

Design of a Wide-angle Low-loss Equal-power Optical Divider

Bandar A. Almashary* and Nabeel Abolkhair**

* Electrical Engineering Department, College of Engineering, King Saud University,
P.O. Box 800, Riyadh 11421, Saudi Arabia

** Saudi Telecom Company, Riyadh, Saudi Arabia

(Received 20 July 2005; accepted for publication 05 June 2007)

Keywords: 1x3 divider, Waveguide, BPM, Simulation, Wide-angle, Low-loss, Prism.

Abstract. Beam propagation method is used to simulate numerically a proposed 1x3 optical power divider. Simulation results show that the proposed structure can divide the optical power with a division ratio equal to one and with branching angles as large as 8° and output power efficiencies larger than 80%. The proposed structure is easy to fabricate and it employs a prism at the branching region and two stages of branching to reduce the radiation loss and get the uniform division property.

Introduction

Optical dividers are key components in integrated optical circuits. They are widely used as power dividers and combiners in optical modulators and switches, which are key components in modern optical communication networks. Some researchers have focused on dividers with two output branches (Y-branch) (Yabu *et al.*, 2001; Hsu *et al.*, 2003; Wang *et al.*, 2002; Lin *et al.*, 2001). However, the conventional divider is constructed by distributing the optical power from one input waveguide into several outputs with certain branching angle. This structure suffers from two main problems. The first one is associated with the severe radiation loss, particularly with branching angles larger than 2° (Tsutsumi *et al.*, 1988). This restricts the branching angle to small values. However, keeping branching angles small makes these devices large and difficult to fabricate with reasonable cost. The second problem is the unequal division of optical power between the output branches. For more than two branches, more input power is transmitted to the central waveguide(s) than to the sideward ones. Many efforts have been devoted to reduce the radiation losses due to the branching angle, or to

come up with designs that split the power equally between the output branches (Yabu *et al.*, 1999; Banba *et al.*, 1992). A new design for the 1x3 divider was proposed (Wang *et al.*, 2000; Wang *et al.*, 2003) and it addresses the two problems together. However, although it offers an equal division of optical power between the three output branches at angles up to 6° , the transmission power efficiency degrades for angles larger than 3.6° . Recently, some researchers have published new designs to build equal power divider without a need to an extra fabrication process (Yong *et al.*, 2005). However, their design suffers from a limitation due to the small branching angles that it can achieve.

In this paper, a new single-mode optical power divider with a micro-prism, two power expanders and two stages of branching is proposed. Careful design has achieved an equal distribution of the input power at a wider angle and with higher efficiency. Device performance is evaluated numerically using beam propagation method (BPM), and the simulation results are presented. Simulation results show that the proposed design can achieve wider branching angles with higher transmission power efficiency compared to the structures in (Wang *et al.*, 2000; Wang *et al.*, 2003).

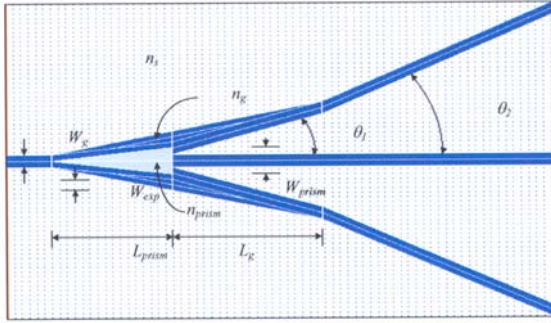


Fig. 1. Proposed 1x3 optical divider.

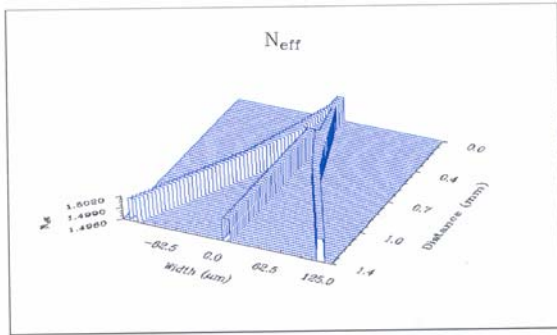


Fig. 2. Refractive indices profile.

Proposed Structure

Figure 1 shows the proposed 1x3 optical divider. The guiding layer index is 1.502, the substrate index is 1.496, and the prism index can be varied between the two indices values. The length of the divider is assumed to be 1.4 mm, and light wavelength is 1.5 μm . The prism is placed at the branching region, and it has a lower refractive index compared to the guiding layer, therefore the phase-front in its center travels at a higher speed compared to the two sideward phase-fronts. As a result, phase-front in the center region is accelerated more than phase-fronts in the sideward regions. This causes the prism to steer the propagated optical field towards the outer branches. Adding expanders at the sideward branches with refractive index equal to the guiding index helps in increasing the power in these branches (Wang *et al.*, 2000). By careful design, it is possible to optimize the structure geometry and parameters to have the propagated field divided equally between the three branches.

