Novel Design and Operation of Photonic- integrated WSS for Ultra-wideband Applications

Novel Design and Operation of Photonic-integrated WSS for Ultra-wideband Applications

Lorenzo Tunesi
Politecnico di Torino, IT
lorenzo.tunesi@polito.it

Ihtesham Khan
Politecnico di Torino, IT
ihtesham.khan@polito.it

Muhammad Umar Masood
Politecnico di Torino, IT
muhammad.masood@polito.it

Enrico Ghillino
Synopsys, Inc., USA
enrico.ghillino@synopsys.com

Andrea Carena
Politecnico di Torino, IT
andrea.carena@polito.it

Paolo Bardella
Politecnico di Torino, IT
paolo.bardella@polito.it

Vittorio Curri
Politecnico di Torino, IT
curri@polito.it

***Abstract*—Photonic integrated solutions for switching applications can yield large bandwidth and high reconfigurability while requiring low power and footprint. We propose a modular, scalable photonic integrated multi-band wavelength selective switch, able to independently route the input fiber channels to an arbitrary number of output ports.**

***Index Terms*—Wavelength Selective Switch, Photonic Integrated Circuit, Multi-Band Transmission**

I. Introduction

The rapid increase in internet traffic due to bandwidth-intensive applications and the new Internet of Things (IoT) paradigm required an improvement of the current optical network infrastructure. The current aim of the service provider is to exploit the residual capacity of the network, maximizing the return of the hardware already available. This solution requires scalable switching systems capable of handling ultra-wide bandwidths of operation, enabling Wavelength-Division-Multiplexing (WDM) in a Multi-Band Transmission (MTB) scenario. To this end, Photonic Integrated Circuit (PIC) can provide highly reconfigurable switching solutions, characterized by low cost, footprint, power consumption, and large bandwidth of operation. In this scenario, we propose a fully integrated Wavelength Selective Switch (WSS) compatible with the Silicon Photonic platform, with the capabilities to handle filtering and switching of WDM comb in an MBT scenario, covering the S+C+L optical transmission bands. The solution has been designed following a modular approach; as such, it can be scaled up to the required number of output fibers and routed channels.

