

# Multi Mode Interferometer plus simplified coherent coupling to design a small footprint SOI power splitter

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## ABSTRACT

In this contribution we present a new approach to fabricate under SOI platform very small footprint power splitter. The design strategy is based on the well-known simplified coherent coupling combining to a multi mode interferometer (MMI) structure. Along this paper, the sensibility of design parameters are analyzed and discussed. By this new approach which includes a MMI to spatially split the optical modes, can be constructed a very compact device. This opens a new avenue to improve and enhance the performance of integrated devices developed under SOI scheme and with high integration.

**Keywords:** SOI platform, power splitter, small footprint, MMI, simplified coherent coupling .

## 1 INTRODUCTION

Nowadays, silicon photonic technology has a relevant importance in optical communications systems mainly due to some fabrication and functionality advantages, these are: small footprint devices, CMOS process compatibility and high integration level. In particular in this contribution we focus on silicon-on-insulator (SOI) which is the most popular platform within silicon photonics [1]. The high refractive index contrast between silicon and silica layers makes possible submicron waveguides and tight bends, also state-of-the-art electronics industry foundry processes can be performed for optical goals. However, unlike electronic circuits where electrical routing can be accomplished flexibly, optical routing is limited either for optical conditions or technological limitation.

Each optical design must be performed taking into account the design rules of a CMOS process. For example, many fundamental components (e.g. Y-branch) used in integrated photonics show better performance if sharp corners and spline interpolation are conducted, but usually they apart design rules [2]. In order to solve the issues, geometries based on simplified coherently coupled, multi-sectional bends could be experienced. Simplified coherent coupling is a technique to bend light through small straight waveguides with sharp curves. Several studies have already reported on bent waveguides and splitters with low-loss, compact and efficient devices compared with other types of geometries. Physically, decoupled light in a curve can be coupled back into a subsequent curve if the difference between the phase of modes (guided and unguided) is an odd multiple of  $\pi$  [3][4]. Under this approach, the bending loss is a periodic function that depends strongly on section length, the difference between the effective index of the guided mode and the weighted average effective index of the unguided excited modes at the bends. Additionally, the losses also depend on the propagated wavelength, due to the coupling between guided and radiated modes. In this paper, we propose a new design of a Y-branch that combines the coherent coupling theory to deflect the light with a multimode interference structure used to split the light. We present a device with a high transmission efficiency and a very small footprint. The photonic component is designed to be fabricated with the modern CMOS photonics process, particularly on silicon-on-insulator platform. Simulations are performed to study the relationship between the transmitted power and the design parameters. Moreover, we establish a free design parameter that can be adjusted according to the desired application.

## 2 POWER SPLITTER DESIGN AND CHARACTERISTICS

The designed power splitter device consists of a 340-nm-thick crystalline silicon core on top of a buried oxide layer with a thickness of 2  $\mu\text{m}$  on a silicon substrate and a silicon dioxide deposition of 1  $\mu\text{m}$  as final cladding. Standard single mode strip waveguide width for  $\lambda_0=1.55 \mu\text{m}$  is 450 nm. In order to validate the optical design we have conducted computational simulations. These are made by the 3D finite-difference time-domain (3D-FDTD) method [5][6]. As it can be seen, in Figure 1 (a) is sketched the design draw of the power splitters. In this picture, the optical length paths used to construct the integrated device based on the simplified coherent coupling is detailed. Additionally, a multi-mode interference waveguide (MMI) is used to divide the incoming light. All of parameters to be optimized for this approach are: L1, L2,  $\theta$ , LMMI and WMMI, are also described in this figure. In the SOI platform very small footprint can be reached under this design scheme,

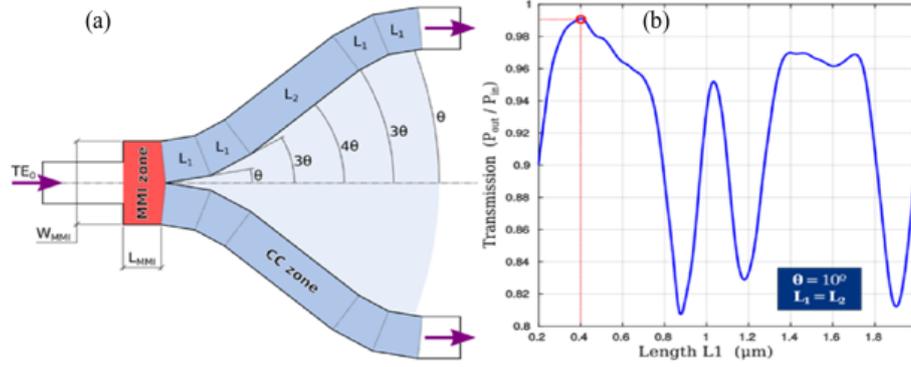


Figure 1. (a) Schematic of the proposed power splitter. The mode TE<sub>0</sub> is coupled to the designed power splitter. (b) Transmission in the coherent coupling zone by sweeping the length L<sub>1</sub>, with L<sub>2</sub> = L<sub>1</sub> and  $\theta = 10^\circ$ .

since the effective bent of the proposed design is more abrupt than a typical bend waveguide structure. From the coherent coupling theory, the most important parameter to be determined is the length of L<sub>1</sub>. This parameter will define the periodic behavior of the structure, so we have studied the dependence of the power transmission versus the length of L<sub>1</sub> path. In order to simplify the analysis, the simulation has been made by assuming L<sub>2</sub> = L<sub>1</sub> and  $\theta = 10^\circ$  (half aperture angle), note that it is useful write L<sub>2</sub> in terms of L<sub>1</sub> times. As shown in Fig. 1 (b), there are many maximum and minimum peaks of transmission. This peak structure is a kind of periodic function over the path length L<sub>1</sub>, and for the first period the highest transmission is observed when L<sub>1</sub> is equal to 0.4  $\mu\text{m}$ . As the goal of this kind of structures is achieved a small footprint device, we take the shortest length in the first period of transmission.

