Optimizing PIC Design for High Performance using Genetic Algorithms

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Sergio Rivera Lavado[1], Jessica César-Cuello[1], Daniel Gallego[2], and Guillermo Carpintero[1]
[1]Universidad Carlos III de Madrid, Av. Universidad 30, Leganés, 28911, Spain
[2]LeapWave Technologies, Avenida Gregorio Peces-Barba, 1.
Parque Científico UC3M, 1.2.C.17, 28919 Leganés, Madrid, Spain

Introduction

Addressing the escalating design complexity of modern Photonic Integrated Circuits (PICs), particularly those incorporating feedback mechanisms leading to expansive solution spaces (e.g., mode-locked lasers), this work introduces a novel machine learning-driven optimization framework. Our methodology synergistically integrates efficient photonic device design principles with circuit parameter optimization facilitated by Genetic Algorithms (GA), and predictive modelling leveraging diverse regression techniques. Simulation results rigorously demonstrate significant performance enhancements in achieving targeted optical modulation characteristics, underscoring the transformative potential of machine learning for advanced PIC design and optimization. The developed Python-based framework seamlessly interfaces with Lumerical INTERCONNECT, providing a powerful tool for tackling these intricate challenges.

The Optical Circuit

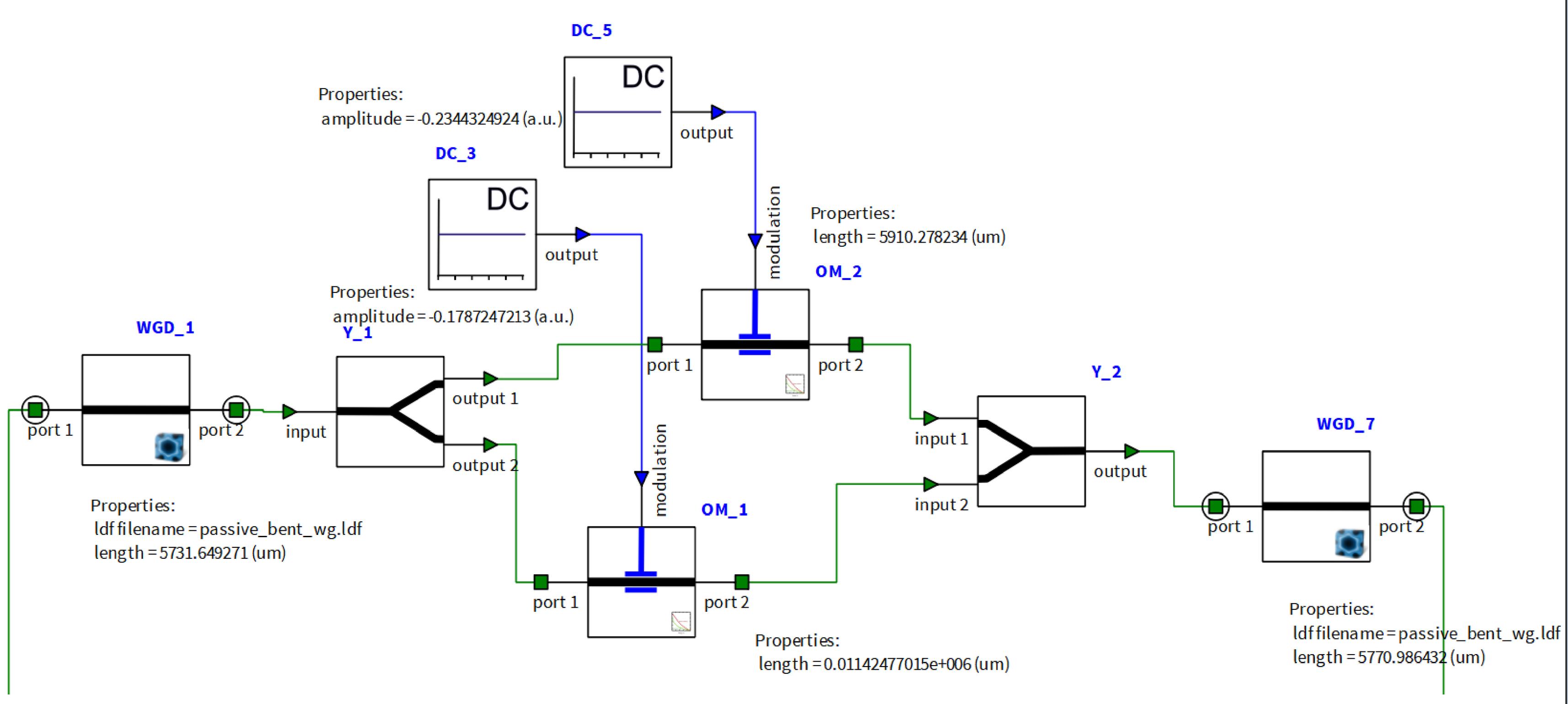


Fig. 1. Detail of one of the four MZI structures simulated in the loop optical circuit.

