

Low-loss, fine resolution wavelength-selective switch realized at a silicon photonics foundry

Vivek V. Wankhade^{1,†}, Saleha Fatema^{1,†}, Lucas M. Cohen^{1,†}, Navin B. Lingaraju², Bohan Zhang³, Deniz Onural³, Miloš Popović³, and Andrew M. Weiner¹

¹School of Electrical and Computer Engineering, Purdue University, West Lafayette, IN 47907.

²SRI International, 1100 Wilson Blvd. Suite 2800, Arlington, VA 22209.

³Department of Electrical and Computer Engineering, Boston University, Boston, MA 02215.

[†]Equal contribution; *amw@purdue.edu

Abstract: We report a demonstration of a 3-channel wavelength-selective switch with individual channel bandwidths of 2 GHz and drop port loss below 1 dB, paving the way for efficient spectrum utilization in quantum networking applications. © 2023 The Author(s)

At the most general level, quantum networks will be tasked with mediating communication and entanglement between physically separated quantum systems. While there has been progress in facilitating these tasks between satellite-based and terrestrial free-space links, optical fiber will be a critical tool for connecting quantum resources in dense and short-reach communications like local area and metropolitan area networks. One advantage of optical fiber, in addition to low loss, is that it supports massive parallelization of communication channels in the spectral domain to support terabit data rates. Wavelength-multiplexing could similarly help boost the rate of quantum state transport over fiber, but existing network infrastructure has largely been designed for the 100 GHz spacing of the ITU grid. This presents a challenge for quantum communication because the bandwidth of signals, especially those entangled with matter-based qubits, is well below 1 GHz [1]. Consequently, gains from wavelength multiplexing are limited by poor use of spectral bandwidth. Wavelength-selective switches (WSS) that support flex concepts and that are based on liquid crystal-on-silicon (LCoS) technology support finer channel resolution (down to 20 GHz), but one incurs a high penalty in terms of optical loss (4-5 dB) [2]. In the last few years, photonics foundries have emerged as a viable option for rapid prototyping and volume production of high-performance optical components and making it possible to develop hardware tailored to the needs of quantum networks. Here we report the demonstration of a foundry-fabricated 3-channel WSS that implements all 6 possible routing permutations on a 10 GHz spectral grid.

Figure 1(a) is a concept illustration of our 3-channel WSS showing reconfigurable wavelength-selective routing of different spectral channels across three output ports. One limitation of commercial foundries is that propagation losses in single-mode strip waveguides is on the order of 2-3 dB/cm [3]. While such losses are tolerable for on-chip routing in small-scale photonic integrated circuits (PICs), they impose limitations in devices based on resonant geometries. In the case of microresonator-based spectral filters, single-mode geometries limit one's ability to realize filters that support both the fine channel resolution (< 10 GHz) and the low drop loss (< 1 dB) necessary for quantum applications.

Our WSS design overcomes these limitations through the use of wide multimode waveguide segments in racetrack-based filters. This geometry minimizes field overlap with the sidewall of the waveguide and dramatically reduces the average propagation loss through the racetrack filter [4]. An in-depth illustration of our chip-scale geometry, where each output channel is realized through coupled racetrack resonators, is shown in Figure 1(b). Figure 1(c) is close up of a single racetrack and highlights the three modular elements in our design – a single-mode directional coupler with a 500 nm-wide cross-section, a short 500 nm-wide to 2 μ m-wide taper [5], and

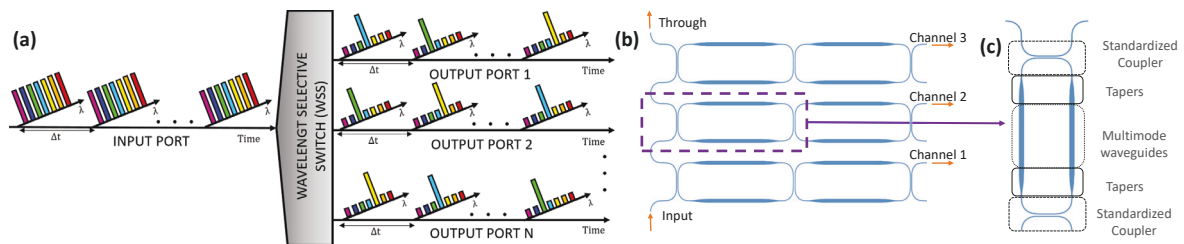


Fig. 1: (a) Conceptual diagram of a 3-channel WSS. (b) Layout of the 3-channel WSS. (c) Zoom-in view of an individual racetrack.

