



**HAL**  
open science

# Modulation Instability Control via Optical Seeding and Machine Learning Optimization

Lynn Sader, Van Thuy Hoang, Yassin Boussafa, Raktim Haldar, Vincent Kermene, Michael Kues, Benjamin Wetzel

## ► To cite this version:

Lynn Sader, Van Thuy Hoang, Yassin Boussafa, Raktim Haldar, Vincent Kermene, et al.. Modulation Instability Control via Optical Seeding and Machine Learning Optimization. 2023 Conference on Lasers and Electro-Optics Europe & European Quantum Electronics Conference (CLEO/Europe-EQEC), Jun 2023, Munich, Germany. pp.1-1, 10.1109/CLEO/Europe-EQEC57999.2023.10232691 . hal-04307448

**HAL Id: hal-04307448**

**<https://hal.science/hal-04307448>**

Submitted on 29 Nov 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.

# Modulation Instability Control via Optical Seeding and Machine Learning Optimization

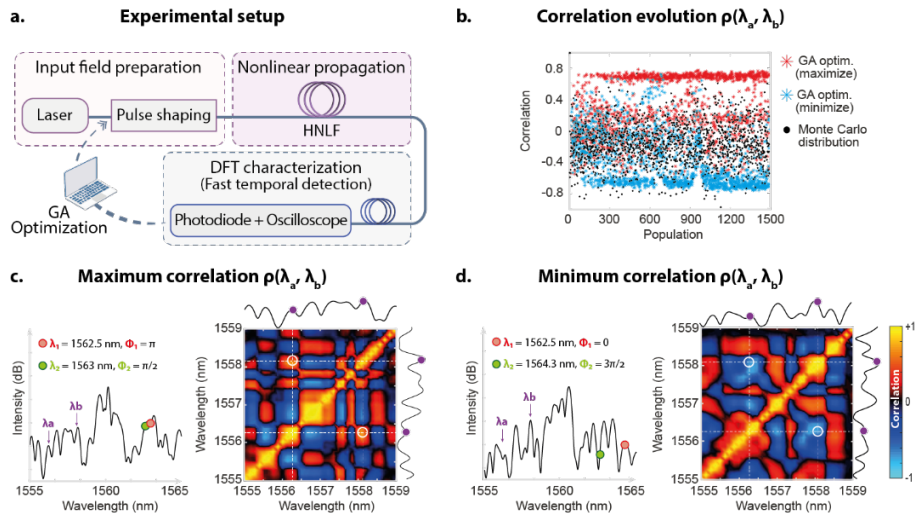
Lynn Sader<sup>1</sup>, Van Thuy Hoang<sup>1</sup>, Yassin Boussafa<sup>1</sup>, Raktim Haldar<sup>2,3</sup>, Vincent Kermene<sup>1</sup>, Michael Kues<sup>2,3</sup>, Benjamin Wetzel<sup>1</sup>

1. XLIM Research Institute, CNRS UMR 7252, University of Limoges, 87060 Limoges, France

2. Institute of Photonics, Leibniz University Hannover, 30167 Hannover, Germany

3. Cluster of Excellence PhoenixD, Leibniz University Hannover, 30167 Hannover, Germany

Spectral broadening due to Modulation Instability (MI) during nonlinear propagation in fiber optics, can arise from noise amplification and involve incoherent and complex coupled processes, making their experimental control challenging. Over the years, MI control within both noise-driven and seeded regimes demonstrated different degrees of success [1-3]. In this experimental study, we propose a new approach of MI control by all-optical seeding, whose parameters are suitably adjusted via machine learning optimization techniques. In particular, we use Genetic Algorithms (GA) to tune the wavelength and phase parameters of two weak (yet coherent) optical seeds competing with spontaneous (noise-driven) MI dynamics. This all-optical control of noise-driven nonlinear dynamics is used to optimize the correlation between two specific wavelengths in the incoherent output spectrum. Experimentally, an 80 fs laser pulse, centered at 1560 nm, is filtered using a programmable spectral filter to reshape the broadband pulse into a picosecond pump and conjointly generate two seeds with controllable parameters (i.e., wavelength  $\lambda$  and phase  $\Phi$ ) - see Fig. 1(a). The three input signals are then amplified before entering a highly nonlinear fiber (HNLF), and the fluctuating output spectra detected in real-time using the dispersive Fourier transform (DFT) technique [4]. The corresponding spectral correlation maps can be extracted, as seen in Fig. 1(c-d), and the correlation between two selected wavelengths  $\rho(\lambda_a, \lambda_b)$  can be optimized by iteratively adjusting the wavelength and phase of the input seeds, as shown in Fig. 1(b).



**Fig. 1** a. Experimental setup. b. GA optimization results when maximizing (red) and minimizing (blue) the correlation between target wavelengths  $\rho(\lambda_a, \lambda_b)$  compared with the correlation obtained from random seed parameters using Monte-Carlo method (black). c. GA-optimized spectrum (left) and correlation map (right) with the seed parameters  $(\lambda_1, \Phi_1)$  and  $(\lambda_2, \Phi_2)$ , obtained for a maximal correlation  $\rho(\lambda_a, \lambda_b)$ . d. Same results for a minimal correlation  $\rho(\lambda_a, \lambda_b)$ .

The experimental results in Fig. 1(b) demonstrate that GA can efficiently optimize the correlation between different spectral components in the output spectrum, with a faster convergence than a Monte-Carlo method. For instance, the results of Fig. 1(c,d) show that the correlation between 1556.3 and 1558.1 nm can be adjusted from a maximal positive value of  $\rho(\lambda_a, \lambda_b) = 0.78$ , to a minimal negative value of  $\rho(\lambda_a, \lambda_b) = -0.77$ . This approach opens new paths towards tailoring incoherent nonlinear interactions and complex dynamics in guided optics. We expect this experimental control to be extended using deep-learning to mitigate time-consuming measurements [5].

## References

- [1] J. M. Dudley, et al. "Modulation instability, Akhmediev Breathers and continuous wave supercontinuum generation," *Opt. Express* **17**, 21497-21508 (2009).
- [2] D.M. Nguyen, et al. "Incoherent resonant seeding of modulation instability in optical fiber," *Opt. Lett.* **38**, 5338-5341 (2013)
- [3] B. Frisquet, et al. "Collision of Akhmediev Breathers in Nonlinear Fiber Optics," *Phys. Rev. X* **3**, 041032 (2013)
- [4] T. Godin, et al. "Recent advances on time-stretch dispersive Fourier transform and its applications," *Adv. Phys.: X* **7**, 2067487 (2022).
- [5] M. Närhi, et al., "Machine learning analysis of extreme events in optical fibre modulation instability," *Nat. Commun.* **9**, 4923 (2018).

This work received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme under grant agreement No. 950618 (STREAMLINE project) and No. 947603 (QFreC project). B.W. acknowledges the support of the French ANR through the OPTIMAL project (ANR-20-CE30-0004) and the Région Nouvelle Aquitaine (SCIR & SPINAL projects). M.K. acknowledges funding from the German Federal Ministry of Education and Research, Quantum Futur Program (PQuMAL) and from the German Research Foundation (DFG) under Germany's Excellence Strategy within the Cluster of Excellence PhoenixD (EXC 2122, Project ID 390833453).