The simulated circuit architecture incorporates a feedback loop featuring a selectable filter stage followed by amplification. This configuration allows for precise control over signal characteristics within the loop..

Simulation Setup – Genetic Algorithm-Lumerical

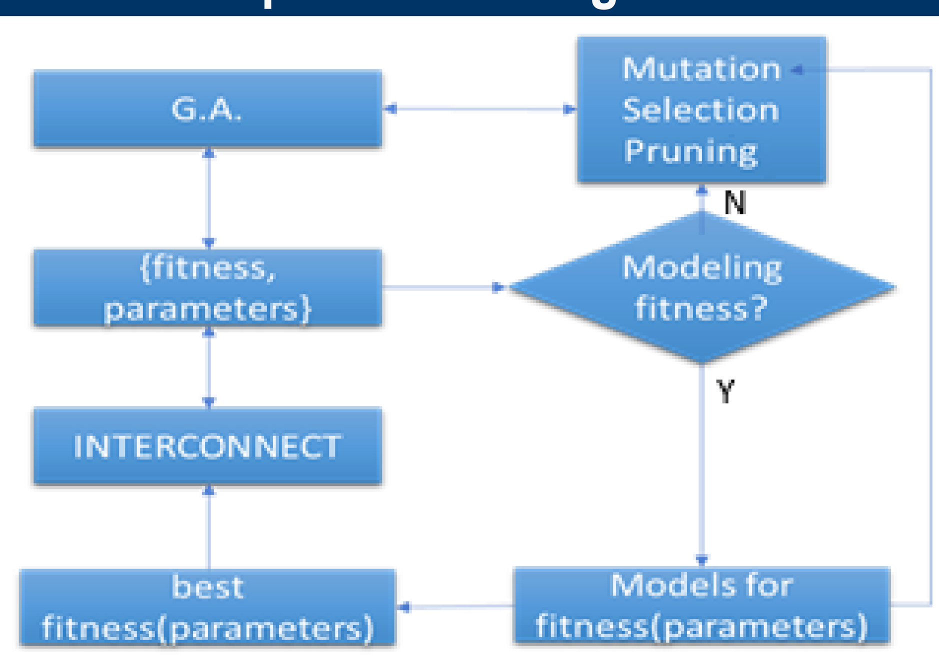


Fig. 2. Optimization algorithm flowchart.

