A new method for layout optimization of $1 \times N$ optical power splitters

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Abstract: A new method for layout optimization of $1 \times N$ power splitters is presented. A genetic algorithm is used to reduce the device footprint. Simulation results show that insertion loss and uniformity are improved.

OCIS codes: (230.1360) Beam splitters; (230.3120) Integrated optics devices; (230.3990) Micro-optical devices; (230.7390) Waveguides, planar;

1. Introduction

Optical power splitters play an important role in fiber-to-the-home (FTTH) networks [1]. The requirements for power splitters in practical use are low insertion loss, large bandwidth, and good uniformity. In regard of this, $1 \times N$ power splitters made of cascaded 1×2 power splitter unit-cells are the most promising candidates. Throughout the years, most of the attention has been paid to the optimization of 1×2 splitter unit-cells [2-5], while little efforts have been made for the improvement of the layout structure.

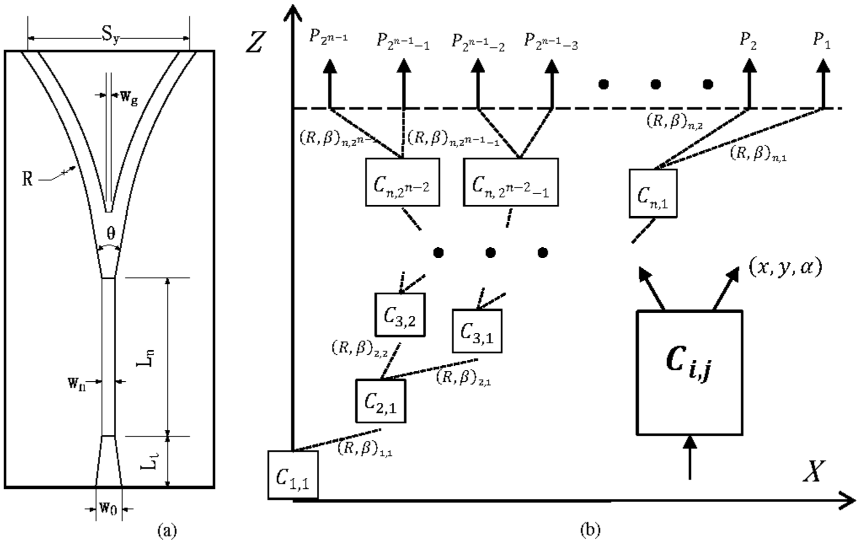
Here we present a new method to optimize the layout of 1 × N power splitters, with a particular focus on the connection between adjacent unit-cells. A genetic algorithm [6] is employed to perform the nonlinear optimization. Beam propagation method (BPM) simulations show that both insertion loss and uniformity have been improved compared to regular designs.

2. Design flow

Our design is divided into two steps, unit-cell design and connection optimization, which will be discussed in detail in the following subsections.

(1) Unit-cell design

A unit-cell is basically a 3-port device with one centered input and two symmetric outputs. Our unit-cell is based on a Y-junction, composed of an input taper, a narrow waveguide region, and two intersecting arcs, as shown in Fig. 1 (a). **N**arrow waveguide is used to suppress higher-order modes to improve output uniformity. Design parameters include single mode waveguide width w_0, input taper length L_t, narrow waveguide width w_n and length L_n, branching angle θ, and radius R. BPM simulations over the operating band (1260 nm ~ 1610 nm) give the optimized design values: $w_0 = 5.0\ \mu m$, $w_n = 3.5\ \mu m$, $L_t = 85.94\ \mu m$, $L_n = 500\ \mu m$, $\theta = 1.0^o$, $R = 5000\ \mu m$, and $S_y = 2.0\ \mu m$.



(a) (b)

Figure 1. (a) Layout of a 1 × 2 unit-cell, including an input taper, a narrow waveguide, and an output taper. (b) Illustration of the mathematical model for the 1 × N power splitter.

(2) Connection optimization

Figure 1(b) illustrates the 1 × N splitter mathematical model based on two dimensional Cartesian coordinate system, where the unit-cell is represented by $C_{i,j}$ with three ports. Every port can be denoted by a vector with three components: (x, z, a), where (x, z) represents the position and α the orientation.

