# Thermally-controlled transparency in multi-ring cascaded filters

*Lorenzo Tunesi, Andrea Carena, Vittorio Curri, Paolo Bardella*
*Department of Electronics and Telecommunications, Politecnico di Torino*

## Introduction

MicroRing Resonators (MRR) are **fundamental building blocks** for implementing filtering and switching **Photonic Integrated Circuits (PICs).** They represent an extremely versatile component in optical communications switching, signal processing, photonic computing and neuromorphic applications. Depending on the target application and required response the single ring element can be cascaded to create more **complex devices** (Fig.1), which allows **tailoring of the spectral output**. such as central frequency, 3dB bandwidth, Free-Spectral Range (FSR) and losses.

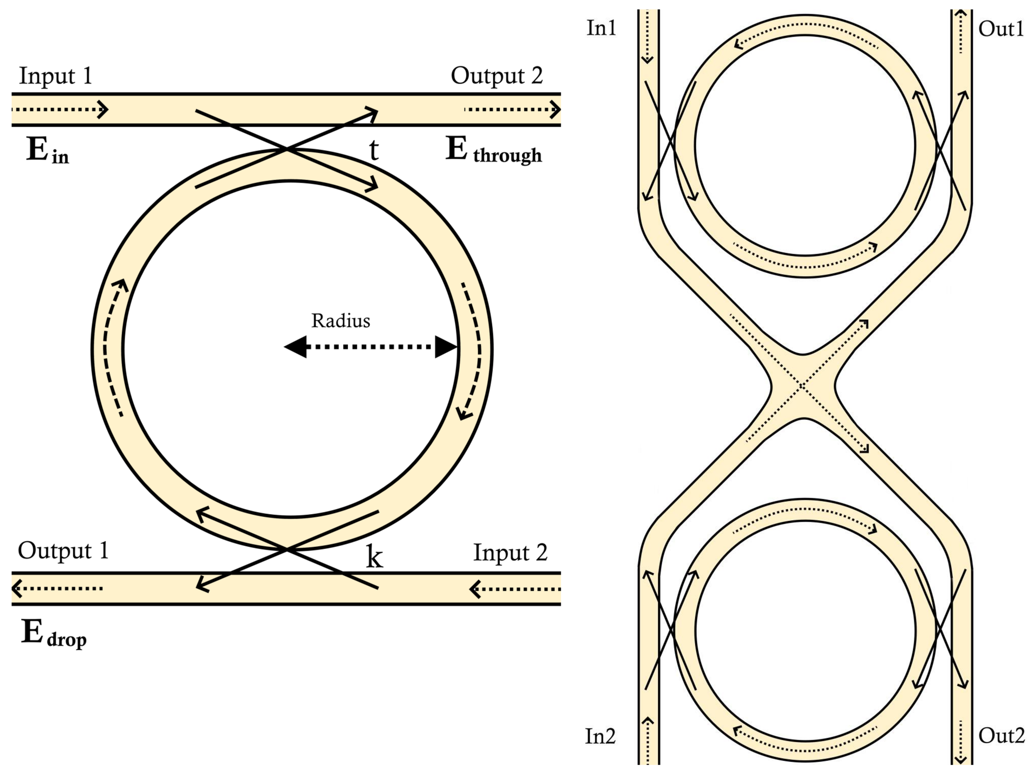


**Figure 1: a) Single Ring Configuration b) second-order cascaded filter**

Despite their numerous advantageous properties, MRR structures also present drawbacks due to their intrinsic **principle of operation, manufacturing limitations, and calibration process**. Their design [1] and control scheme [2] must account for the high uncertainty sensitivity, and **many methods have been proposed** to tune and calibrate the manufactured devices [3], with **thermal-based methods** being the most common.

These control methods, however, have not been applied to enhance the functionality of the MRR devices as **switching structures**: the typical goal is the **alignment of the resonant peaks** and the compensation of the relative rings index variation. We propose an **asymmetric control scheme** in cascaded multi-ring structures creating a flat-band transparent state, which can be used to turn-off the rings resonance and toggle off the device, leveraging the **destructive interference** typically unused in such devices.