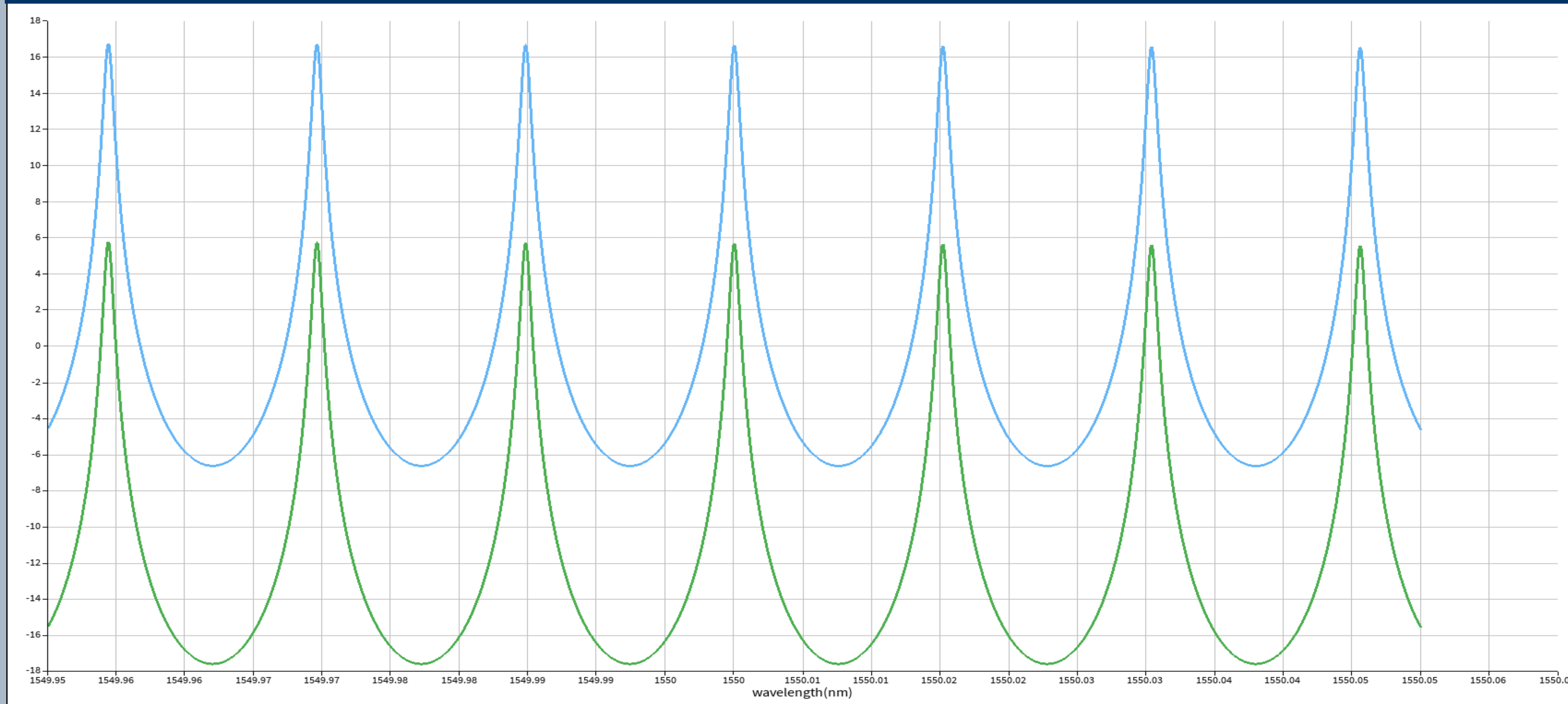
Inspired by the principles of natural selection, Genetic Algorithms (GAs) constitute a robust optimization paradigm. This evolutionary computation technique iteratively refines a population of candidate solutions across successive generations through stochastic processes mimicking biological selection, genetic crossover, and mutation. The objective is to converge towards an optimal or near-optimal solution within a defined problem space.

In the context of photonic integrated circuit (PIC) optimization, various design parameters, including DC bias voltages, waveguide dimensions, and modulator lengths, can be leveraged to achieve specific operational configurations. Notably, certain parameters are statically defined during fabrication, while others, such as applied voltages, offer post-fabrication tunability. This duality allows for the definition of a multi-dimensional variable space that governs the search landscape of the GA. The target hardware, which could be a spectral filter or a tunable laser, dictates the optimization objective. The discrepancy between the simulated and the desired transfer function serves as the quantitative fitness metric guiding the evolutionary process.

