On (*N*+1)-Stage Planar Photonic Switches

[1]Fakher Eldin M. Suliman, [2]Kamaruzzaman Seman, Senior Member IEEE, and [3]Abu Bakar Mohammad

Faculty of Electrical Engineering
Universiti Teknologi Malaysia
81310 Skudai, Johor Bahru, Malaysia

Emails: [1]fakhry65@hotmail.com
[2]kzaman@suria.fke.utm.my
[3]bakar@suria.fke.utm.my

Abstract- ***N*-stage planar architectures are attractive for photonic switches made of directional couplers because they have no crossovers. However, compared to crossbar switches, they have fewer number of crosspoints and therefore are rearrangeably nonblocking. To have a small number of crosspoints and at the same time improve the blocking probability, the (*N*+1)-stage planar switch is proposed in this paper. The development of this switch from the former one will be explained. The tow switches will be compared to address their performance, advantages, and limitations.**

Subject Terms- **Photonic switching, planar architecture, rearrangeably nonblocking.**

I. INTRODUCTION

Photonic switching architectures based on 2 x 2 optical SEs are attractive since they can be constructed from directional couplers. The directional coupler switch is a device with tow inputs and tow outputs, both of which are optical signals [1]. The state of the device is controlled electrically.

Although other materials can be used as a substrate, Lithium niobate is the most mature technology for optical switch fabrication. A feature of these switches is they can route optical information regardless of its bitrate or coding format [1]. This hybrid device will be the switch element of our optical switching system model in this paper.

There are several criteria for a good switching architecture from system considerations [2]. First, for a given switch size, *N*, the number of crosspoints should be as small as possible. When the number is large, implementation is expensive and the optical path is subject to large power loss and crosstalk. Second, optical paths should go through equal number of crosspoints to reduce the power variation at the switch output and to avoid the near-far problem. Third, when designed to reduce the crosspoint number in total and in each path, a switch can have a large internal blocking probability. In some switches, the internal blocking probability can be completely reduced to zero by using a good switching control or rearranging the current switching configuration. These cases are called wide-sense nonblocking and rearrangeably nonblocking, respectively [3]. If a blocking condition never arises in a switch it is said to be strictly nonblocking. Many switching architectures have been designed to minimize the number of crosspoints. Clos, Benes, planar, and Banyan are some examples [4].

The paper is organized as follows; section II provides an overview of *N*-stage planar switches and explains their importance in the design of directional coupler-based photonic switching systems. In section III, the development of the (*N*+1)-stage planar switch will be presented. The performance of the developed switch compared to the *N*-stage switch is discussed in section IV. Section V concludes the discussion.

II. *N*-STAGE PLANAR SWITCHES

An *N*-stage planar architecture of size 4 is illustrated in Figure 1. Because it has no crossovers, it is attractive to photonic switches made of directional couplers. The crossover between two paths in a directional-coupler-based photonic switching system is implemented as a cross-through between two waveguides [5] in [6]. A cross-through between tow waveguides is costly, can cause crosstalk and signal loss, and increase the manufacturing complexity.

The *N*-stage planar switch has a number of crosspoints less than half of that in a single crossbar and a maximum number of crospoints in a connection path better than that of a double crossbar. Because of the fewer number of crosspoints, one primary disadvantage of the *N*-stage planar switch is it is rearrangeably nonblocking [7] in [1].

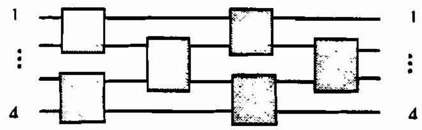

Figure 1 An N-stage planar switch of size 4.

The N-stage planar switch has $N/2$ odd stages and $N/2$ even stages (see Fig. 1). The odd stages are of $N/2$ switching elements (SEs) each, while the even stages are of $N/2 - 1$ SEs each. In general an N x N network requires N stages, where N may be even or odd. The total number of SEs is:

$$N/2(N/2 + N/2 - 1) = N/2(N - 1) \quad (1)$$

The minimum possible size of a planar switch is the single 2 x 2 SE itself. The maximum number of SEs (crosspoints) in a connection path is obtained when the optical signal crosses a SE in every stage of the switching system, that is, when it crosses N SEs.

The N-stage planar switch can also be designed by reversing Figure 1. In this case (Figure 2) the switch will have $N/2$ odd stages of $N/2 - 1$ SEs and $N/2$ even stages of $N/2$ SEs. The total number of SEs, of course, is still as given in (1).

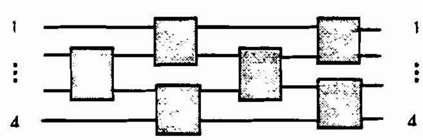

Figure 2 An N-stage planar switch of size 4 (A mirror view of Fig. 1).

From a design point of view, the two systems are similar but to choose between them we need to study the performance of each. To do that and for simplicity we selected a small 4 x 4 planar switch in this paper.

III. (N+1)-STAGE PLANAR SWITCHES

To have a smaller number of crosspoints and at the same time to improve the blocking probability, the (N+1)-stage planar switch is developed. A 4 x 4 switch of this type is shown in Figure 3.