## Cascaded MRR structures

We consider as the reference structure a **two-stage ladder MRR device** (Fig. 2), with two second-order MRR stages coupled through a π-phase shift section. These structures allow the synthesis of many different filtering responses [4], and are characterized by a flat-top transmission band

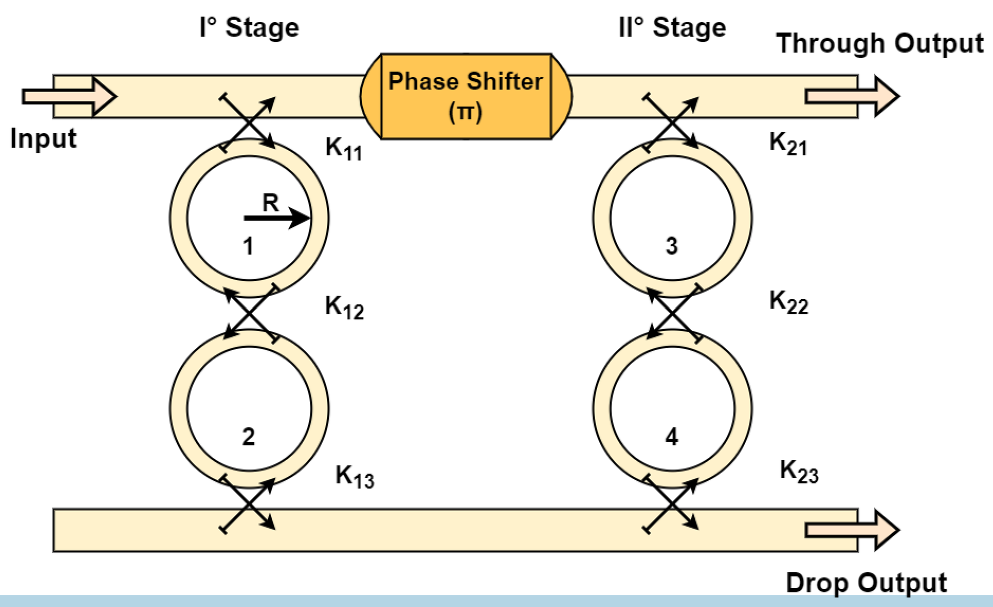


**Figure 2: Two-stage Ladder MRR device. In our analysis the coupling coefficients have been set to k11=k13=0.8 k12=0.1 k21=k23=0.3 k22=0.2. The ring radius is assumed equal by design in all four MRRs.**

These structures offers a prime example for the proposed control method, as they must have **four heating pads** for the rings, as to allow **independent tuning of each MRR**.

With traditional thermal compensation on all rings (#1 through #4) the device can be tuned as depicted in Fig.3a, introducing a **shift in the resonant peak** and changing the main channel and periodic images. By instead introducing an asymmetric control, tuning the opposite ring in each pair (#1-#4 or #2-#3), we can obtain the destructive interference depicted in Fig3.b