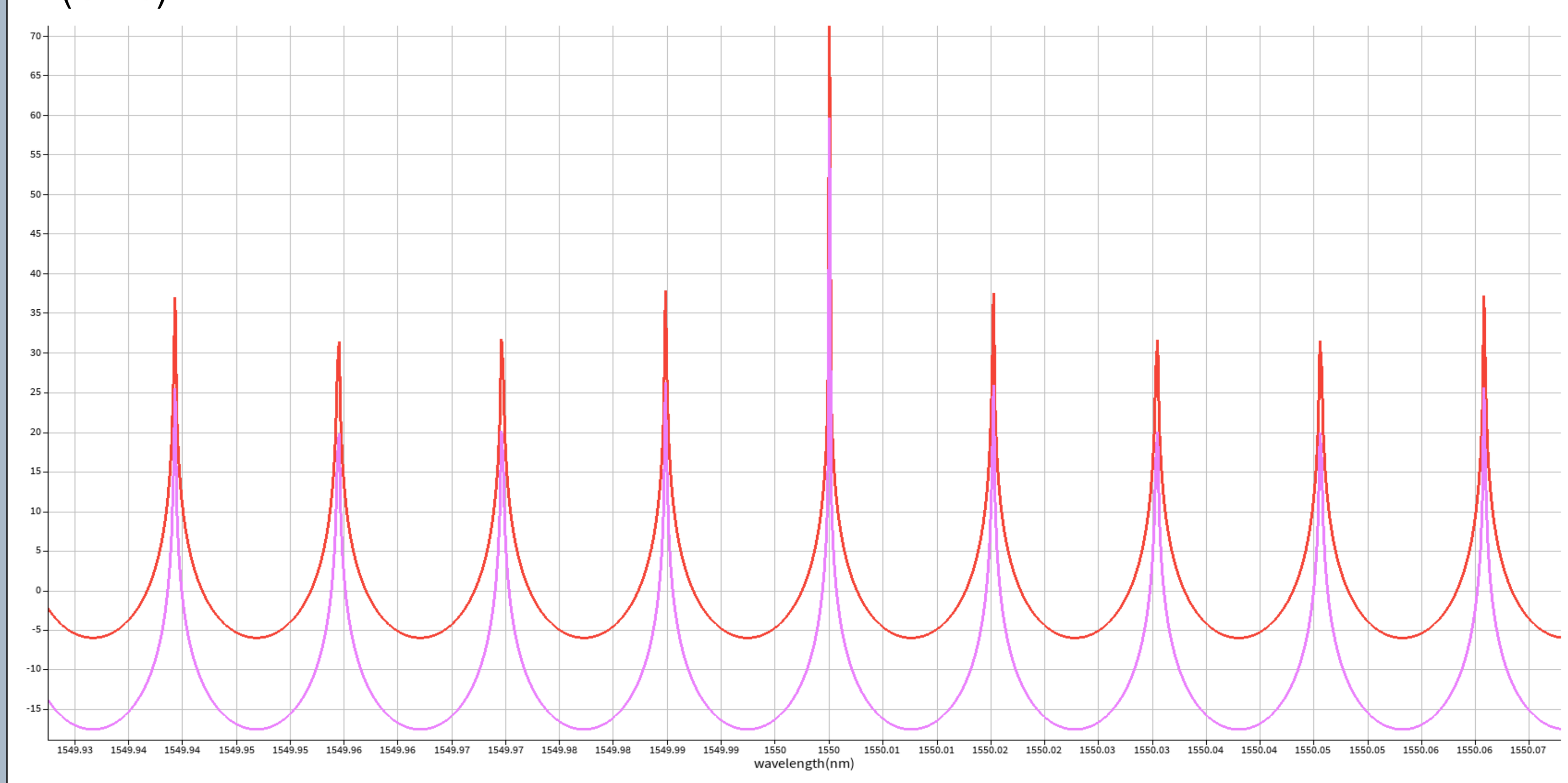
Furthermore, the computational efficiency of GA-driven PIC optimization can be significantly enhanced through surrogate modelling. By leveraging a sufficiently large dataset of prior simulations, accurate predictive models of the PIC's behaviour can be developed, substantially accelerating the evaluation of candidate solutions within the GA.

ANSYS Lumerical INTERCONNECT facilitates a real-time, programmatic interface between the optimization algorithm and high-fidelity PIC simulations. This powerful integration unlocks the potential to harness cutting-edge machine learning methodologies for the advanced design and optimization of photonic integrated circuits, paving the way for unprecedented levels of performance and functionality.

