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Modular Photonic-Integrated Device for Multi-Band Wavelength-Selective Switching

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Abstract: *We propose a Silicon Photonics based WSS for S+C+L bands, independently routing any input channel to the desired output fiber. BER and OSNR for a system with 30 total channels are evaluated with Synopsys Optsim.*

Keywords: *WSS, Photonic Integrated Circuits, WDM, Switching Multi-Band*

I. INTRODUCTION

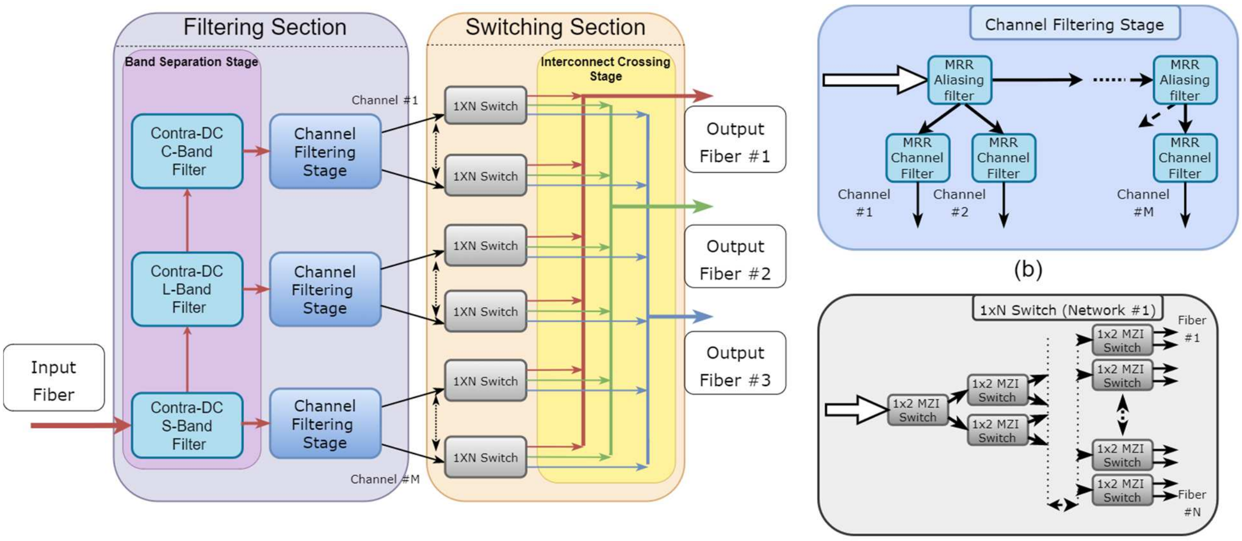
Today's communication landscape is seeing a fast-growing increase in resource requirements, due to both a larger user-base as well as more bandwidth and resource-intensive applications and standards. New technologies and paradigms, such as 5G and Internet-of-Things (IoT) require an expansion and improvement of the underlying optical communication network [1], which represents the backbone required for handling the modern traffic and global connection. This expansion of the optical network capabilities can be approached with two main solutions: new infrastructure and fiber deployment, or improved and optimized management of the currently available network capacity. From the network operation point of view, the deployment of new infrastructure represents a more expensive solution; as such, technologies and devices that can utilize the residual network capacity are a more desired and cost-effective solution. In this context, multi-band paradigms and transmission schemes represent the main avenue to utilize fully the current infrastructure resources [2], allowing better management of the aforementioned increase in resource demand. Considering the standard Wavelength-Division Multiplexing (WDM) protocol already deployed on the current network, the Band-Division Multiplexing (BDM) paradigm can lead to full usage of the remaining available fiber spectrum. In order to deploy this technology, the underlying switching and routing devices must be able to operate on an ultra-wide bandwidth. In this context, solutions based on Photonic-Integrated Circuits (PICs) are widely suited, due to their advantages, such as large bandwidth of operation, low power consumption, as well as small footprint. Additionally, PICs can provide a cost-effective solution, both due to their large-scale manufacturing possibilities and the low deployment costs. As such, we propose a fully-integrated Wavelength-Selective Switch (WSS) based on Silicon Photonics standards, able to route independently every channel of a given input signal towards a target output port, allowing multi-band operation on the S+C+L optical transmission windows.

II. WAVELENGTH-SELECTIVE SWITCH STRUCTURE

The proposed WSS architecture represents a modular and scalable structure for a 1xN switching device, allowing independent and conflict-avoiding routing of the input WDM comb channels towards the N output ports. This is achieved by separating the filtering and switching operations into multiple stages, allowing a more flexible design of the structure based on the required number of output ports or expected input channels: by tailoring the sub-modules, the structure can be designed to handle the arbitrary routing 1xN for M given channels in the S+C+L bands of operation.