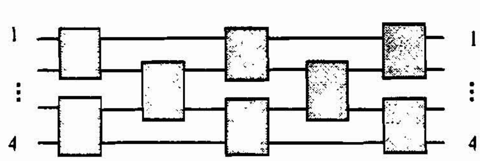

Figure 3 An (N+1)-stage planar switch of size 4.

The idea is simple; based on Figure 1; to convert an N-stage planar switch to a (N+1)-stage switch we add one stage of switches at its most right. Although the same idea can also be applied on the system of Figure 2, we did not chose it for the same reasons as concluded in section II.

This design has $N/2+1$ odd stages each of $N/2$ switches and $N/2$ even stages each of $N/2$-1 switches. Hence, the number of stages is:

$$(N/2 + 1) + N/2 = N + 1 \quad (2)$$

The total number of SEs is given by:

$$N/2\,(N/2 + 1) + (N/2 - 1)\,N/2 = N^2/2 \quad (3)$$

An N x N network requires N+1 stages, where N may also be even or odd. However if N is odd the system will have N+1 stages of $\lfloor N/2 \rfloor$ switches each and the total number of SEs will be given by $\lfloor N^2/2 \rfloor$. Figure 4 shows a planar switch of size 3.

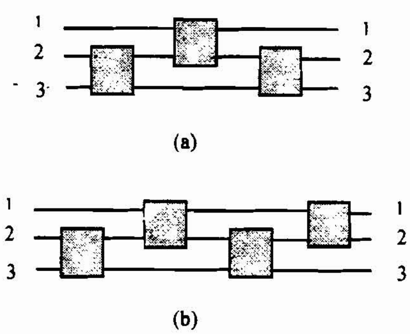

Figure 4 A planar switch of size 3: (a) the N-stage design and (b) the (N+1)-stage design.

IV. PERFORMANCE COMPARISON

In Table 1, the possible number of routes from any input to any output of Figure 1 is given. The technique used to calculate these possible numbers of routes is based on the channel graphs of the given switching systems.

It can be noticed that every input node can be connected through 9 different routes to the outputs. Corner-to-corner node connections (input nodes 1 and 2 to output node 4 or input nodes 3 and 4 to output node 1) can be setup through only one route.

Table 1 Possible numbers of routes for Fig 1.

Outputs / Inputs	1	2	3	4
1	2	3	3	1
2	2	3	3	1
3	1	3	3	2
4	1	3	3	2

On the other hand, using Figure 2 provides the possible number of routes shown in Table 2. Here the number of routes increased only for the center input nodes 2 and 3 while the corner-to-corner connections (in this case input node 1 to output nodes 3 and 4 or input node 4 to output nodes 1 and 2) experienced more reduction.

Table 2 Possible numbers of routes for Figure 2.

Outputs / Inputs	1	2	3	4
1	2	2	1	1
2	3	3	3	3
3	3	3	3	3
4	1	1	2	2

Now, the question is still there; which system is better? On top of its better routing chances and considering the control of the system – given that it is rearrangeable – the first design (Figure 1) can be chosen since all its input nodes have the same number of total possible routes, that is 9. In other wards it simplify the control complexity.

Adding a stage to a network means more possible routes for setting up a connection path. The numbers of possible routes for each of the input – output pairs for Figure 3 are tabulated in Table 3.

Table 3 Possible numbers of routes for Figure 3.

Outputs / Inputs	1	2	3	4
1	5	5	4	4
2	5	5	4	4
3	4	4	5	5
4	4	4	5	5

By comparing Tables 1 and 3, it can be noticed that more chances for connecting input-output pairs are now available. These chances have been improved four times in the cases of corner-to-corner connections and five times in the other cases of connections. For large values of N the improvement increases sharply.

However if N is odd, it was found that there is still a considerable amount of improvement but less than that found for if it is even. This is clear from Table 4 and 5 where the numbers of possible routes for Figure 4*a* and *b* are given respectively.

The maximum number of SEs that can be crossed by an optical signal for the (N+1)-stage design is N+1, which is only one, switch more compared to the N-stage design. The number of maximum SEs along a connection path directly represents the attenuation degree (considering the attenuation caused by the interference between the fibers and the waveguides within the directional couplers) that the signal will experience.

Table 4 Possible numbers of routes for Figure 4*a*.

Outputs / Inputs	1	2	3
1	1	1	1
2	1	2	2
3	1	2	2

Table 5 Possible numbers of routes for Figure 4*b*.

Outputs / Inputs	1	2	3
1	2	2	1
2	3	3	2
3	3	3	2

The developed switch design increases the N-stage design's signal attenuation by an acceptable (specially for large N) factor of only $1/N$. that is, the attenuation caused by the additional SE of the last added stage.

Because directional couplers are long thin devices, their length limits the size of matrix that can be fabricated on one substrate and according to [1] this can be solved by spreading a planar switch matrix over several substrates. This insures that by adding one stage in the design of (N+1)-stage planar switch a fabrication problem will not be faced.

V. CONCLUSION

To have a smaller number of crosspoints and at the same time to improve the blocking probability of a planar photonic switches, in this paper we introduced a (N+1)-stage planar photonic switch. Based on a 4 x 4 switch, we compared between the N-stage switches and the (N+1)-stage ones by addressing their performance, advantages, and limitations. The discussion shows that a valuable increase in the number of possible routes between input-output pairs can be obtained at a limited signal attenuation and design fabrication cost. Currently we are working on a more detailed performance study of the switch.

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