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Design and modeling of flower like microring resonator

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ABSTRACT

This paper presents a novel multi-channel optical filter structure. The proposed design is based on using a set of microring resonators (MRRs) in new formation, named flower like arrangement. It is shown that instead of using 18 MRRs, by using only 5 MRRs in recommended formation, same filtering operation can be achieved. It is shown that with this structure, six filters and four integrated demultiplexers (DEMUXs) are obtained. The simplicity, extensibility and compactness of this structure make it usable in wavelength division multiplexing (WDM) networks. Filter's characteristics such as shape factor (SF), free spectral range (FSR) and stopband rejection ratio can be designed by adjusting microrings' radii and coupling coefficients. To model this structure, signal flow graph method (SFG) based on Mason's rule is used. The modeling method is discussed in depth. Furthermore, the accuracy and applicability of this method are verified through examples and comparison with other modeling schemes.

1. Introduction

Optical filtering devices are key elements in wavelength division multiplexing (WDM) and optical time division multiplexing (OTDM) networks [1–5]. These networks' compatible filters should satisfy the following conditions: comparability of passband bandwidth with signal's spectrum, flatter top frequency response, fast transition between passband and stopband and large stopband rejection [6]. Moreover such networks need filters with various free spectral ranges (FSRs) and precise channel selectivity. Microring resonators (MRRs) are good candidates for such devices. High quality factor and integration capability of MRRs make them a promising candidate to be used as an add/drop filter [7–9]. These kinds of filters can be designed by using a single MRR or series of different coupled MRRs. The drawback of using a single MRR is its Lorentzian like response. This leads to significant cross talk between channels [6]. Moreover it has no box like shape response. These kinds of structures also cannot practically cover all the C-band span [10]. To improve these filters' characteristics instead of using single MRR, combination of multiple different MRRs are used [5]. These structures have unique characteristics such as acceptable stopband rejection ratio, box like/flatter top frequency response shape and flexible wide FSR that can cover C-band span.

In this paper, a four petal flower like filter is designed and analyzed. Each petal consists of a MRR with desired radius and its corresponding waveguide bus. Our proposed structure is shown in Fig. 1. There are four input/drop ports and 5 MRRs with different radii in our design. It will be shown that with this structure 6 filters with FSRs of 213, 240, 350, 400, 455 and 560 GHz are obtained. To achieve same filtering operation in conventional way [11], one should utilize six serially coupled triple microring resonators (SCTMRs) in typical configuration, as shown in Fig. 2(a). As in the proposed structure instead of 18 MRRs, only 5 MRRs are used, in addition to miniaturization of filtering devices, the cost and complexity of optical networks are also reduced. MRR also can be configured so that they can be used as demultiplexer (DEMUX) [12,13]. Typical 1 × 6 DEMUX is shown in Fig. 2(b). The flower like structure also can be used as four integrated 1 × 3 passive DEMUXs. By selecting each input port, three optimum optical paths to 3 drop ports are formed. As a result, three output signals with different FSRs at each drop port are obtained. DEMUXs are fundamental components in WDM and OTDM networks. DEMUX characteristics, such as cost and complexity, are important parameters in progress of these devices [14]. Using the proposed structure, these obstacles can be overcome.

By some modifications in presented structure, number of filters and DEMUXs (and their corresponding output ports) can be increased. This can be done by adding more petals to the suggested structure. Furthermore by adding MRRs to each petal filtering characteristics of structure are improved.

Optical filter design can be discussed/done by solving electromagnetic equations in time or frequency domain. But for MRRs based filter structures using this scheme became nonintuitive and very hard to follow [15]. The scattering matrix method [16] and the transfer matrix method [17,18] are alternative analytical

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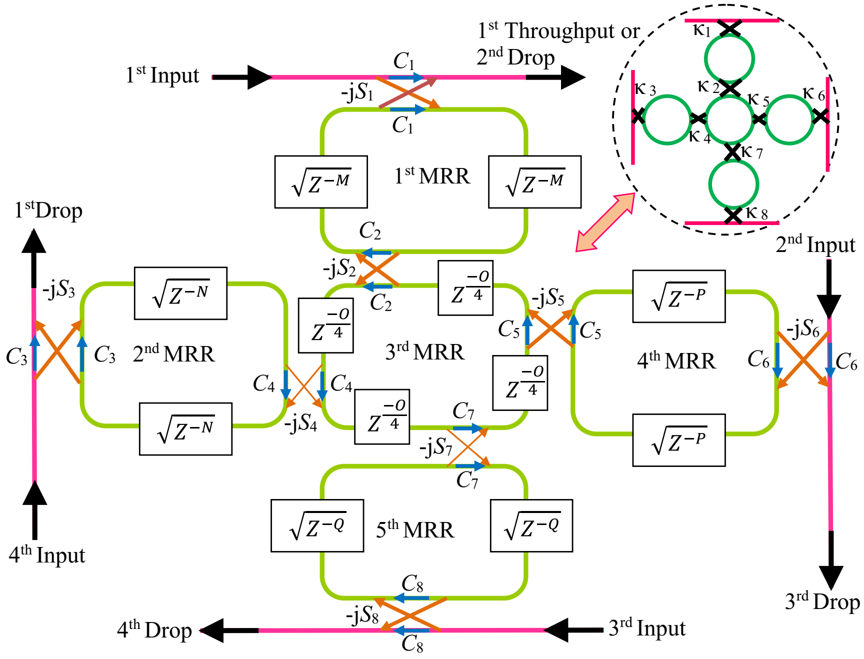

Fig. 1. Structure and SFG diagram of flower like MRR.

