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Crossover Reducing Integrated Nested Rings Optical Switch

Nan Xie and Katsuyuki Utaka

Graduate School of Advanced Science and Engineering, Waseda University
3-4-1 Okubo, Shinjuku-ku, Tokyo 169-8555, Japan. Tel/Fax: +81-3-5286-3394
nan@akane.waseda.jp

Abstract

A novel integrated optical switch topology based on nested rings of MMI switching elements. Grid switch architectures can be realized with reduced number of switches and crossovers compared to the conventional Beneš system.

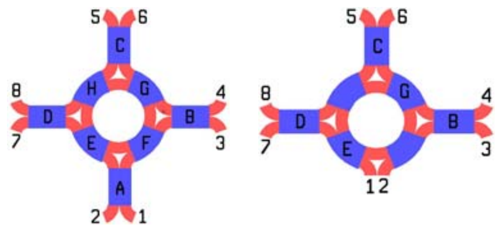
Introduction

Previously, we proposed a novel non-blocking Multimode Interference-based Ring Switch (MIRS) using a ring topology of 2x2 MMI elemental switches [1]. While conventional switch networks are formed by the side-by-side cascading topology, the MIRS is realized by placing rings around a central core. Regarding a scalable NxN switch network, the aim of this device is to reduce the number of elemental switches and crossovers, smaller physical device area, and omni-directional access. In recent years, 2x2 MMI-based switches have been developed by means of electro-optics such as the Multimode Interference Photonic Switch (MIPS) [2], and thermo-optics, which is inexpensive but of lower switching speed [3]. The nature of MMI allows for low loss, low crosstalk, scalability, and low cost. Its reversibility also asserts itself as an excellent candidate for bi-directional input switching in large grid networks either integrated or non-integrated.

Reduced MIRS Topology

We first digress from the conventional cascade network of elemental 2x2 switches and realize that a ring arrangement of four MMI switches, along with access MMI switches, gives rise to a 4x4 system. This becomes the core of the MIRS, illustrated in Fig. 1(a). The labels A-H indicate the respective elemental 2x2 MMI switches and numbers 1-4 and 5-8 indicate four input and output ports respectively. A closer view of the pattern leads to an extension of the Beneš switch with inter-row cross-switches that facilitate the feedback between individual input ports. Intuitively, the switching permutations of on/off elements A-H are flexible. Assuming the MMI 'off' state generates cross-images then straight-images are formed with the 'on' state. We can realize any combination of paths except for when port 1 connects to 2 and port 3 to 4 simultaneously. In total, there are 66 optimal feedback combinations.

If feedback is omitted, we can reduce the 4x4 MIRS, shown in Fig. 1(b), with 24 optimal path combinations out of a total of 64. The total number of required switching elements is five, which is one fewer compared to the conventional Beneš configuration.



(a) (b)

Fig. 1. (a) 4x4 MIRS in the ring topology and (b) the reduced version

For higher NxN systems, further rings are placed around the perimeter of the nested 4x4 core, shown in Fig. 2. In this design, ports are switched between the inner and outer rings. This topology includes the ring elements R_r, intermediate elements I_r, and the access elements A_r. Similar to the 4x4 case, the 8x8 MIRS is also reducible by removing the elements indicated.

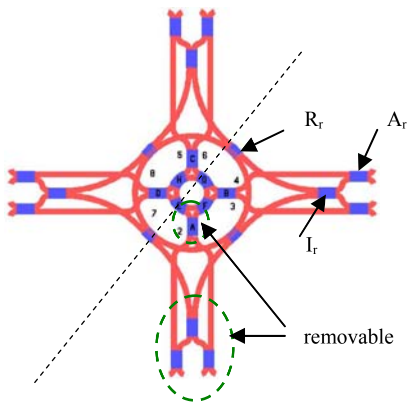


Fig. 2. 8x8 MIRS in the nested ring topology

The MIRS equation for the number of elemental switches required for an NxN network is represented by m.

$$m(N) = \frac{7N}{8} + m\left(\frac{N}{2}\right) + 3m\left(\frac{N}{4}\right) \quad \text{(N=16, 32, 64…)}$$

This switch network configuration can reduce m up to 20% when N=8 and 11% at N=64 with respect to the Beneš topology. If access ports are restricted only in the horizontal directions, we can realize equivalent Beneš setups. This, however, eliminates the omni-directional nature of the MIRS.