The proposed structure is depicted in Fig.1a, highlighting the general connection and circuit structure of the operational blocks; the channels comb extraction is handled by a cascade of filtering elements, tasked with separating the three main bands in the first stage, while the second section handles the individual channels: this second stage, depicted in Fig.1b, sends each individual channel to an independent 1xN switching network, which allows the routing to the correct output port. The switching structures have been designed as a cascade of simpler 1x2 Optical Switching Elements (OSE), shown in Fig.1c, which provide an overall smaller solution with respect to a single large scale multi-stage switching network.

In this analysis, the architecture has been studied considering a target implementation with 3 possible output fibers, taking into account 30 input channels: the structure and its components have been simulated using the Synopsys Photonic Circuit Design Suite, while the overall Quality-of-Transmission (QoT) degradation has been characterized as an Optical Signal-to-Noise Ratio (OSNR) penalty.



(a) (c)

Fig. 1: (a) General structure of the proposed WSS. (b) Highlight of the channel filtering cascade. (c) 1xN Switching architecture

III. **COMPONENTS DESIGN AND SIMULATION**

Three main PIC-based devices have been modeled and implemented to achieve the desired functionality, with Contra-Directional Couplers (CDC) and Micro-Ring Resonators (MRR) used for the filtering stage, while Mach-Zehnder Interferometers (MZI) have been used for the switching section. The three components' layout and simulated performances can be seen in Fig.2.

The CDC filters (Fig.2 left) have been used to achieve the initial band-separation, due to their flat pass-band of operation and sharp band transition. The design of such elements for these large bandwidths is achieved through perturbation of the pitch of the gratings, as discussed in [3]. The overall footprint for the required CDC is the order of 10^{-3} m; as such, a different solution has been implemented for the individual channel filtering to reduce the overall device size. The following channel extraction is achieved two-stage ladder MRR filters (Fig.2 center), which can be precisely tailored [4] to obtain the desired frequency response, targeting only a single channel. Due to the filtering aliasing introduced by MRR-based structures, an additional layer of anti-aliasing filters has been implemented, minimizing the crosstalk both intra and inter-band.

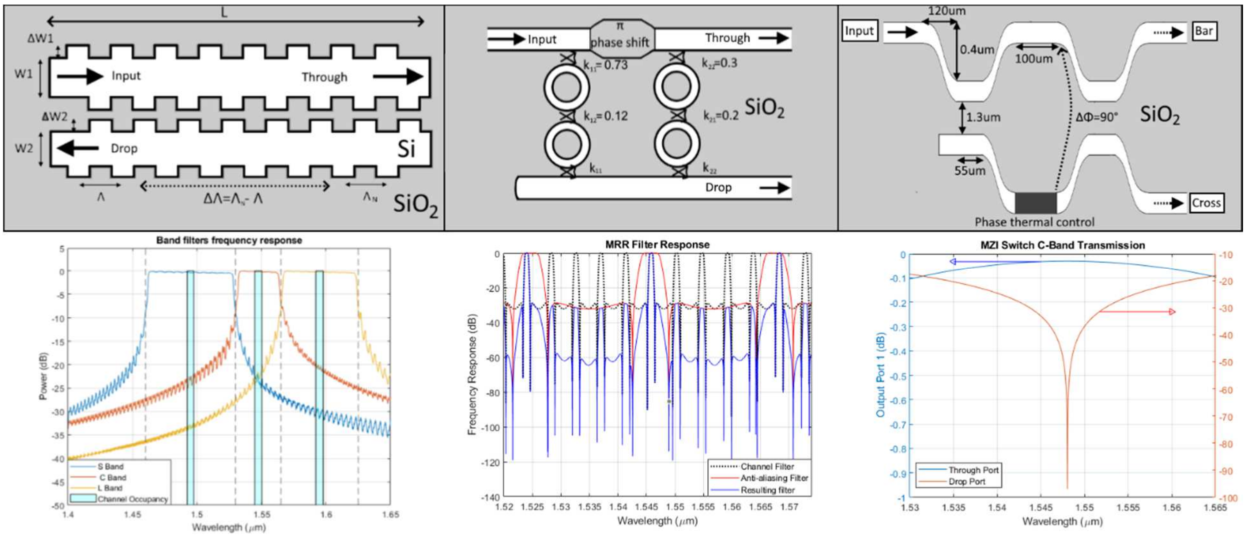


Fig. 2: Schematic (top) and corresponding simulated spectral response (bottom) of the fundamental blocks of the of the WSS (left to right: Contra-Directional Coupler, Two-stage ladder MRR filter, MZI thermally-controlled switch)

Finally, the switching operation is achieved through MZI-based thermally controlled elements (Fig.2 right), which can be designed to achieve a sufficiently flat and large transmission band for the desired application [5]. The following interconnect crossing network has been modeled considering each waveguide crossing as a frequency-independent lossy element, introducing 0.04dB of loss over the whole considered spectrum.