In order to increase the branching angle with less effect on the divider efficiency, we propose using two stages of branching. The first is at the branching

point, and the second is some where far from that point. The second angle will cause extra loss; however, the loss incurred by such increase in the total branching angle is believed to be less than the loss obtained if the increment is made at the original branching point.

Simulation Results

To demonstrate the operation of the proposed divider numerically, the software package BPM_CAD (Optiwave Co.) has been used throughout this simulation. It is based on the finite-difference beam propagation method. BPM_CAD is used to calculate the optical field and the power in each branch. With the input power P_{in} , the transmission efficiency (η) of the divider is defined as follows:

$$\eta = [(P_1 + 2 P_2) / P_{in}] \quad (1)$$

where P_1 and P_2 are the power in the central and sideward branches, respectively.

In conventional dividers, η is normally less than one. In our proposed structure we optimized its geometrical and material parameters in order to obtain the highest efficiency at the largest angle with equally divided power. Figure 2 shows the refractive index profile of the proposed structure. This includes the three different regions: the guiding, the prism and the substrate refractive indices. The guiding and the substrate regions have fixed refractive indices of 1.502 and 1.496, respectively. However, the prism region index is considered as a parameter, which we will optimize to get the best design. In choosing the prism index and the other geometrical parameters such as the prism length (L_{prism}), prism width (W_{prism}), expander width (W_{exp}), guide width (W_g), and the first stage length (L_g), we tried to reach the largest branching angle with almost equal division of power while keeping η larger than 80%. The values of the parameters were chosen close to those of the structure proposed by Wang (Wang *et al.*, 2000) for the sake of comparison.

The proposed structure in Fig. 1 is simulated with the following parameters values: $n_{prism} = 1.50033$, $L_{prism} = 265 \mu\text{m}$, $W_{prism} = 19 \mu\text{m}$, $W_{exp} = 8 \mu\text{m}$, $W_g = 9 \mu\text{m}$, and $L_g = 330 \mu\text{m}$. With these values, it is demonstrated that one can reach a large branching angle (θ_2) up to 6° with a division ratio of one and an efficiency of 87.9%. Figure 3 shows the optical field intensity obtained from the BPM simulation at the

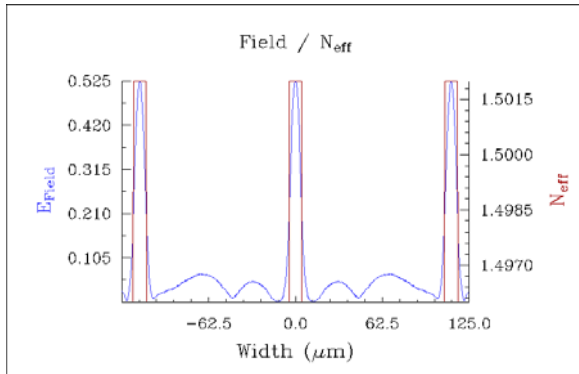


Fig. 3. Output optical field with $\theta_2 = 6^\circ$.

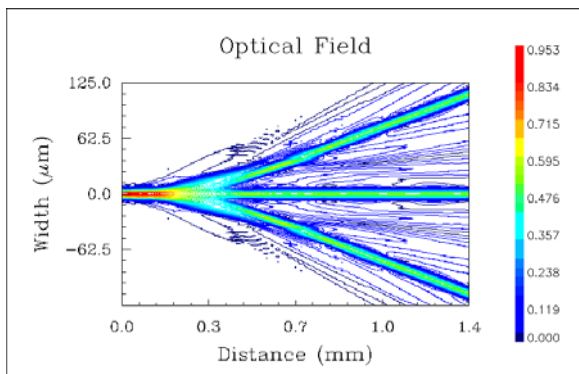


Fig. 4. Optical field distribution in the entire structure with $\theta_2 = 6^\circ$.

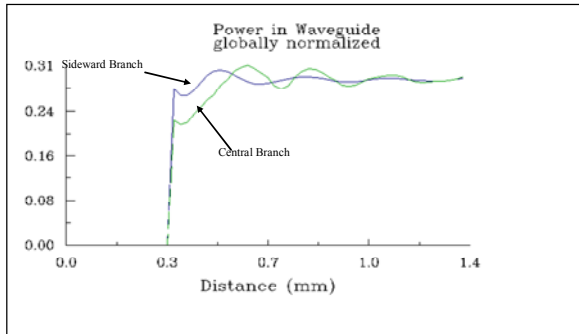


Fig. 5. Optical power of central and sideward branches with $\theta_2 = 6^\circ$.