MMI Behaviors

MMI simulations using the Eigenmode Expansion Method (EEM) showed low loss and low crosstalk using bi-directional inputs. For the MMI switching operation, the MIPS method is utilized. Fig. 3 shows the behavior of an index-modulated MMI switch. The 'off' state output is at the lower output region while the 'on' state causes the interfered fields to relocate towards the upper output region. Considering polymer materials, as an example, an MMI switch with a length of 200μm and a Δn of 0.03 produces a crosstalk less than -30dB. For curved MMI structures, a comparison between cross-port power loss of polymer and silicon MMI couplers as well as plain waveguides is illustrated in Fig. 4. Since higher refractive index difference between the core and the cladding is desired for waveguide bending, the same is true for MMI couplers. In this case, for a bending MMI device power loss of 0.1dB, the radius of curvature for silicon is 500μm, 5-8 times less than typical polymers. Typically, polymer waveguide widths are usually larger compared to semiconductor waveguides.

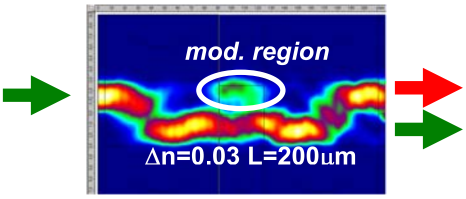


Fig. 3. MIPS-based MMI switch

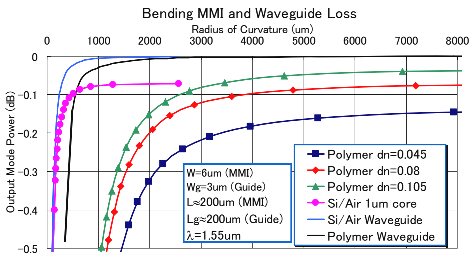


Fig. 4. Bending MMI and waveguide loss

Grid Architecture

In the simplest case of multi-directional access, 8x8 MIRS can be arranged in a grid-like fashion shown in Fig. 5. In this case, node-to-node distance is around the length of five MMI elements plus the diameter of curvature of the MIRS outer ring. Suppose the MMI lengths are 100μm with a 0.1dB device loss diameter of 500μm, then the node-to-node distance is around 2mm. The area of a grid network of 40 ports, shown in Fig. 5, is less than 1cm^2.

Crossover Reduction

In an integrated optical switch system, crossovers are difficult to be realized. One possibility of realizing integrated waveguide crossovers is by using the three-dimensional MMI method [4] with polymers. This method also enables the implementation of multilayer optical devices to increase device density. A comparison between of the number of crossovers in the MIRS and the Beneš systems is illustrated in Fig. 6. The benefit of the MIRS and the MMI coupler is visible with 34% reductions in the number of crossovers compared to the Beneš system when N=16.

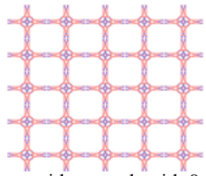


Fig. 5. 40 port grid network with 8x8 MIRS

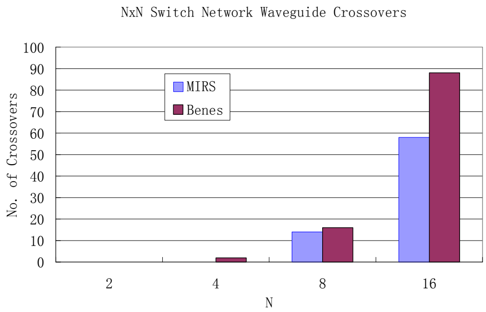


Fig. 6. NxN MIRS waveguide crossovers

Conclusion

We report a new switching network topology to reduce the number of elemental switches compared to the conventional Beneš setup. The MMI devices are included in the MIRS due to their promising dual input isolation, low loss capabilities, switching operation, and curving options. The MIRS benefit for the reduction of waveguide crossovers is evident as well as the ability to maximize device real estate in a grid-like network topology.

References

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