# Designing of a 1 x 8 Optical power splitter based on coupled mode theory

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**Abstract.** In this work, we designed a T-shaped 1 x 8 balanced optical power splitter design based on the Coupled-mode theory. Vertical silicon slot waveguides are employed in the design which provides the optical confinement in TE-polarization. The layout of the optical power splitter is unique and offers four output ports with each on two sides of the chip. Furthermore, the bending losses of the waveguides are lessened by ~ 80 % by moving the slot towards the outer sideline of the bend as compared to the symmetric slot waveguide.

## 1. Introduction

Silicon photonics has become the key area of research and development in the comprehension of micro and nano-meter scale optoelectronic devices [1]. Optical power splitters are important components for splitting and combining the optical signals, which have attracted extensive consideration in integrated photonic systems [2]. There is a rising demand for these components in the field of integrated optics. The characteristics with low cost and compactness are highly preferred.

In this work, we propose a design of a 1x8 optical power splitter based on vertical slot waveguides. The working principle of this device is established on coupled-mode theory [3, 4]. The physical models for coupled-waveguide systems consist of two or more dielectric waveguides placed in close vicinity. These waveguides can be parallel to each other and can have irregular separations. Equation 1 and 2 are the coupled mode equations. Where $A_1$and $A_2$ are the local amplitudes of the two modes. $\Delta\beta$ signifies the mismatch in propagation constant between the waveguides.

$$dA_1 / dz + j\kappa A_2 \exp(-j\Delta\beta z) = 0 \tag{1}$$

$$dA_2 / dz + j\kappa A_1 \exp(+j\Delta\beta z) = 0 \tag{2}$$

The variations in $A_1$ in waveguide 1 are connected to the $A_2$ in waveguide 2 through the coupling coefficient $\kappa$ and vice-versa. In other words, the mode amplitudes are coupled together. The coupling coefficient is conceivably the most important parameter of the coupler. The main requirement for $\kappa$ to be large is that the evanescent tail of the E-field penetrates waveguide1 to a substantial amount. Therefore, it can be stated that κ is most strongly affected by inter-waveguide gap (g), which should be small.

A slot waveguide is a unique structure that permits the light to be strongly confined and guided inside a nanometer-scale region of low index material (slot) that is surrounded by two layers of high index material (slab) [5, 6]. Strong confinement of light in a slot is due to discontinuity of the electric field perpendicular to the interface between materials with low and high refractive index. There are numerous benefits of using this distinctive structure such as a small beat length of the guided light and a strong optical confinement in the slot region that results in remarkably low losses. Besides, CMOS compatible materials and technology can be used in slot waveguide fabrication [7].

## 2. Device design

We suggested a T-shaped 1x8 balanced optical power splitter based on 90o bend vertical asymmetric slot waveguides simulated by using commercial finite element method (FEM) simulation tool COMSOL Multiphysics 5.1. Scattering boundary conditions were used at the outer edges of the FEM simulation window to estimate an open geometry. The optical power splitter is designed for a wavelength of 1550 nm. The refractive index of Silicon (nSi) and sapphire ($nSiO_2$) is set at 3.47 and 1.44, respectively, for chosen wavelength. The schematic of a 1x8 optical power splitter is shown in figure 1. The optical power splitter design is solved in different steps in order to acquire an identical proportion of power at each port.

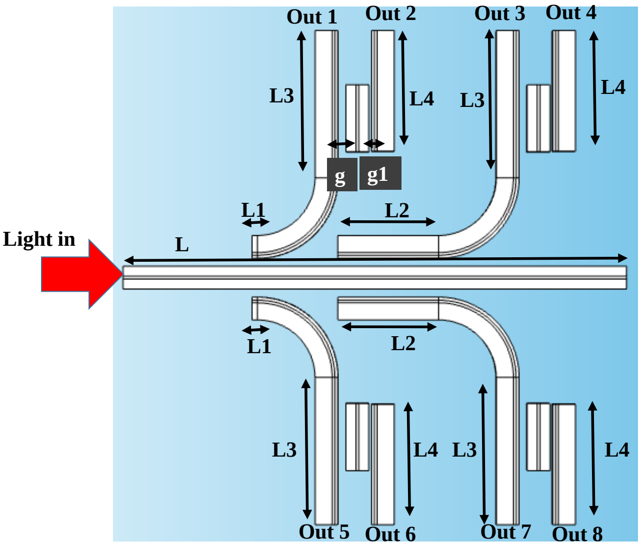


**Figure 1.** Schematic of a 1x8 optical power splitter.

## 3. Power confinement factor in slot waveguide

Before designing a 1x8 optical power splitter, the geometry of symmetric vertical slot WG is optimized in order to obtain the reasonable waveguide parameters. The waveguide width is optimized relative to the waveguide height. As these waveguides are polarization dependent and we used TE-polarization in order to obtain a guided mode. Therefore, the height ($H_{WG}$) of the waveguide is least influential. The maximum confinement is attained at $W_{WG}$= 0.45 µm by using $H_{WG}$= 0.22 µm in a slot size of 40 nm. In order to calculate the optimum value of g between bus waveguide and corresponding waveguides, we varied g in order to obtain the equal power transfer between Out 1 and Out 3. Here, we consider that our design is symmetric and left-side is equal to the right-hand side, hence power distribution between Out 1= Out 5 and Out 3= Out 7. Moreover, we also have to consider that g should be selected carefully where waveguides are not perfectly coupled. Some power should stay on the bus waveguide to travel and later on couples to Out 3 and Out 7. Furthermore, we know that the proportion of power distribution is optimized with the help of variation in coupling length. Therefore, we selected g=120 nm as an initial value for our design.

