



**HAL**  
open science

# Smart Control of Supercontinuum Generation by Machine Learning Towards Multiphoton Microscopy Applications

Van Thuy Hoang, Yassin Boussafa, Lynn Sader, Sébastien Février, Vincent  
Couderc, Benjamin Wetzel

► **To cite this version:**

Van Thuy Hoang, Yassin Boussafa, Lynn Sader, Sébastien Février, Vincent Couderc, et al.. Smart Control of Supercontinuum Generation by Machine Learning Towards Multiphoton Microscopy Applications. 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-EQEC57999.2023.10232490 . hal-04307449

**HAL Id: hal-04307449**

**<https://hal.science/hal-04307449>**

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.

# Smart Control of Supercontinuum Generation by Machine Learning Towards Multiphoton Microscopy Applications

Van Thuy Hoang, Yassin Boussafa, Lynn Sader, Sébastien Février, Vincent Couderc, Benjamin Wetzel

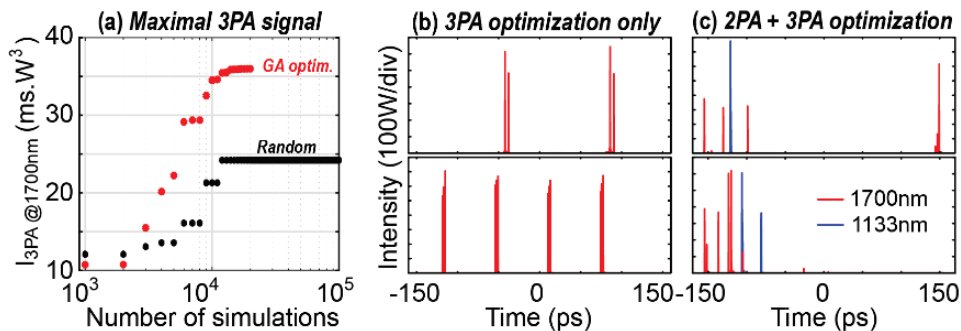
*Xlim Research Institute, CNRS UMR 7252, University of Limoges, 87060 Limoges, France*

Multi-photon excitation (MPE) microscopy has played a significant role in biological imaging techniques since it allows to observe living tissues with further depth and excellent sectioning effect. Modalities of MPE depend on the properties of both the selected fluorophore and the laser excitation (e.g., wavelength, pulse duration, peak power). However, versatile and tunable laser excitation for MPE still constitutes a technical challenge, limited by e.g. the narrow bandwidth of laser gain medium or by the achievable tunability of parametric conversion [1]. As an alternative, supercontinuum (SC) generation has been implemented for multiphoton imaging, as it can provide broadband excitation covering numerous fluorophore multi-photon absorption peaks and can enable multiplexed spectroscopy without wavelength scanning or filtering the excitation light.

Here, we report on the use machine learning (ML) to optimize the spectro-temporal properties of SC generation to selectively enhance MPE signals compatible with a variety of fluorophores and excitation modalities for MPE microscopy. In particular, we numerically consider multiple pulse pattern excitation whose customization and shaping has been previously reported experimentally via the use of a cascade system of Mach-Zehnder interferometers (MZI) on chip [2,3]. This integrated system allows the generation of a maximum of 256 pulses, individually separated by 1 ps. The pulse pattern at the chip output is obtained by adjusting the transmission ratios of the 8 MZIs before amplification and injection into a highly nonlinear fiber. The SC output spectrum is filtered at selected wavelengths. Various ML techniques (e.g., a genetic algorithm (GA)) are used to iteratively maximize multiphoton absorption signals [4] as shown in Eq. (1):

$$I_{2PA} = \int |I_{1133}(t)|^2 dt \quad \text{and} \quad I_{3PA} = \int |I_{1700}(t)|^3 dt \quad (1)$$

We selected two particular wavelengths (1133 and 1700 nm) that can be respectively used for two-photon absorption (2PA) and three-photon absorption (3PA) towards the excitation of a fluorophore with an MPE at a central wavelength of 566 nm. Taking advantage of ML optimization, we can efficiently probe the input parameter space and rapidly enhance the desired MPE signal when compared to random simulations, Fig. 1(a). Besides MPA signal optimization, the use of reconfigurable input pulse patterns allows for versatile adjustment of the temporal output profile at selected wavelengths. This can be seen for instance in Fig. 1(b) for simple 3PA signals with either double or quadruple pulse bunching operation, or for conjoint 2PA and 3PA excitation with more complex interleaved optical waveforms, Fig. 1(c). Additional SC simulations also show the ability to successfully enhance MPE signals for different combinations of fluorophores and/or modalities. Altogether, we expect this approach to mitigate time-consuming adjustments, ensure efficiency in versatile experimental optimization for MPE microscopy, and pave the way towards further MPE microscopy improvements in terms of spatial sectioning, optical toxicity and wavelength selectivity.



**Fig. 1** (a) Evolution of maximal 3PA signal at 1700 nm obtained from Monte-Carlo (random) simulations or via GA optimization. Examples of temporal waveforms obtained after spectral filtering for (b) 3PA optimization or (c) conjoint 2PA and 3PA optimization.

## References

- [1] A. M. Larson, "Multiphoton microscopy," *Nat. Photonics* **5**, 1 (2011).
- [2] B. Wetzel, et al., "Customizing supercontinuum generation via on-chip adaptive temporal pulse-splitting," *Nat. Commun.* **9**, 4884 (2018).
- [3] B. Fischer, et al., "Autonomous on-chip interferometry for reconfigurable optical waveform generation," *Optica* **8**, 1268 (2021).
- [4] V. T. Hoang, et al., "Optimizing supercontinuum spectro-temporal properties by leveraging machine learning towards multi-photon microscopy," *Front. Photonics* **3**, 940902 (2022).

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). 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).