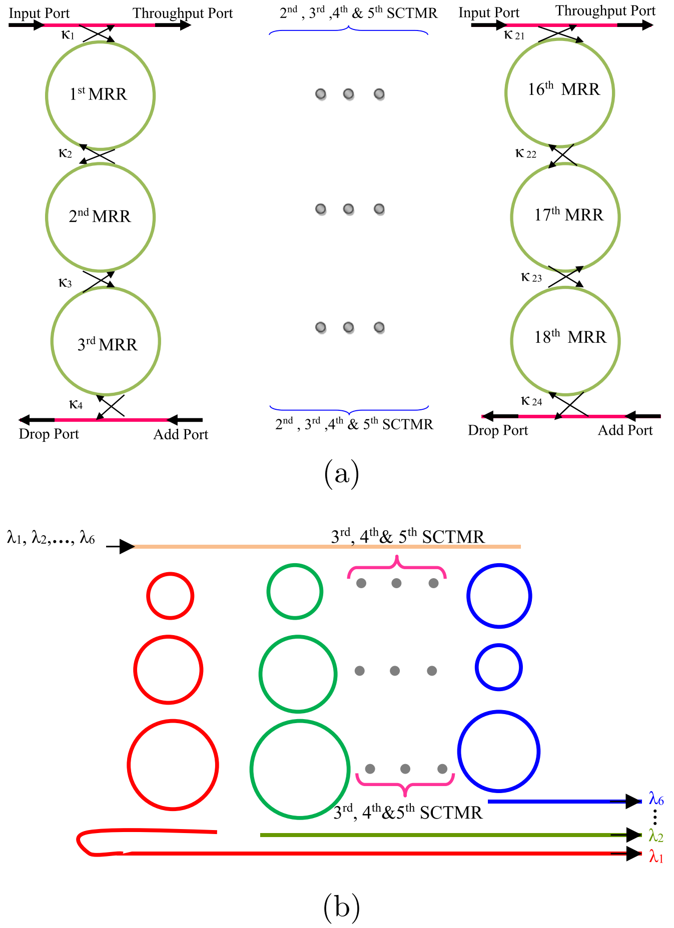

Fig. 2. (a) Six SCTMR filter and (b) 1 × 6 DEMUX structure. Compare the simplicity and compactness of structure shown in Fig. 1 with this structure.

methods that can be used to analyze such filters in Z-domain. Signal flow graph (SFG) method based on Mason's rule is another approach to study these structures. This method is easy to handle, fast, algorithmic in its nature and is very easy for computer implementation [19–21]. Furthermore transfer function of complex photonic circuits that can be determined by this method is very straight-froward in comparison to other methods such as transfer matrix method [19,22,23].

This paper is organized as follows. In Section 2, MRR modeling method is discussed. Then flower like structure is presented in Section 3. The simulation results of proposed structure are shown in Section 4, and finally, the conclusion is discussed in Section 5.

2. SFG method based on Mason's rule

One of the analytical methods for finding transfer function and analyzing complex optical structures is SFG method based on Mason's rule [24]. This method is based on selecting a forward path from the source node to the destination node. This forward path is not allowed to pass a node more than one time. Then a loop is defined by the path in which its source and destination nodes are the same. By multiplying every path gain on the loop, the loop gain is defined. Then the transfer function, H, from the source node to the destination node is described by:

$$H = \frac{\sum_{\nu=1}^{n} T_\nu \Delta_\nu}{\Delta} \tag{1}$$

$$\Delta = 1 - \sum_{i} G_i + \sum_{i,j} G_i G_j - \sum_{i,j,k} G_i G_j G_k + \sum_{i,j,k,l} G_i G_j G_k G_l - \sum_{i,j,k,l,u} G_i G_j G_k G_l G_u \tag{2}$$

where n is the MRR number, T_ν is path gain of the νth forward path between input and drop port, G_i is the loop gain of the ith loop, Δ is determinant of graph and Δ_ν is the cofactor value of Δ for the νth forward path, with the loops touching the νth forward path removed. It should be noted in each summation of (2), just products of loop gains of any pairwise nontouching loops are considered [25]. To determine the transfer function using Eq. (1), the