A multimode interference waveguide is proposed to divide the light into two branches. Fig. 1 shows the schematic configuration of the MMI waveguide suggested. This, based on self-imaging effect, is a widely used component in the integrated photonics which can perform many different splitting and combining functions [7] [8] [9]. Even though the key structure of an MMI device is a waveguide designed to support a large number of modes, we used a small enough structure that supports only two modes. From a constructive perspective, it is convenient to use a multimode interference waveguide with a small width, in our case it is twice of the single-mode waveguide. As the characteristic self-imaging length L<sub>MMI</sub> has a quadratic dependence on the width W<sub>MMI</sub>, the footprint will remain very small if we use that size of multimode structure [10]. For all that, we choose W<sub>MMI</sub> = 0.9  $\mu\text{m}$  in our device. We initially simulate the propagation of the light by considering an infinite length MMI structure, the interference pattern for this situation is shown in Fig. 2a(top). The input electric field is reproduced at a specific length with slight phase retardation, and the modes in this MMI region also become only symmetrical modes. One should keep in mind that the wavelength dependence in many applications cannot be; in fact, it was found lower wavelength sensitivity than structures with larger W<sub>MMI</sub> dimensions [5] [6]. Once the propagation has been studied, we proceeded to define the optimal length in which two images of the incoming single-mode are reproduced. Simulations were performed by setting the free parameter L<sub>2</sub> at 0.4  $\mu\text{m}$  and sweeping the L<sub>MMI</sub> length. The results of these simulations are illustrated on the bottom of Fig. 2 (a), where the power transmission in one of the two branches is plotted as a function of the multimode interference length. As we can see in this figure, the best condition of splitting was found at L<sub>MMI</sub> = 0.415  $\mu\text{m}$ . With all of the optimized design parameters, we proceed to study the relationship between the transmitted power and the length of L<sub>2</sub> path. This simulation is shown in Fig. 2 (b). As can be clearly seen in Fig. 2(b-bottom), the device presents a periodic transmission that is between -3.05dB and -3.15dB because it prevails the coherent coupling effect. On the the top of Fig. 2(b) is also observed that large L<sub>2</sub> segments present peaks in the wavelength transmission, which are not less than -3.22dB.

Finally, the most important feature of this design is the very small footprint; for instance, the footprint of a typical MMI 1x2 with similar behavior is 6x34.7  $\mu\text{m}^2$ , whereas the footprint of the 1x2 power splitter based on coherent coupling is about 6x4  $\mu\text{m}^2$ .

In summary, we have proposed and demonstrated an ultra-compact, nicely adaptable and highly efficient Y-branch power splitter on silicon-on-insulator. We combine two techniques for that, the simplified coherent coupling and the multimode interference structure to bent and split the light, respectively. The design parameters were optimized to reduce the footprint and maximize the transmission. Besides, a free design parameter to be adjusted according to the application is provided. We have achieved a transmitted power between -3.05dB and -3.15dB, depending on the free design parameter L<sub>2</sub>. Finally, our design proved to be almost 9 times smaller than one other commonly used device with similar behavior.

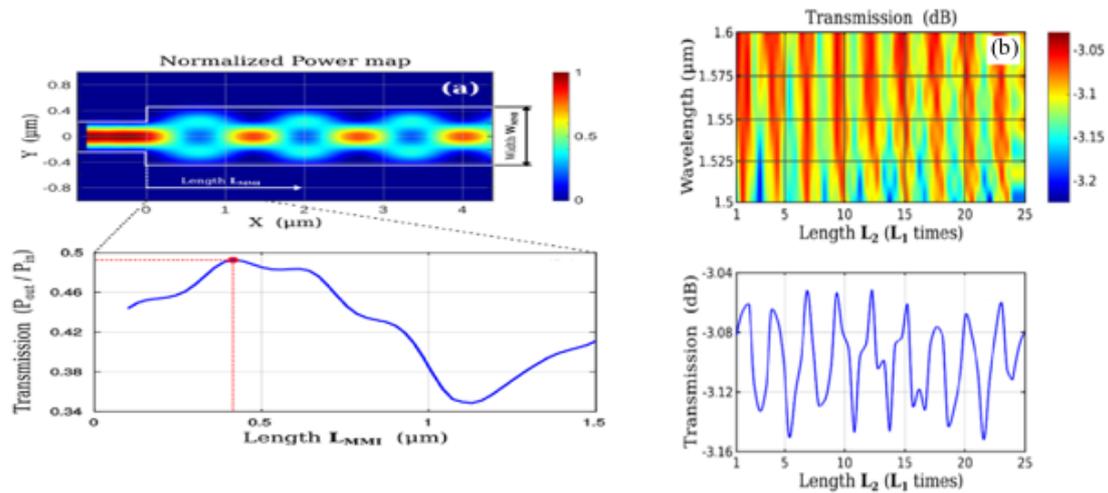


Figure 2. (a) Tuning the MMI parameters: (top) Normalized power map; and (bottom) Length  $L_{MMI}$ . (b) Transmission on a branch by sweeping the free parameter  $L_2$  between 1 and 25 of  $L_1$  times; (top) power map with respect to wavelength, and (bottom) total power transmission.

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