

# FSR-free filter with hitless tunability across C+L telecom band

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**Abstract:** An FSR free coupled-resonator filter over the extended C+L band (1520 nm–1620 nm) is experimentally demonstrated. Two novel strategies are introduced: the non-integer-ratio Vernier design combined with the controllable-loss hitless tuning scheme.

## Introduction

Tuneable optical filters are key functional building blocks of optical networks, where flexible and dynamic allocation of WDM channels is required for routing between network nodes. Channel selection must be operated without introducing perturbations to the other channels, this feature being known as hitless tuning.

Silicon microring resonator (MRR) filters are suitable candidates for this application, because they can combine wide passbands, steep roll-offs, high extinction ratios in very compact devices. To overcome the free-spectral range (FSR) limitation due to the minimum bending radius of MRRs and achieve tunability across a wide wavelength range, Vernier schemes can be utilized [1]. In the conventional Vernier architectures, MRRs with different FSRs are selected according to integer relative ratios, enabling the implementation of filters with an overall FSR as high as 40 nm [2]. Larger FSR is achievable by cascading several Vernier filters [3]. Moreover, hitless tuning schemes for coupled MRR filters employ selective detuning of the MRR resonances after filter disconnection from the bus waveguide through the use of tunable couplers [4]; however, this approach does not apply to Vernier schemes due to the appearance of off-band spurious notches during the tuning.

In this work, we present the design and experimental demonstration of an FSR-free hitless-tuneable Vernier filter based on a fourth order coupled MRR architecture fabricated on a silicon photonic platform. Two novel key strategies are introduced to achieve FSR-free hitless tuning operation: a Vernier architecture with non-integer FSR ratios between MRRs and a controllable loss in the ring chain. Hitless tunability across the extended C+L band (1520 nm – 1620 nm) is achieved by combining thermal tuning of the MRR resonances with the introduction of controllable loss in MRRs to disconnect the filter from the input waveguide.

## Concept and implementation of the FSR-free Vernier filter

The proposed filter architecture consists of four coupled MRRs connected to bus waveguides through tuneable couplers implemented by Mach-Zehnder interferometers [Fig.1(a)]. Starting from an initial filter design achieved by using conventional Vernier techniques (with integer FSR ratios), a numerical optimization procedure was implemented to modify the design according to non-integer FSRs, targeting the suppression of the side-passbands, while keeping the spectral shape of the main passband. Figure 1(b) shows the frequency domain response of the optimized filter, where the FSR ratios are [5.73 3.3 4 4.8] and the power coupling coefficients are [7%, 1%, 0.3%, 0.8%, 6%]. Intentionally neglecting the wavelength dependence of directional couplers, aperiodic FSR-free response is achieved across more than 120 THz (1  $\mu$ m wavelength range). Solutions to implement ultrabroadband couplers in silicon photonics have been recently proposed [5].

The proposed filter design was implemented on a 220-nm commercial silicon foundry (AMF). Figure 1(c) presents the measured frequency response of Through and Drop port across a 1520 nm -1610 nm wavelength range (limited by measurement instruments). The MRRs of the filter are thermally tuned by exploiting thermal cross-talk free algorithms [6]. The Drop-port response exhibits a 3dB bandwidth wider than 39 GHz across the whole wavelength range with more than 20dB of-out-band isolation at 50 GHz spacing from the central wavelength of the passband. The Through port of the filter shows spurious out-of-band notches less than 1.2 dB deep; corresponding out-of-band peaks on Drop port frequency response are lower than 33dB. The two MZI tunable couplers connecting the filter to the bus input/output waveguide allows filter shape optimization by compensating the wavelength dependence of the directional couplers. The absence of side-passband in the measured wavelength range confirms the aperiodic FSR-free behaviour of the filter.

## Hitless tuning of ultra-wideband Vernier filter

The tuning strategy proposed in this work exploits controllable loss induced through variable optical attenuators (VOA) implemented through p-i-n junctions integrated in the waveguide of the MRRs according to the schematic of