In a regular design, adjacent unit-cells are connected by S-bends (two successive arcs with opposite bending directions), thus all unit-cells are aligned in parallel. In our design, however, only one arc is used for each connection, leading to various orientations of unit-cells. The position of each arc is fully described by its radius R and bending angle β. In the final stage, every output port of $C_{n,j}$ is connected to its corresponding horizontal location P_j (determined by the output waveguide lateral separation) by one or two arcs.

To optimize the layout, the maximum of the z coordinates in $\{P_j\}$ should be minimized. The P_j can be readily calculated once the $2^n - 2$ inter-cell connection parameters are given. On the other hand, the nonlinear constraints are relatively subtle. One obvious constraint is that no light coupling should occur between any two waveguides along the light paths, and we formulate this by letting $|x_{i,2j} - x_{i,2j+1}| > D_{min}$ for $1 \le i \le N$, $1 \le j \le 2^{i-1}$, where $D_{\min}$ is the minimum distance between adjacent ports. Otherwise, more strict constraints are needed. The MATLAB global optimization toolbox is used to perform the genetic algorithm. The layouts of 1 × 8 and 1 × 16 power splitters are shown in Fig. 2.

(a) (b)

Figure 2. Layouts of compact power splitters (not to scale)

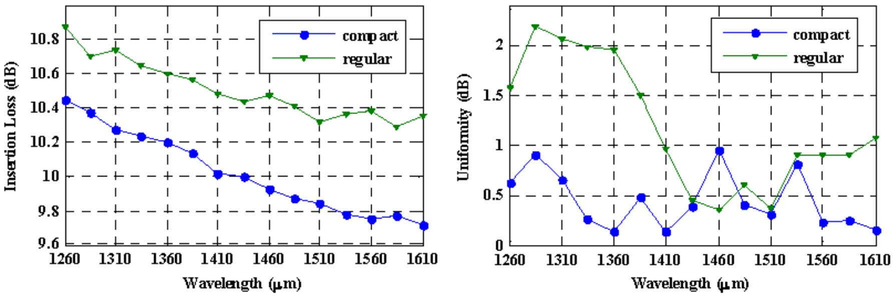
3. Simulation and analysis

Table 1. Comparison of device layout height for 1 × 4 to 1 × 32 power splitters

Splitter Type	Our design (μm)	Regular (μm)	Reduction (%)
1 × 4	3800.837	4378.349	13.19
1 × 8	5233.642	7460.853	29.85
1 × 16	6852.521	11455.014	40.18
1 × 32	9314.280	16697.447	44.22

The power splitter designs are based on silica planar lightwave circuits (PLC) with an index contrast of 0.75%. Note that the single mode waveguide width is $w_0 = 5.0\ \mu m$, smaller than the commonly adopted $6.0\ \mu m$, so that the single mode condition maintains at short wavelengths. As can be seen from Table 1, the device layout height reduces more as the number of output ports increases (the layout width is fixed by the output waveguide array separation).

BPM simulation results of 1 × 8 power splitters of both regular and our optimized (compact) power splitters are given in Fig. 3. It shows that insertion loss is reduced by >0.4 dB over the whole operating band, while uniformity is improved more in the shorter wavelengths, which can be attributed to the mode suppression of the narrow waveguide.



(a) (b)

Figure 3. (a) Insertion loss and (b) output uniformity for both our compact and regular power splitters over the operation band 1260 μm ~ 1610 μm.

4. Conclusion

In this paper, we present a design optimization method to minimize the device footprint of $1 \times N$ optical power splitters. A mathematical model is built and a genetic algorithm is used. The method features a reduced device area by optimizing connecting waveguide between successive 1×2 power splitter unit-cells. The device height is shortened by up to 44% for 1×32 power splitters. BPM simulations show that our optimized 1×8 power splitter has a lower insertion loss and a better uniformity over the fiber optic communication band 1260 μm ~ 1610 μm. More improvements can be made by further optimizing unit-cell, inter-cell connection and genetic algorithm.

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