## 4. Optimization of the interaction length of a balanced 1x4 OPS

The interaction length (L1 and L2) of slot waveguides connected to a bend waveguides play an essential role in coupling the major fraction of light from one waveguide to another. We started by designing a balanced 1x4 optical power splitter. In this stage the accurate selection of L1 and L2 is important. When L1=L2, the maximum and equal proportion of power is coupled to out 1 and out 5 through bend waveguides and the residual power which is close to zero couples to out 3 and out 7 which makes the optical power splitter imbalance. Consequently, we should alter L1 up to a point where half of the power couples to out1 and out 5 and the other half should travel in the bus waveguide and couples to out 3 and out 7. The length (L3) of out 1, out 3, out 5 and out 7 is maintained at 2200 nm. The equal power distribution for 1x4 optical power splitter is obtained at 80 nm and 1500 nm for L1 and L2, respectively.

## 5. Reduction of bending losses

We proposed to shift the slot towards or away from the bend in order to reduce the bending losses of the slot waveguide. The width of waveguide is fixed at 340 nm including slot=40 nm. The slot was displaced towards and away from the bend by maintaining the total width of the waveguide constant and notices the deviation in the field power. The shifting of a slot from the center of the waveguide maximizes the E-field inside the slot moreover reduces the bending losses in the structure due to the improved confinement of light in the slot. The losses tend to reduce as the slot shifts toward or away from the bend but there is a finite limit to displace the slot. Though, the minimum losses of 2.41 dB were obtained at 115 nm slot displacement towards the outer periphery of the bend. This occurs due to the maximum overlap of the two evanescent tails of the high index waveguide in the left cladding region.

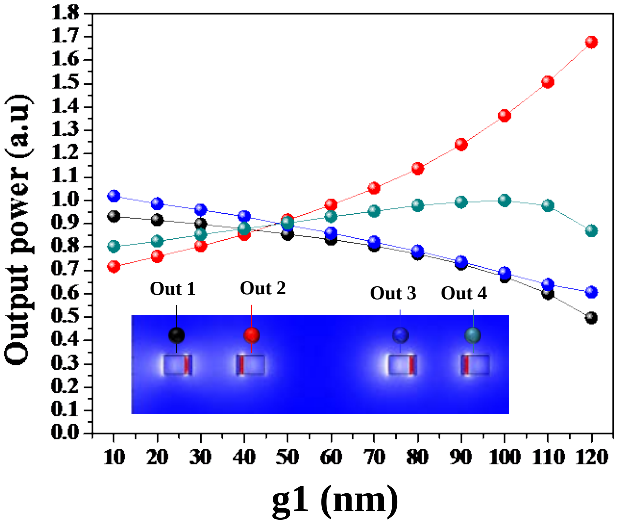


**Figure 2.** Optimization of a balanced 1x8 optical power splitter by varying g1.

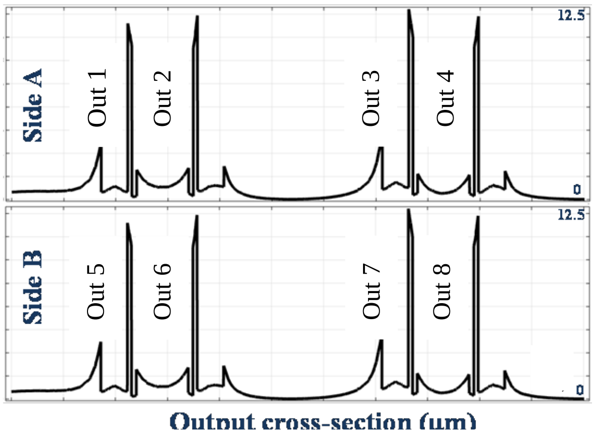


**Figure 3.** Line graph of a balanced 1x8 optical power splitter.

## 6. Balanced 1x8 optical power splitter

In the previous sections, we achieved a design of a balanced 1x4 optical power splitter. Now, we will introduce two bridge waveguides and two additional ports on each side of the bus waveguide in order to further divide the power. Bridge waveguide provides an acceptable separation between respective output ports. The length of the out 2, out 4, out 6 and out 8 is maintained at 1800 nm whereas bridge waveguide is fixed at 1000 nm. L4 is slightly smaller than L3 which allows the mode to travel a

significant distance in L3 before coupling to the bridge waveguide. The balanced power distribution is obtained at g1= 50 nm with a slight tolerance of ±5 nm as shown in figure 2. The contour plot of the left side of the 1x8 optical power splitter is plotted in the inset of figure 2.
The line graph of a 1x8 optical power splitter is shown in figure 3. A line graph is plotted by cutting the output ports at half of the waveguide height ($H_{WG}/2$) and obtained an E-field distribution at the output of each output port.

## 7. Conclusion

In this work, we proposed a T-shaped 1x8 balanced optical power splitter based on silicon-on-insulator vertical slot waveguides. The layout of the design is distinctive which provides four output ports with each on two sides of the chip. The bending losses of the waveguides were reduced to 80% by shifting the slot towards the outer periphery of the bend. Based on this design, splitters with different power distributions can be developed by fluctuating the inter-waveguide gap.

## 8. References


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