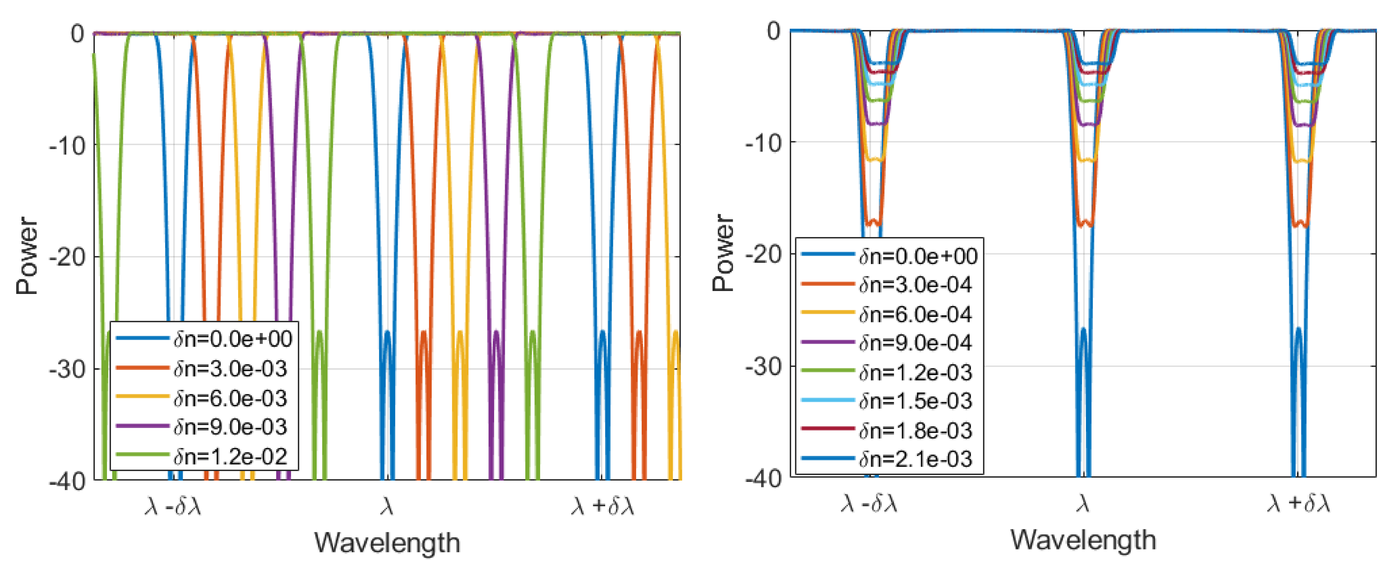


**Figure 3: Spectral response for (a) uniform applied thermal bias and (b) asymmetric rings shifts**

This effect, properly calibrated, adds a third state to the traditional MRR device tuning, introducing a **transparency state** where the structure acts a **lossy flat-band element.**

## Results

The structure has been simulated in MATLAB using closed-form analytical models, as well as through Synopsys Optsim Design Suite. The thermal control has been modeled as **an effective index shift** considering traditional **Silicon Photonics** material properties ($\delta n/\delta T = 1.3\times10^{-4}\ K^{-1}$)

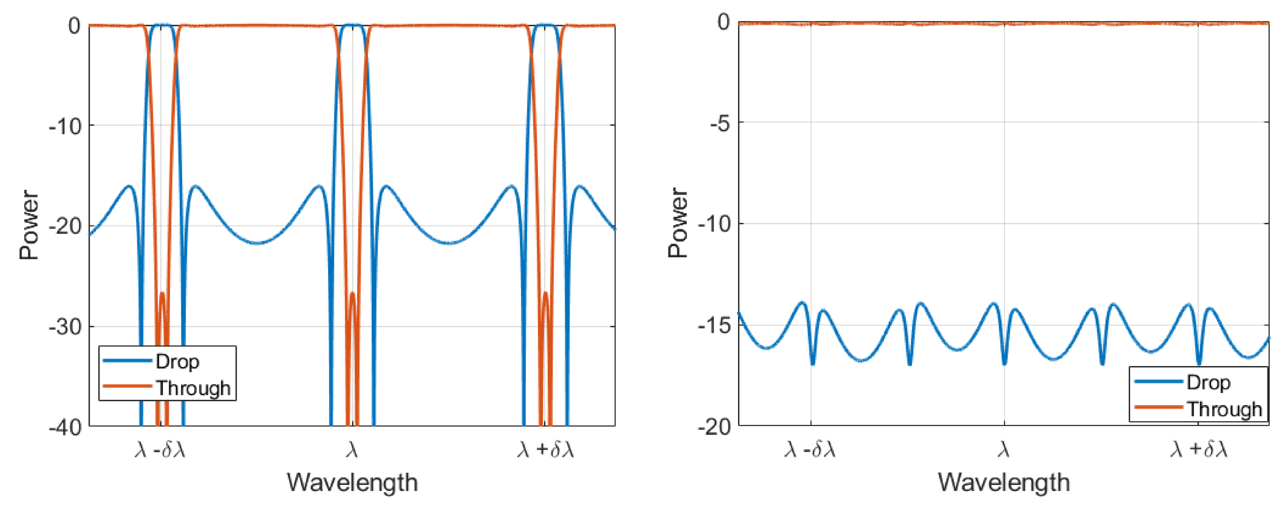


**Figure 4: (a) normal response for a calibrated device (b) transparent response under asymmetric tuning**

We demonstrate that the transparency state can be induced for index shifts comparable to **traditional thermal tuning range**, allowing a **on-off toggle behavior** on top of the traditional thermal control scheme.

## CONCLUSIONS

We showcase an application of asymmetric index control in cascaded multi-stage MRR structures, leveraging destructive interference to implement a new state with respect to traditional channel tuning .

This phenomena can be extended to arbitrary-size MRR ladder structures, allowing a bar-switching state without requiring any additional heating and control structures other then the default calibration pads.

## REFERENCES

1. A. Shafiee, et al, "Inexact Silicon Photonics: From Devices to Applications," in Photonics in Switching and Computing 2021 (Optica Publishing Group, 2021).
2. L. Tunesi, et al., "Machine Learning Aided Prediction of Fabrication Uncertainties in Integrated Multi-Ring Filters," in CLEO 2023, Technical Digest Series (Optica Publishing Group, 2023), paper STh4H.2.
3. H. Jayatilleka et al., "Wavelength tuning and stabilization of microring-based filters using silicon in-resonator photoconductive heaters," Opt. Express 23, 25084–25097 (2015).
4. A. P. Masilamani et al., "Design and realization of a two-stage microring ladder filter in silicon-on-insulator," Opt. Express 20, 24708–24713 (2012)