Design and Verification of a Q-Band Test Source
for UAV-Based Radiation Pattern Measurements

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Machine Learning aided characterization of multi-stage integrated ring resonator filters

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Abstract: Modern optical transmission standards require steep band-pass filters enabling spectrally efficient channels spacing. For this aim, we propose a machine-learning agent to assist in the characterization of complex ring resonator filters to fulfill the transmission requirements.

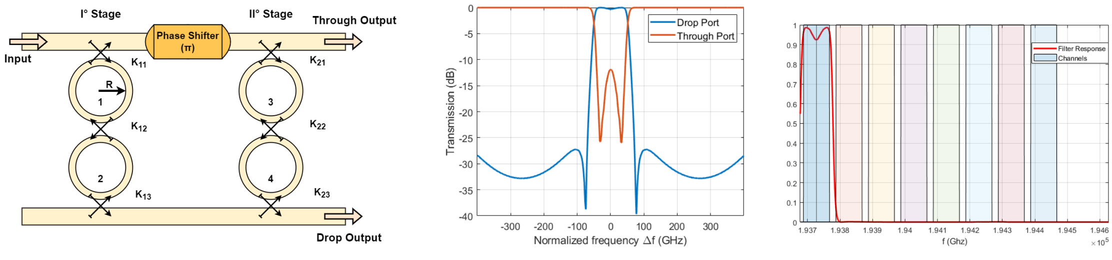
1. Introduction

In the last decade, advancements in Photonic Integrated Circuits (PICs) and systems have revolutionized different technologies such as optical communication, medical assessment, solar energy systems, and quantum computing. In the framework of optical communications and networks, PICs are widely used to implement state-of-the-art Wavelength-Division Multiplexing (WDM) transport because of their unique characteristics of wide bandwidth, low cost, power efficiency, and small footprint. Considering these characteristics, PICs are fundamental for the widespread and cost-effective expansion of today's optical networks. One of the most widely used photonic structures for PIC implementations is the Micro Ring Resonator (MRR), which provides design flexibility and overall small footprint. MRR is typically used for filtering purposes; an add-drop MRR filter is made by two parallel waveguides coupled an integrated ring, and it allows routing of signals at certain frequencies from one waveguide to the other, acting therefore as a bandpass filter. The response of such filters is periodic due to the nature of the introduced roundtrip phase shift, which creates periodic resonance based on the design length of the ring structures. More complicated structures can be obtained properly connecting in series and parallel multiple rings, in order to match the necessary transfer function profile. Generally, the design of photonic structures remains a critical problem in photonics investigation. In recent years, different techniques have been proposed to assist photonic structural design, such as adjoint methods [1] and evolutionary algorithms [2]. To further expand the capabilities and cover the design of those architectures for which closed-loop formulas may not be available, the photonics industry explores a data-driven approach that overcomes the shortcomings (local minima and expensive computations) of conventional design techniques. This approach is possible thanks to the latest simulation tools, which provide an accurate characterization of photonics structures and provide the capability to generate synthetic data. This potentiality to generate a dataset enables the new development and design possibilities through data-driven methods and models.

In this work, we propose a Machine Learning (ML) framework that assists in designing complex MRR-based filters. The proposed ML model is trained on the dataset obtained by simulating multiple device instances with random physical parameters configurations, allowing the extraction of a transmission efficiency metric based on transmission characteristics, such as the channels spacing. The dataset has been generated for two main state-of-the-art Free Spectral Ranges (FSRs): 75 GHz and 100 GHz using the Synopsys© toolkit.

