



Ring-assisted modal conversion for on-chip mode-division multiplexing signal processing

Alberto Parini, Yann Boucher

► To cite this version:

Alberto Parini, Yann Boucher. Ring-assisted modal conversion for on-chip mode-division multiplexing signal processing. Design, Automation & Test in Europe conference (DATE 2017) - 3rd International Workshop on Optical/Photonic Interconnects for Computing Systems (OPTICS Workshop), Mar 2017, Lausanne, Switzerland. hal-01503078

HAL Id: hal-01503078

<https://hal.science/hal-01503078v1>

Submitted on 6 Apr 2017

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

Ring-assisted modal conversion for on-chip mode-division multiplexing signal processing

Alberto Parini

FOTON Systèmes Photoniques, CNRS UMR 6082,
University of Rennes 1, ENSSAT, F-22305 Lannion, France
alberto.parini@univ-rennes1.fr

Yann G. Boucher

FOTON Systèmes Photoniques, CNRS UMR 6082,
University of Rennes 1, ENSSAT, F-22305 Lannion, France

Abstract— We present a system composed of a two-mode waveguide coupled to a single-mode racetrack resonator. In this configuration, each resonance can be exploited to achieve a complete even-to-odd (odd-to-even) mode power conversion, thus allowing transparent channel switching in mode-multiplexed (MDM) networks. The spectral response of the system is evaluated by extending the single-mode scattering parameters formalism to the multi-mode propagation domain.

Keywords— *Optical networks on-chip; mode division multiplexing; microring resonators; photonic integrated circuits; silicon photonics; scattering parameters.*

I. INTRODUCTION

As energy issues are increasingly affecting the scalability of high-performance multi-core microprocessor architectures, the implementation of optical links (Optical Network-on-Chip ONoC) between computational cores is foreseen as a possible way to increase data throughput while, at the same time, reduce the overall microprocessor power consumption [1].

The majority of the ONoCs solutions proposed so far in literature rely for their operation on wavelength-division multiplexing (WDM) techniques, hence exploiting the wavelength as a degree of freedom for channel allocation. Nevertheless, the effective use of WDM for on-chip signal networking is clearly subordinate to the availability of silicon-compatible laser sources, eventually multi-wavelength. Although some recent results confirmed the technological feasibility of silicon photonic transceivers including III-V bonded laser sources [2], the integration of active cavities on silicon remains a challenging task, with the existing technological solutions providing contrasting performance in terms of available optical power and electric-to-optical power conversion efficiency.

To reduce the number of laser sources required on the chip, or to optimize the use of the available ones, a possible solution relies on the exploitation of a further dimension inherent to optical communications, namely the modal order [3]. In mode-division multiplexing (MDM) systems, communication channels are allocated, on the same wavelength, to the various propagation modes of a multi-mode waveguide. Therefore, MDM techniques make available an additional degree of freedom (the transverse modal spatial distribution) for the design of on-chip integrated optical systems [4,5].

The deployment of a complete MDM-based on-chip interconnection network clearly requires the design of a full

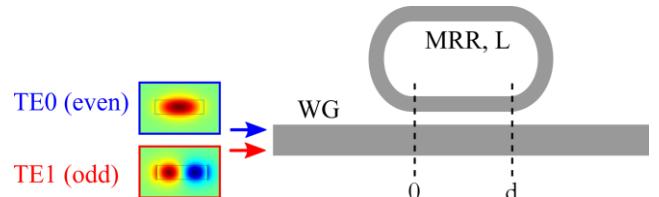


Figure 1: The system under investigation consists of a two-mode (TE_0, TE_1) waveguide (WG) coupled along a distance d to a single-mode racetrack resonator (MRR) of total perimeter L .

set of new functional building-blocks (routers, add-drops, mode converters) able to selectively process optical signals with respect to the modal order. In this work, we address in particular the issue of transparent mode-conversion, and we explore the operation of a configuration consisting of a two-mode waveguide laterally coupled to a single-mode resonator. The presence of the resonator breaks the translational invariance of the field propagation in the two-mode waveguide, thus enabling a cross-power exchange between the *even* and *odd* modes of the waveguide, which would be otherwise remain orthogonal.