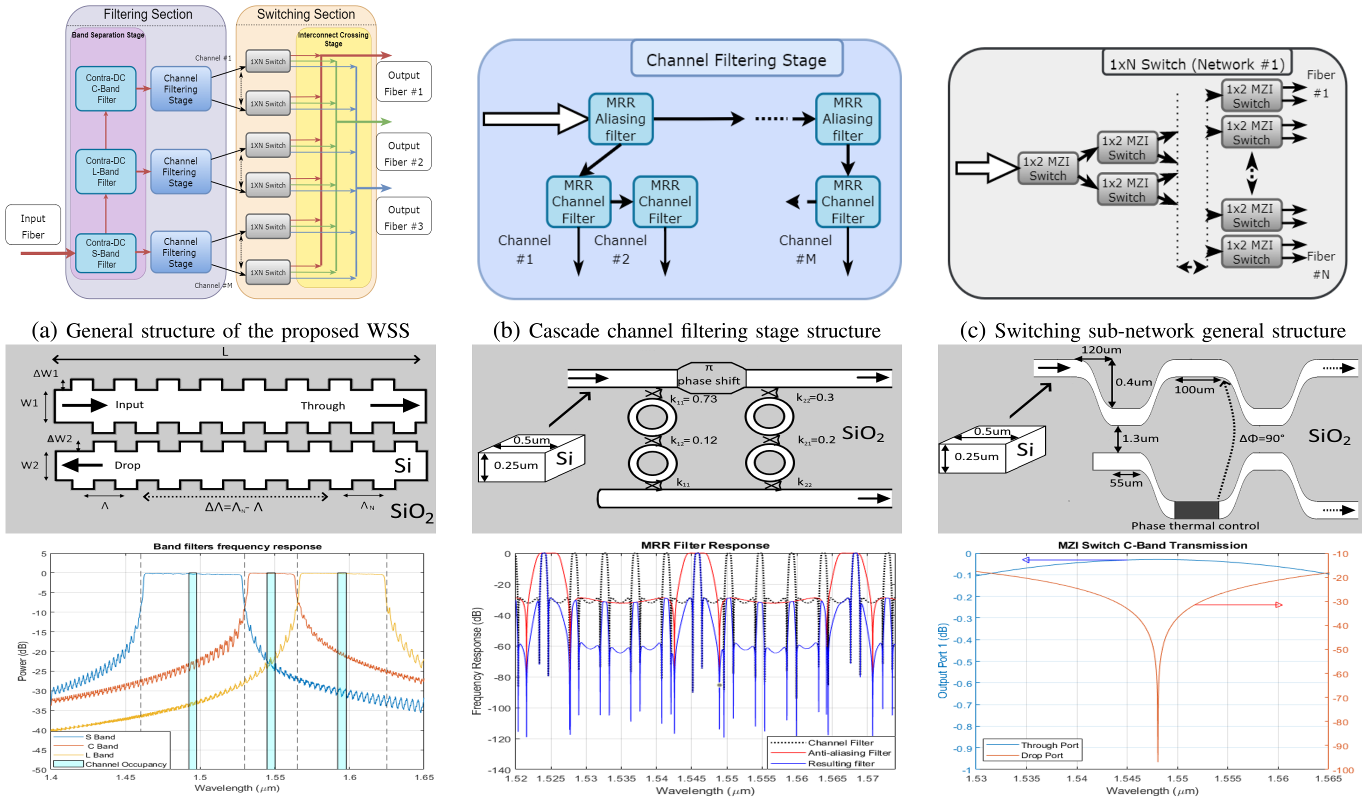
II. Wavelength Selective Switch

The proposed WSS can independently route each channel of the input WDM comb towards the required output fiber, avoiding any routing conflict or dependency between the different channel paths. The structure main operations are divided into two different cascaded stages **Fig. 1a**: the WDM signal comb must be filtered into the individual channels, which is handled by the first stage, and each channel must be independently routed to the required port through a switching network, which is enabled by the second stage of the structure. The filtering of each channel is carried out through a cascade of multiple filters: this is implemented to reduce the aliasing and crosstalk between the adjacent channels and the main operating bands. The first section of the filtering stage is tasked with separating the S+C+L bands of operation, which is then followed by multiple filtering blocks, depicted in **Fig. 1b**, which extract the individual channels. The structure and internal components of such blocks are described in the next section, although their main target is mitigating the aliasing issues due to the periodic nature of phase-based photonic integrated filters. Once the individual channels are separated, the switching operation is carried out through M parallel $1{\times}N$ switching networks, considering N possible output fibers and M total channels. This is achieved through simple multistage switching networks, shown in **Fig. 1c**, which are constructed from elementary $1{\times}2$ Optical Switching Elements (OSE).

The main advantage of these structures, with respect to larger multistage switching topologies, lies in the simpler control scheme that can be implemented without requiring complex conflict-avoidance algorithms. After this stage, the connection to the required port is obtained through an interconnect crossing stage, which is necessary to correctly connect each subnetwork output. The modularity of each section of the structure allows the scalability to achieve a higher number of output fibers and channels. However, the desired Quality of Transmission (QoT) may impose some limitations on the maximum achievable size.

III. Internal component design and simulation

The design and simulation of the internal components enabling the required functionalities have been carried out through different models. They range from Beam-Propagation Methods (BPM), Coupled-Mode theory (CMT) (analytical solutions), and Finite-difference Time-domain (FDTD) physical simulation, depending on the accuracy and complexity required. The Synopsys Rsoft, a photonic circuit simulation tool, has been used to verify and tailor the design. The implementation targets the Silicon Photonic Platform (SOI), with Silicon (Si) on Silicon Dioxide (SiO2) ridge waveguides designed and simulated with width W$=550\,\mathrm{nm}$ and height



(a) General structure of the proposed WSS

(b) Cascade channel filtering stage structure

(c) Switching sub-network general structure

(d) Contra-directional coupler filter used for the band separation stage

(e) Two-stage ladder MRR filter used for the channel separation

(f) MZI implementation for C-band switching

Fig. 1: General schematic of the WSS and its internal component response

H=220 nm, unless differently specified. Three main devices have been designed to achieve the required operation: the band-separation stage is achieved through Contra-Directional (CD) Couplers, the channel separation through two-stage ladder Micro-ring Resonator (MRR) filters, and the switching operation through thermally-controlled Mach-Zehnder Interferometers (MZI). The three CD-couplers frequency behavior and filtering bandwidth can be designed by tuning the grating period chirp [1], as shown in the **Fig. 1d**. For our implementation these values correspond to $\Lambda =$[0.289, 0.313, 0.325] µm, with $\Delta\Lambda =$[20, 8, 18] nm for the S+C+L bands, respectively. The channels are then selected through multiple cascades of two-stage ladder MRR filters, depicted in **Fig. 1e**; the MRR filter implementation allows a smaller footprint with respect to the CD-coupler; as such, they're better suited towards the channel separation. To avoid aliasing due to the periodic nature of MRR frequency responses, an additional layer of filters is present, designed with a larger Free Spectral Range (FSR) with respect to the individual channel bandwidth. Other than reducing the aliasing, this architecture also reduces the number of filters encountered by each channel, limiting the insertion loss experienced by the far-side channels of the input signal. The additional aliasing filters allow the structure to handle a larger number of channels with respect to straightforward MRR cascades. However, for larger-scale implementations with more than 20 channels in each band, this simple two-stage structure is insufficient, requiring an additional layer of filtering elements. This solution is as modular in nature as the rest of the design, allowing the expansion of the underlying architecture based on the required number of channels and their spectral characteristics. The MRR length and coupling parameters have been obtained through analytical means [2], with the waveguide-ring coupling verified through BPM in the Synopsys suite. The switching is instead implemented through MZI-based OSE **Fig. 1f**, which can be thermally controlled to enable the desired configuration. MZI-based OSE can achieve large flat transmission bands, making them a viable solution for traditional switching architecture [3].

Overall the proposed WSS scheme and its main components allow low-loss filtering and switching, enabling a fully integrated photonic WSS.

References

[1] M. Hammood *et al.*, "Broadband, silicon photonic, optical add–drop filters with 3 dB bandwidths up to 11 THz," Opt. Let. **46**, 2738–2741 (2021).

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

[3] I. Khan *et al.*, "Optimized management of ultra-wideband photonics switching systems assisted by machine learning," Opt. Express **30**, 3989–4004 (2022).