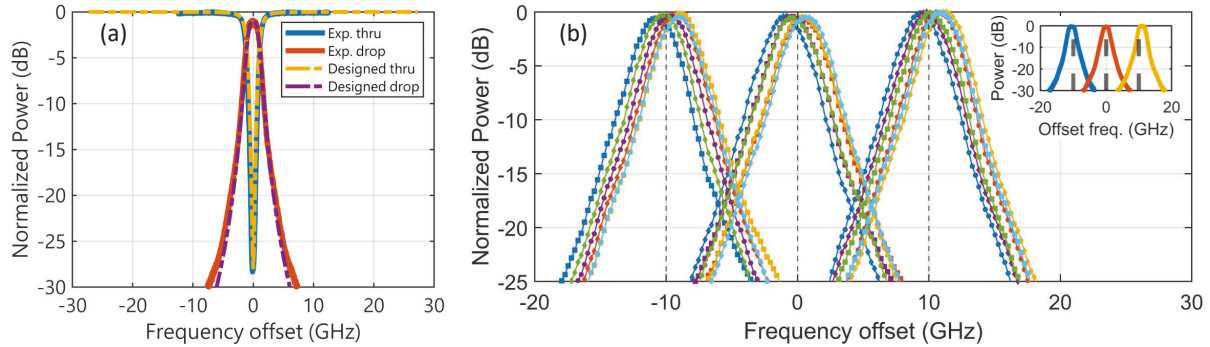


Fig. 2: (a) Designed and measured response of the second-order filters in this work. (b) The six permutations of a three-channel wavelength selective switch as measured from an optical spectrum analyzer. The different markers correspond to different channels, and different colors correspond to different permutations. The figure at the inset shows all channels of a single permutation as measured from a swept laser. Here, a crosstalk less than 20 dB can be seen.

700 μm -long straight waveguide segments with 2 μm -wide cross sections. The loss of each of these elements was extracted from devices on earlier AIM Photonics active multi-project runs [5, 6] and used to model the performance of second-order racetrack-based filters. Figure 2(a) shows a comparison between this theoretical model and the measured transmission spectrum of one of the filters. We note good agreement between the model and data to realize a filter with a linewidth of ~ 2 GHz and a drop loss of ~ 1 dB.

The performance of the WSS is assessed by capturing the transmission spectra for each of the three output channels when the input to the system is broadband amplified spontaneous emission. In particular, we examined the performance of the system on a hypothetical 10 GHz grid: -10 GHz, 0 GHz, and +10 GHz. Each channel was aligned to a unique position on this three-point grid. There are six permutations for three channels on this grid, and the spectra for each state taken from an optical spectrum analyzer are shown in Fig. 2(b). We denote these permutations as 1-2-3, 2-3-1, 3-1-2, 1-3-2, 2-1-3, and 3-2-1, with the first number in the series denoting the channel aligned to the -10 GHz grid point, the second number the channel aligned to 0 GHz grid point and the last number the channel aligned to the +10 GHz grid point. The inset shows one of the states (1-2-3) scanned using a continuous wave laser with ~ 25 dB of isolation between adjacent channels. Each racetrack resonator in the WSS is thermally tuned by driving doped-silicon heaters which are connected to metal pads and are wire-bonded to a printed circuit board to enable straightforward access to drive electronics. A Maple Leaf probe station (SD 90) is used for automated fiber alignment [7], and heaters in the wire-bonded die are supplied with power from the source-measurement unit of the probe station through an interposer from Qontrol (INT8FFC).

To align each channel to the target wavelength, we developed an optimization routine using open-source Python libraries. Here, we use a multi-objective minimization routine [8]. Using the common through port for feedback, the routine minimizes power at each resonance location enabling maximum power output at the drop port. Our routine is critical for aligning channels at a 10 GHz grid in the presence of thermal crosstalk. As can be seen from the imperfect overlap of transmissions spectra in Fig. 2(b), our optimization routine enables frequency setting accuracy of 0.7 ± 0.1 GHz with the filters of the WSS.

In summary, the photonic integrated WSS examined here can permit wavelength-selective routing of quantum channels on 10 GHz, or potentially smaller, frequency grids. Despite the narrow linewidth supported by filters in the WSS, drop loss is less than 1 dB. These results, coupled with recent advances in photonic wire bonding [9], suggest that low-loss wavelength-selective switches with fine channel resolution can be realized in a scalable manner with repeatable processes.

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