



HAL
open science

Intra-Modal Phase-Sensitive Four-Wave Mixing in a Few-Mode Fiber

Valentine Gaudillat, Margaux Barbier, Laurent Bramerie, Mathilde Gay,
Marianne Bigot-Astruc, Pierre Sillard, Yannick Dumeige, Christophe
Peucheret

► **To cite this version:**

Valentine Gaudillat, Margaux Barbier, Laurent Bramerie, Mathilde Gay, Marianne Bigot-Astruc, et al.. Intra-Modal Phase-Sensitive Four-Wave Mixing in a Few-Mode Fiber. 2023 Conference on Lasers and Electro-Optics Europe & European Quantum Electronics Conference (CLEO/Europe-EQEC), European Optical Society, Optical (Formerly OSA), IEEE Photonics Society, Jun 2023, Munich, Germany. 10.1109/CLEO/Europe-EQEC57999.2023.10232196 . hal-04201308

HAL Id: hal-04201308

<https://hal.science/hal-04201308v1>

Submitted on 9 Sep 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Copyright

Intra-Modal Phase-Sensitive Four-Wave Mixing in a Few-Mode Fiber

Valentine Gaudillat¹, Margaux Barbier¹, Laurent Bramerie¹, Mathilde Gay¹, Marianne Bigot-Astruc²
Pierre Sillard², Yannick Dumeige¹, Christophe Peucheret¹

1. Univ Rennes, CNRS, FOTON – UMR 6082, F-22305 Lannion, France
2. Prysmian Group, Billy Berclau, 62092 Haisnes Cedex, France

Phase-sensitive parametric processes based on four-wave mixing (FWM) in third-order nonlinear media are attractive for the demonstration of numerous functionalities including low-noise amplification, high-sensitivity detection and signal phase quantization with applications to e.g. communication and sensing [1]. Until now, such processes have been demonstrated exclusively in single-mode optical fibers and waveguides. Meanwhile, the exploitation of the spatial (transverse) dimension of waveguides is also being explored for such applications, for instance in order to provide a new multiplexing degree of freedom in telecommunications [2]. One open question is whether the use of phase-sensitive processes can be made compatible with optical fibers and waveguides supporting multiple spatial modes. Some (inter-modal) phase-sensitive processes have been numerically investigated in few-mode fibers (FMFs) [3]. However, to the best of our knowledge, no experimental demonstration of phase-sensitive processes in FMFs has been reported so far. In this work, we demonstrate experimentally intra-modal phase-sensitive FWM, separately in two modes (LP₀₁ and LP₁₁), in a 2-km long step-index FMF [4] supporting 4 LP-modes at 1550 nm.

The experimental setup is represented in Fig. 1(a). Intra-modal degenerate phase-sensitive processes are demonstrated in either the LP₀₁ or the LP₁₁ mode by injecting two continuous-wave (CW) pumps and a CW signal into the chosen mode of the FMF. The three waves are generated from a sinusoidally (20 GHz) phase-modulated (PM) CW laser to ensure that the signal frequency ω_0 is halfway between the frequencies of the pumps (ω_{p1} and ω_{p2}) and that all interacting waves are phase coherent. For the LP₁₁ demonstration, a $0|\pi$ phase plate (PP) is used to shape the beam phase distribution. An amplitude and phase programmable filter (WS) is used to vary the input signal phase $\Delta\phi$. Due to intra-modal FWM, an idler is generated in the same mode at a frequency equal to that of the signal, resulting in interferences at the signal/idler frequency ω_0 . The power at ω_0 is measured as a function of the input signal phase for both LP₀₁ and LP₁₁ modes (Fig. 1(b)). As expected, both experimental curves have π -periodic sinusoidal variations. The experimental results are in good agreement with numerical simulations of nonlinear propagation in FMFs obtained by solving the multimode nonlinear Schrödinger equation [5] for LP₁₁. For LP₀₁, the experimental results are shifted by 2 dB compared to the simulation results, as a result of stimulated Brillouin scattering, which is not taken into account in the model.

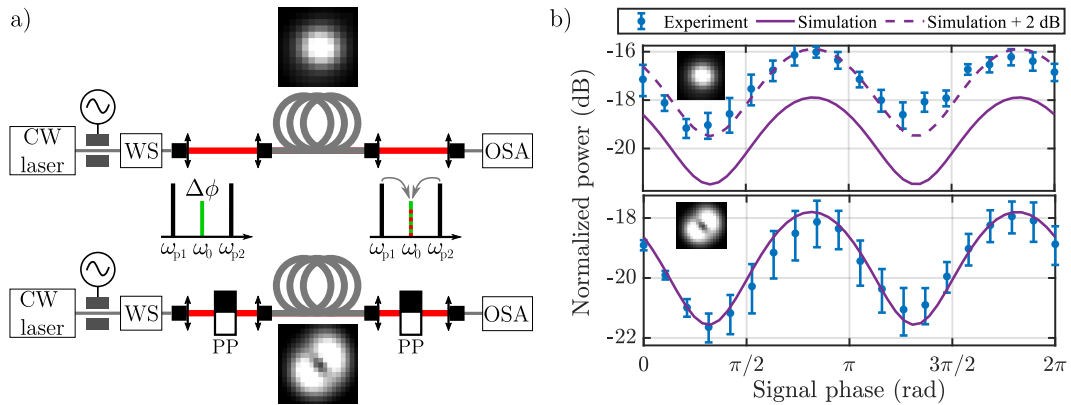


Fig. 1 a) Experimental setup for LP₀₁ (top) and LP₁₁ (bottom) modes. b) Normalized signal/idler power at ω_0 as a function of input signal phase in LP₀₁ (top) and LP₁₁ (bottom) modes when a total input power of 22 dBm (equally distributed on both pump waves) is injected into the FMF. Dots: experimental results. Curves: simulated data. OSA: optical spectrum analyzer.

In conclusion, intra-modal signal/idler-degenerate phase-sensitive FWM has been demonstrated successfully for the first time in the LP₀₁ and LP₁₁ modes of an FMF supporting 4 modes at 1550 nm.

References

- [1] P. A. Andrekson and M. Karlsson, "Fiber-based phase-sensitive optical amplifiers and their applications," *Adv. Opt. Photonics* **12**, 367 (2020).
- [2] D. J. Richardson, J.M. Fini, and L. E. Nelson, "Space-division multiplexing in optical fibres," *Nat. Photonics* **7**, 354 (2013).
- [3] A. Trichili, M. Zghal, L. Palmieri, and M. Santagiustina, "Phase-sensitive mode conversion and equalization in a few mode fiber through parametric interactions", *IEEE Photonics J.* **9**, 7800710 (2017).
- [4] P. Sillard, M. Bigot-Astruc, D. Boivin, H. Maerten, and L. Provost, "Few-mode fiber for uncoupled mode-division multiplexing transmissions", *European Conference on Optical Communications, ECOC'11*, paper Tu.5.LeCervin.7, Geneva, Switzerland (2011).
- [5] F. Poletti and P. Horak, "Description of ultrashort pulse propagation in multimode optical fibers," *J. Opt. Soc. Am. B* **25**, 1645 (2008).