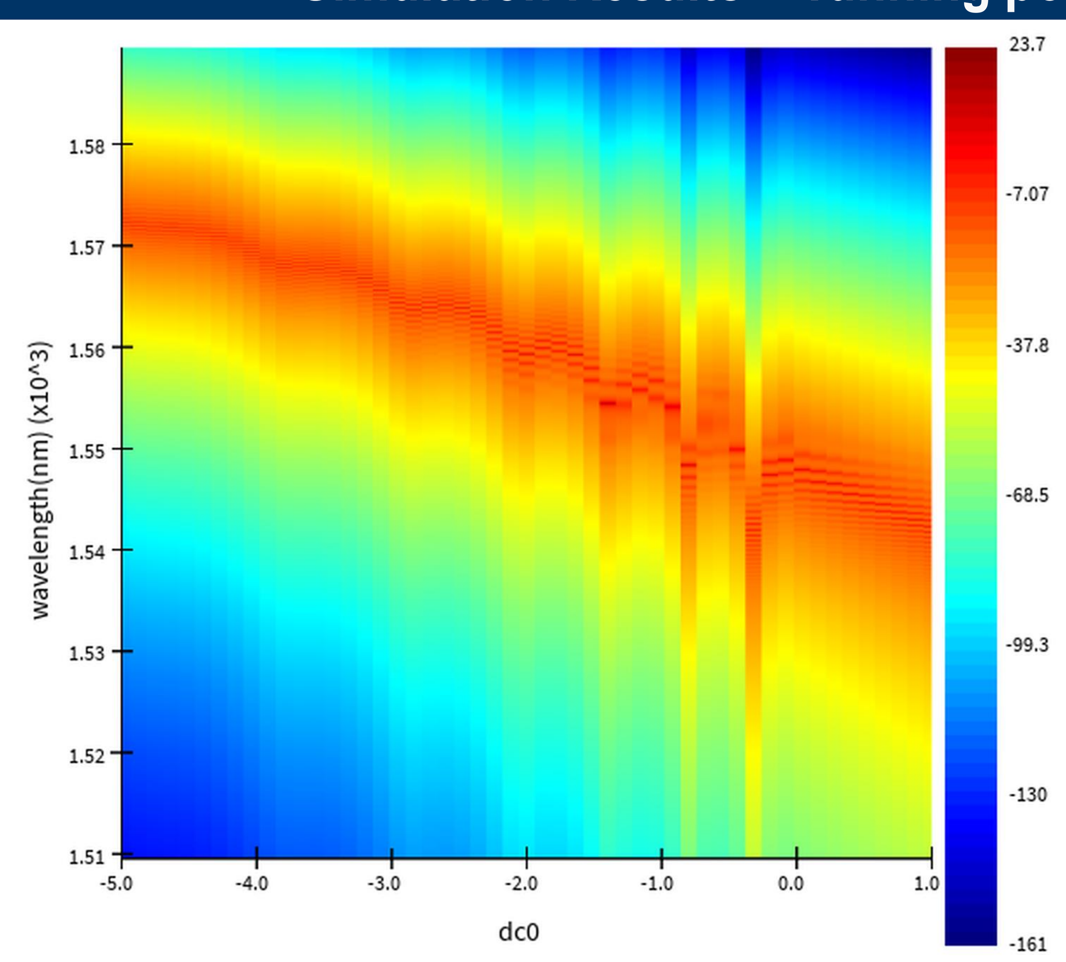
Simulation Results – Combs, Narrow peaks

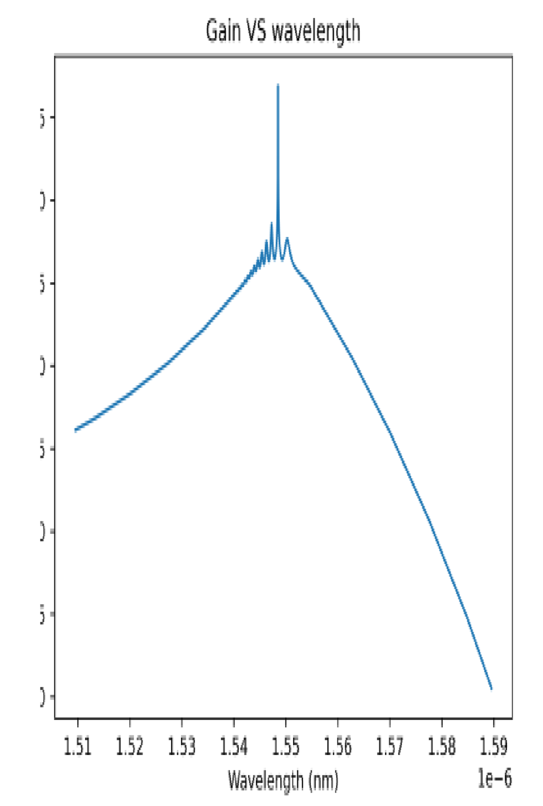


Leveraging a Photonic Integrated Circuit (PIC) comprising concatenated Mach-Zehnder Interferometers (MZIs), a spectral comb can be efficiently generated (top figure). A key advantage of this design is the ability to dynamically tune the spectral peak to a desired frequency (bottom figure) on the fabricated device itself, achieved exclusively via voltage adjustments applied to the integrated optical modulators (OMs).



Simulation Results – Tunning possibilities





A more advanced circuit architecture explores the implementation of a Mach-Zehnder Modulator (MZM) whose operational characteristics, notably its response around a defined frequency, can be electrically tuned via voltage control. This allows for dynamic spectral or temporal shaping of the optical output.

Conclusions

We presented an automated methodology for designing and analyzing photonic integrated circuits, surpassing manual design approaches in Ansys Lumerical INTERCONNECT. By leveraging machine learning, the optimization process is accelerated through genetic algorithms and regression techniques, enhancing optical modulation performance.

Acknowledgements

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