2. Architecture of MRR Filter and Dataset Generation

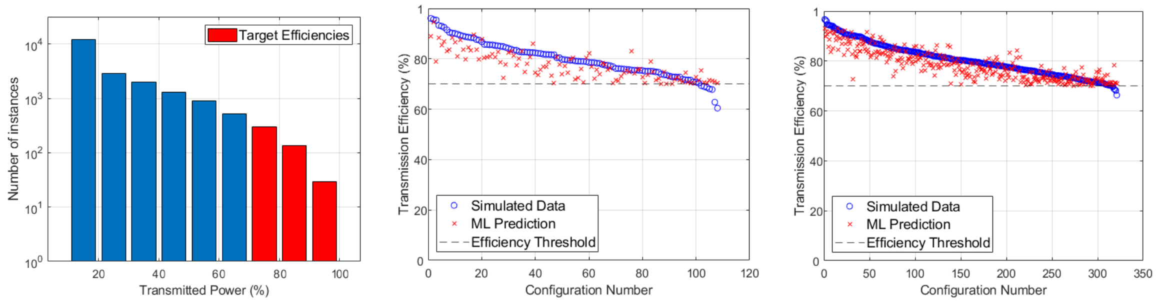
The proposed analysis has been carried out on a multi-stage ladder MRR filter, used as the reference device to characterize the prediction performance of the developed ML agent. These complex MRR structures allow the implementation of higher-order filters with respect to simple first and second-order devices, granting the possibility of designing steeper band-pass filters, which are required in the envisioned application. The device consists of a two-stage ladder configuration, with two coupled MRR elements in each of the stages coupled through two bus waveguides. The top waveguide introduces a π-phase shift to the bottom bus, with the general layout depicted in Fig. 1a: the MRR reference radius has been fixed to operate at a central frequency of 193.73 THz (R= 19.708μm), while the waveguide-ring coupling factors are symmetric in each stage, between the top and bottom bus and their respective MRR ($\kappa_{11} = \kappa_{13}$, $\kappa_{21} = \kappa_{23}$). This configuration allows the implementation of a four order band-pass response, characterized by a flat-top transmission region, as well as steep roll-off [3]. The frequency response depicted in Fig. 1b has been obtained through the OptSim© simulation environment, for a 200 nm×450 nm Silicon waveguides buried in Silicon Oxyde, having as target application FSR=100 GHz: the filter shows the desired performances, with an extremely flat transmission band as well as a steep cut-off region. This behavior has been obtained by tuning the coupling coefficients to the values: $\kappa_{11} = 0.16$, $\kappa_{12} = 0.42$, $\kappa_{21} = 0.91$ and $\kappa_{22} = 0.10$. While evaluating the frequency response as a function of the coupling coefficients can be achieved through deterministic or closed-loop formulas, we propose an alternative design paradigm, employing ML to highlight optimal design parameters configurations based on the required channels FSR. The dataset for the training has been obtained by simulating 10 000 random configurations of the coupling coefficients, extracting a transmission efficiency metric as a function of the channels spacing. The metric has been chosen as the transmitted power percentage considering a reference WDM comb with 8 adjacent channels, as shown in Fig. 1c. The dataset has been generated for two main state-of-the-art FSRs: 75 GHz and 100 GHz.



(a) (b) (c)

Fig. 1: (a) Layout of the ladder two-stage MRR filter; (b) simulated frequency response for a 100 GHz FSR target implementation; (c) Reference WDM comb overlapped with the designed channel frequency.

3. ML-assisted Design Results and Conclusion



(a) (b) (c)

Fig. 2: (a) Power transmission distribution for the generated dataset: the solution efficiency threshold is highlighted in red. (b,c) ML prediction error against the simulated data for the target threshold for 75 GHz and 100 GHz respectively.

The proposed ML agent is developed by exploiting the high-level Application Program Interface (API) of the TensorFlow© platform. The ML agent utilized a Deep Neural Network (DNN) [4], having three hidden layers with 30 neurons per layer. The simulated DNN model manipulated *ReLU* as an activation function, and mean square error (MSE) is used as a loss function. The DNN model is set up for training steps of 10 000 and a learning rate of 0.01. The training set consists of 70% of the dataset, while the test set applies the remaining 30%. Furthermore, the proposed DNN utilizes the coupling coefficients κ at the input ports as features while the power efficiencies at the output port are labels. The validation of the ML agent has been done by comparing the predicted transmission efficiency to the simulated one, depicted in Fig. 2a: given the target goal of finding suitable coupling configurations, we are interested in the performance predictions above a given threshold (75%). The predictions are shown in Fig. 2b, and Fig. 2c, compared with the simulated data: the ML predictions are closely distributed around the actual simulated data, with only limited erroneous classifications close to the selected threshold. The results obtained during this investigation show the accuracy and potentiality of the ML agent in aiding the characterization and design of such devices through a simulating data-driven method, without requiring access to a deterministic formula or closed-loop model of the device.

References

[1] S. D. Campbell *et al.*, "Review of numerical optimization techniques for meta-device design," Omex **9**, 1842–1863 (2019).

[2] C. A. C. Coello *et al.*, *Evolutionary algorithms for solving multi-objective problems*, vol. 5 (Springer, 2007).

[3] A. P. Masilamani and V. Van, "Design and realization of a two-stage microring ladder filter in silicon-on-insulator," Opt. Express **20**, 24708–24713 (2012).

[4] I. Khan *et al.*, "Machine-learning-aided abstraction of photonic integrated circuits in software-defined optical transport," (SPIE, 2021), p. 117130Q.