II. SYSTEM LAYOUT AND MODAL TRANSFER FUNCTION

The layout of the investigated configuration is presented in Fig. 1. A two-mode waveguide (WG) is coupled by means of directional coupler of length d to the single-mode racetrack resonator (MRR) of total perimeter L . The waveguide WG is designed to guide the fundamental TE mode with a transversal *even* symmetry (TE_0) and a first order TE mode with a transversal *odd* symmetry (TE_1), the two modes being characterized by their respective propagation constants β_{TE_0} and β_{TE_1} , with $\beta_{TE_0} > \beta_{TE_1}$. The (single) mode circulating in the microring MRR has propagation constant β and its losses are modeled by the parameter γ .

By taking advantage of a formal analogy holding between a two-mode waveguide and a system of two single-mode coupled waveguides [6], the coupling zone highlighted by the dashed rectangle in Fig 2(Top), is replaced by a ternary coupler between three single-mode waveguides, as sketched in Fig. 2(Bottom). This substitution brings back the initial hybrid single/multi-mode propagation problem to an homogeneous single-mode one. Within this new layout, WG1 is the single-mode waveguide belonging to the microring, while WG2 and WG3 are the two single-mode waveguides

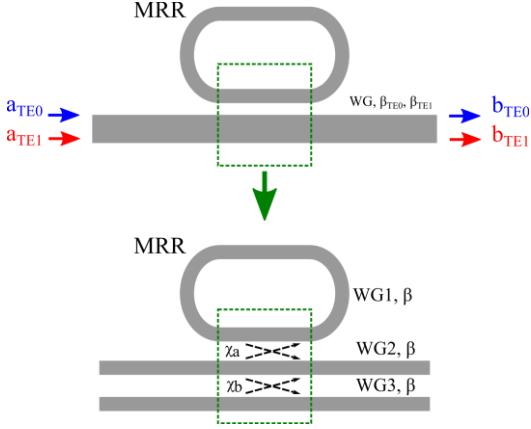


Figure 2: (Top) After substitution of the two-mode waveguide WG with an equivalent coupler between two single-mode ones (Bottom), the interaction zone highlighted by the green-dotted rectangle can be modeled as a ternary directional coupler between three single-mode waveguides (WG1, WG2 and WG3).

which result from the decomposition of the original two-mode section. The governing parameters of the transformed system are the propagation constant β , which is common to all the waveguides, and the two coupling constants (χ_a , χ_b) accounting for the power exchange between WG1 and WG2 and WG2 and WG3, respectively.

After a straightforward application of the (single-mode) scattering parameter approach, the transfer matrix relating the mode amplitudes on the input (a_{TE0}, a_{TE1}) and output (b_{TE0}, b_{TE1}) ports of the system finally reads as:

$$\begin{pmatrix} b_{TE0} \\ b_{TE1} \end{pmatrix} = [J] \cdot \begin{pmatrix} a_{TE0} \\ a_{TE1} \end{pmatrix} = \begin{pmatrix} J_{11}(\beta, \chi_a, \chi_b, \gamma) & J_{12}(\beta, \chi_a, \chi_b, \gamma) \\ J_{21}(\beta, \chi_a, \chi_b, \gamma) & J_{22}(\beta, \chi_a, \chi_b, \gamma) \end{pmatrix} \cdot \begin{pmatrix} a_{TE0} \\ a_{TE1} \end{pmatrix}.$$

For the explicit form of the elements of $[J]$ we refer the reader to Ref. [7].

All the elements of the matrix $[J]$ present an explicit dependence on the spectral parameter β , hence the degree of mode mixing introduced by the system heavily depends on the working wavelength. In the case of a transparent medium ($\gamma = 0$), and for an operating wavelength corresponding to one of the microring resonances ($\beta L = m\pi$ with m integer), the diagonal terms of $[J]$ vanish. The matrix assumes an anti-diagonal symmetry which enables a complete TE0 to TE1 (respectively, TE1 to TE0) mode switching. More explicitly, a TE0 mode on the input port is converted to a TE1 one as it transit through the system and vice versa. On the anti-resonance wavelengths ($\beta L = (2m + 1)\pi$) the vanishing terms in $[J]$ are the diagonal ones and any incident modal state is transferred to the output port unaffected.

