2 and at the signal/pump wavelengths of 1573.3 nm/1553.1 nm are plotted in Fig. 3(b). Agreement between the two derived dispersion maps confirms their validity. The forward dispersion map is then applied to reconstruct the gain profiles of Fig. 3(a), plotted in the same figure with a thick red line. The gain evolutions obtained with the evaluated dispersion profiles show a very good matching with the experimental data. The dispersion profile has also been used to fit the data at a different wavelength (1573 nm) with, once again, a good agreement. It is believed that the unusual gain profile at 1573.3 nm can be attributed to strong dispersion fluctuations along the fiber. As reported in Fig. 3(b), the extracted mean ZDW is 3 nm above the given target value (1550 nm) but the fluctuations fall within the tolerance given by the manufacturer. When parametric pump is tuned within this spectral region of large ZDW shift, the gain profile becomes strongly distorted when compared to uniform fiber predictions, as shown in Fig. 3(a), enabling a quality recording of the gain profile above noise levels and thus efficient dispersion map extraction.

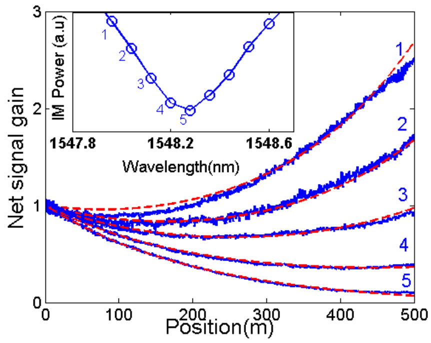

Fig 2: PS-FOPA gain distribution extracted from experimental traces at a pump wavelength of 1557 nm for different signal wavelengths (blue) and from the analytical uniform fiber expression (dashed red). Inset: Measured Instability modulation spectrum

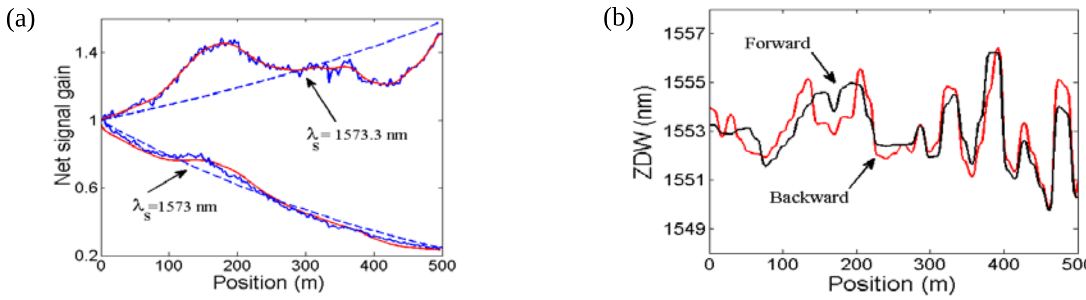

Fig. 3: (a) Measured PS-FOPA gain at pump wavelength of 1553.1 nm (blue). The analytical uniform fiber expression (dashed blue) and the gain calculated from the extracted dispersion (red). (b) Dispersion map extracted from the gain measured in counter directions.

In conclusion, the longitudinal distribution of gain along a PS-FOPA has been extracted through the intercession of a BOTDA scheme. Measurements for different spectral positioning of the parametric pump show that, as expected, the impact of dispersion fluctuations on the gain profiles is much stronger close to the ZDW. Using an optimization algorithm, consistent ZDW fluctuation maps have been retrieved from both ends of the FUT.

4. Reference

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