IV. RESULTS AND CONCLUSIONS

Having defined the main components of the structure, the WSS has been simulated in Optsim, using the Synopsys Digital Signal Processing (DSP) library to extract the Bit-Error Rate (BER). This simulation has been run considering a coherent transmission scenario with channel Free-Spectral Range (FSR) =100GHz, using 16-QAM modulation format and symbol rate R_s=60GBaud: 10 channels have been placed in each of the band under analysis (S+C+L), for a total of 30 global channels.

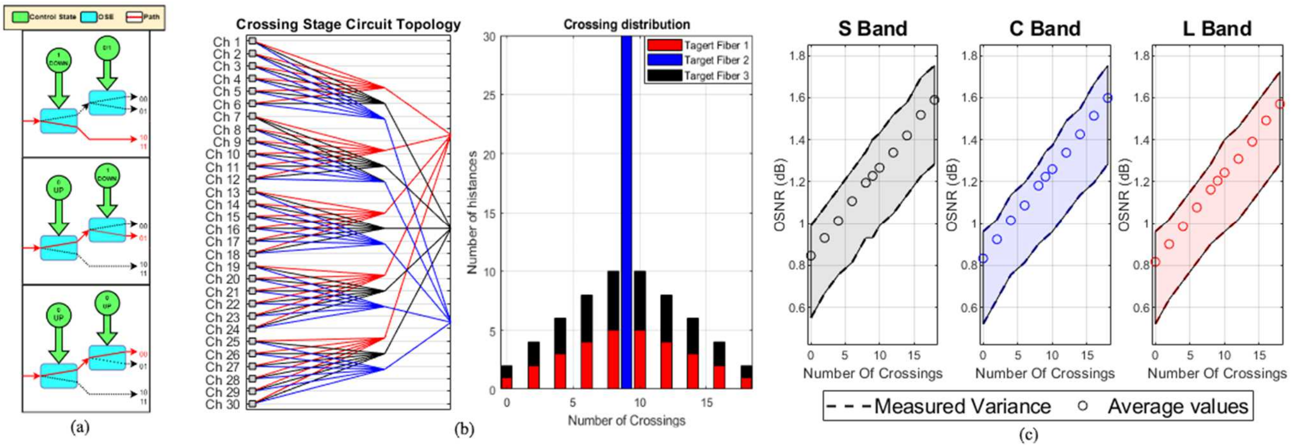


Fig. 3: (a) Switching combinations, (b) crossing structure (c) measured OSNR penalty for the different routing configurations of the thirty channels under analysis.

Considering a target BER of 10^{-3}, the simulation results have been used to evaluate the added penalty with respect to the back-to-back system, extracting the QoT metric (ΔOSNR).

This simulation has been run considering all three possible routing states of each channel, as depicted in Fig.3a. Each routing of every channel corresponds to several encountered waveguide crossings, as shown by the circuit topology in Fig.3b: in order to reduce the number of waveguide crossings, the interconnects are combined into five groups, leading to the distribution depicted in the histogram. Given the design choice of the WSS architecture, two main penalties can be extracted as to characterize the device: while the filtering and switching elements introduce a flat penalty, independent of the requested routing state, the interconnect stage is responsible for the path-dependent penalty. This has been characterized as a function of the number of encountered crossing elements, as depicted in Fig.3c, considering the QoT of each channel under every possible interconnect configuration. The result clearly shows a compatible penalty behaviour in all three windows under analysis, highlighting the wide-band capability of the designed components. At the same time, the overall WSS exhibit a simple control scheme without requiring complex and time-consuming routing algorithms, as the complexity is severely reduced by the parallel structure of the switching sub-networks. Furthermore, thanks to the simple deterministic nature of the path selection, the penalty of each configuration can be easily estimated to provide a virtualized model of the device.

In conclusion, the device and simulations show the capabilities of a fully-integrated solution for WSS implementation, allowing a wide multi-band of operation while maintaining limited penalties and conflict-avoidance routing. The modularity of the proposed architectures also enables scalability, thanks to the expandable and flexible nature of structure stages.

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