In Fig. 3 we report the evolutions of the b_{TE0} and b_{TE1} output mode amplitudes for the case of a purely TE0 excitation on the input port ($a_{TE0} = 1; a_{TE1} = 0$), calculated via the Eq. (1) as a function of the (normalized) spectral parameter βL . As expected, on the microring resonance the TE0 mode power on the input port is completely transferred to

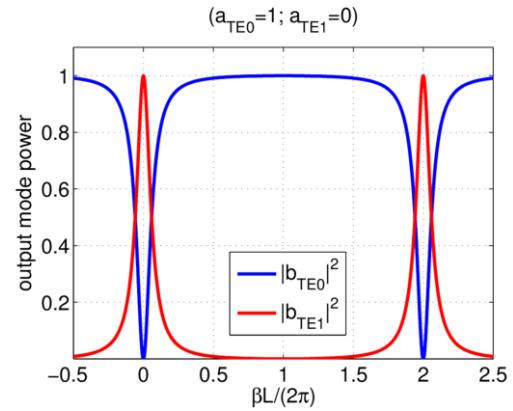


Figure 3: Evolution against the spectral parameter β of the TE0 (b_{TE0} - blue solid line) and TE1 (b_{TE1} red solid line) mode amplitudes on the output port of the system when on the input port is injected a purely TE0 mode ($a_{TE0}=1$, $a_{TE1}=0$). On each microring resonance the TE0 mode is completely converted to the TE1 one.

the TE1 mode on the output port ($b_{TE1} = 1$), while on the anti-resonances no conversion takes place. Moreover, between the resonance peaks anti-resonance conditions, an intermediate degree of mode mixing is achievable.

III. CONCLUSIONS

We presented a configuration consisting of a two-mode waveguide coupled to a single-mode microring resonator. The presence of the microring breaks the symmetry of the system thus enabling cross-mode conversion when operating on one of the resonances. Thanks to its mode-processing capabilities, this configuration is suitable to find application as a functional building-block in MDM photonic integrated circuits.

ACKNOWLEDGMENT

This work is supported by the Labex CominLabs (French National Research Agency program “Investing for the Future” ANR-10-LABX-07-01) within the framework of the “3D-Optical-ManyCores” project.

<http://www.3d-opt-many-cores.cominlabs.ueb.eu/>

REFERENCES

- [1] Bergman, K., Carloni, L.P., Biberman, A., Chan, J., Hendry, G.: Photonic Network-on-Chip Design. Springer-Verlag New York (2014).
- [2] Zhang, C., Zhang, S., Peters, J.D., Bowers, J.E.: 8x8x40 gbps fully integrated silicon photonic network on chip. Optica 3 (7), 785–786 (2016).
- [3] Y. Ding, J. Xu, F. Da Ros, B. Huang, H. Ou, and C. Peucheret, “On-chip two-mode division multiplexing using tapered directional coupler based mode multiplexer and demultiplexer,” Opt. Express vol. 21, no. 8, pp. 10376-10382, (2013).
- [4] L.-W. Luo, N. Ophir, C. P. Chen, L. H. Gabrielli, C. B. Poitras, K. Bergman, and M. Lipson, “WDM-compatible mode-division multiplexing on a silicon chip,” Nature Commun., vol. 5, 3069, (2014).
- [5] J. Wang, Sailing He, and Daoxin Dai, “On-chip silicon 8-channel hybrid (de)multiplexer enabling simultaneous mode- and polarization-division-multiplexing,” Laser & Photonics Reviews. 8(2): L18–L22 (2014).
- [6] Boucher, Y.G.: Analytical model for the coupling constant of a directional coupler in terms of slab waveguides. Optical Engineering 53(7), 071,810 (2014).
- [7] Boucher Y.G., Parini A., and Féron, P., “Resonant modal conversion in a two-mode waveguide”, Opt. Quant. Electron. (2017) 49: 42.