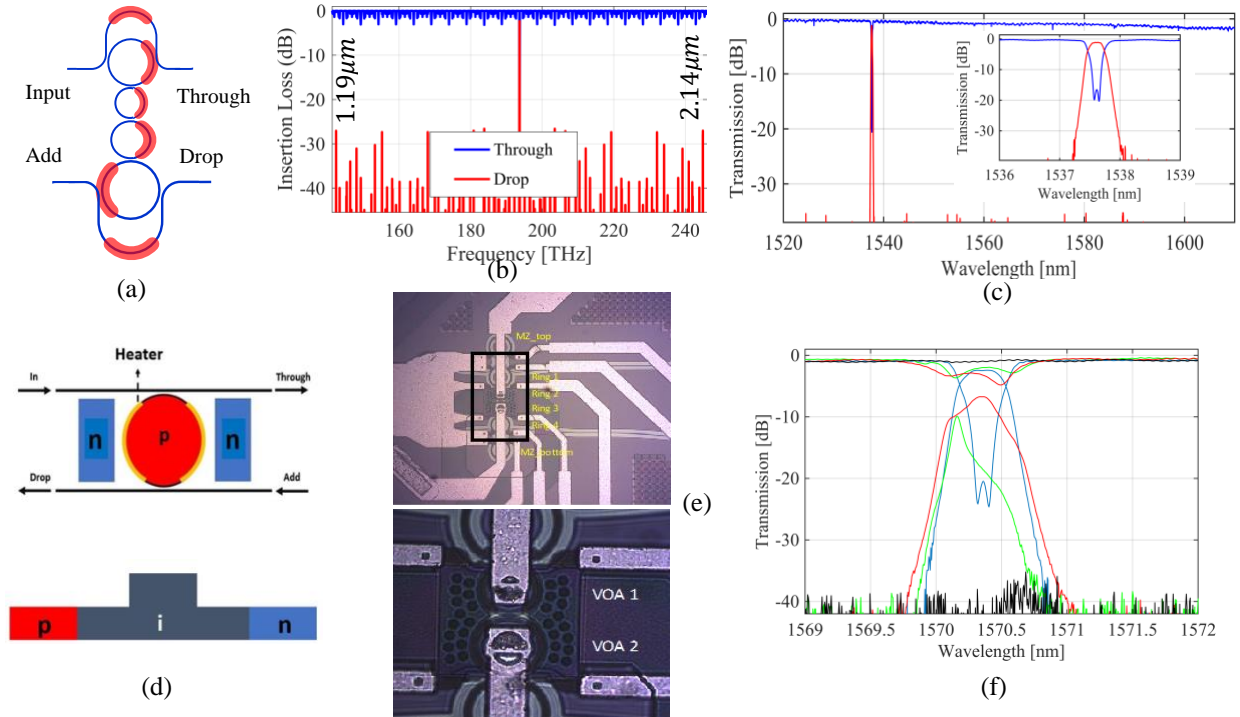


Figure 1: (a) Schematic of the proposed 4th order MRR Vernier filter. (b) Through (blue) and Drop (red) port simulation of the Vernier filter designed according to non-integer FSR ratios (no wavelength dependence of directional couplers) exhibiting FSR-free operation across more than 120 THz (1 mm wavelength range). (c) Frequency response of the silicon filter with passband tuned around 1537.7 nm and FSR-free behavior across a 90 nm wide wavelength range (limited by experimental instrumentation). In the inset, zoomed view over a 3 nm range around the passband. (d) Up: scheme of a single MRR with integrated p-i-n junction, acting as VOA, and a thermal actuator. Down: cross section of the silicon rib waveguide with integrated p-i-n junction. (e) Up: microscopic picture of the silicon photonic filter. Down: zoomed picture showing the VOAs integrated in the 2nd and 3rd MRRs of the filter. (f) Measured frequency response of the filter in Through and Drop port during the hitless operation at 1570.4 nm for different VOAs driving voltages: connected state (0 V, blue), complete disconnected state (1.3 V, black), intermediate states (0.9 V, red; 1 V, green)

Fig.1(d). The VOA is 30  $\mu\text{m}$  long (covering about 60% of the MRR circumference) and can introduce up to 1.4 dB additional round trip loss. Given the loss dynamic of the integrated VOA, numerical results indicate that integrating a VOA in the 2<sup>nd</sup> and 3<sup>rd</sup> MRR of the filter enable complete disconnection (>30 dB isolation) from the bus waveguide.

Figure 1(e) shows a microscopic picture of the fabricated 4-th order filter together with zoomed picture of the VOAs integrated in the two inner MRRs. Figure 1(f) shows the hitless operation of the filter, which is initially tuned at 1570 nm (blue curves) and is progressively disconnected from this channel without introducing perturbation to other channels. Curves in green (1V on VOAs) and red (0.9V) show two intermediate states leading to complete disconnection (black curves, 1.3V). Since VOA operation is accompanied by MRR frequency shift due to plasma-dispersion [7] and thermal effects, the integrated heater is used to counteract unwanted resonance drifts during the filter switching process. More than 30 dB of Drop port disconnection is recorded within the 50 GHz band of each channel and remarkably no notch is observed at Through port. This technique realizes the disconnection process of the filter in nano-second time scale thanks to the high mobility of carriers in p-i-n junction thus fast time response of the VOA, improving three orders of magnitude the performance comparing to state of the art using thermal shifters.

## References

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