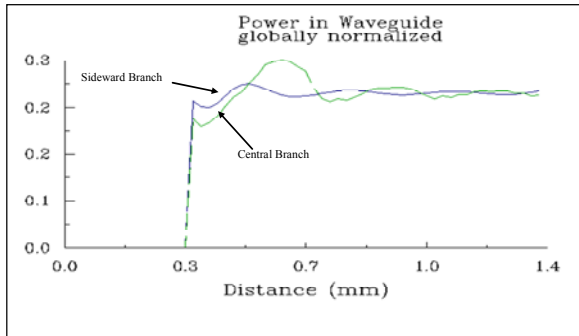


Fig. 6. Optical power of the central and sideward branches with $\theta_2 = 8^\circ$.

output in each branch and the effective index distribution. This result demonstrates the uniformity in the division and the confinement of the optical field in the guiding layer of each branch. Moreover, the result is a single mode with its peak centered in the middle of the guiding layer. This is an extra advantage of this structure, especially if its outputs are going to be coupled to optical fibers.

The 2D distribution of the optical field intensity in the entire structure is shown in Fig. 4. The optical power distribution in the central guiding branch (P_1) and the sideward guiding branch (P_2) are calculated using the simulation results and plotted together in Fig. 5. It should be noticed that the power value is normalized to the input power (P_{in}), and the figure displays the power after the branching point (at 0.3 mm distance from the divider starting point). Also, only the power in one of the sideward branches is shown because the other sideward branch has a similar distribution. This figure demonstrates the equal division property and gives the total output power in each branch normalized to the input power. Therefore, the efficiency can be easily calculated from the figure. Our result shows a significant improvement over the results obtained by Banba (Banba *et al.*, 1992) and Wang (Wang *et al.*, 2000), where they obtained efficiencies of 67% and 20%, respectively, at a branching angle of 6° . Having reached these results, we continued to investigate the possibility to enlarge the branching angle by keeping the inner branching angle (θ_1) as it is and increasing the outer branching angle (θ_2) only. All the geometrical parameters were kept similar to the 6° -case and the prism index (n_{prism}) is optimized to obtain $\eta > 80\%$.

The simulation was repeated for the same proposed structure and Fig. 6 shows the normalized optical power distributions in the central and the sideward branches with $n_{prism} = 1.50016$, and $\theta_2 = 8^\circ$.

The results in Fig. 6 shows that at this larger angle, the proposed structure demonstrates a uniform power distribution between the three branches with $\eta = 80.6\%$. To the best of our knowledge, this is the highest η reported for 1x3 divider with branching angle equal to 8° .

Conclusion

In this paper, we proposed and simulated numerically a new power 1x3 divider which overcomes the two main problems associated with

these structures, specifically the small branching angles imposed by the requirement of low-loss dividers and the need for a uniform distribution of optical power between output branches. Our simulation results show that the proposed structure divides the optical power uniformly at large angles (6° and 8°) with power efficiency larger than 80%. These results show a significant improvement compared with recently proposed structures.

References

- Banba, S. and Ogawa, H.** "Novel Symmetric Three-branch Optical Waveguide with Equal Power Division." *IEEE Microwave Guided Wave Lett.*, Vol. 2, No. 5, (1992), 188-190.
- Hsu, C.; Chen, H. and Wang, W.** "Compact Y-branch Power Splitter Based on Simplified Coherent Coupling." *IEEE Photonic Tech. Lett.*, Vol. 15, No. 8, (2003), 1103-1105.
- Lin, H.** "A Very Low-loss Wide-angle Y-branch with a Composite Diamond-like Microprism." *IEEE Journal of Quantum Electronics*, Vol. 37, No. 2, (2001), 231-236.
- Optiwave Co.** *BPM_CAD Package*. Version 4, Ontario, Canada.
- Tsutsumi, K.; Imada, Y.; Hirai, H. and Yuba, Y.** "Analysis of Single Mode Optical Y-junctions by the Bound Step and Bend Approximation." *IEEE Journal of Lightwave Tech.*, Vol. 6, No. 4, (1988), 590-600.
- Wang, T.; Wang, Y. and Wang, W.** "Single-mode 1x3 Equal-power Divider Using a Substrate Microprism and Two Waveguide Expanders." *IEEE Photonic Tech. Lett.*, Vol. 12, No. 2, (2000), 164-166.
- Wang, Q.; He, S. and Wang, L.** "A Low-loss Y-branch with a Multimode Waveguide Transition Section." *IEEE Photonic Tech. Lett.*, Vol. 14, No. 8, (2002), 1124-1126.
- Wang, T.; Huang, C. and Wang, W.** "Wide-angle 1x3 Optical Power Divider in LiNbO₃ for Variable Power Splitting." *IEEE Photonic Tech. Lett.*, Vol. 15, No. 10, (2003), 1401-1403.
- Yabu, T.; Geshiro, M.; Minami, N. and Sawa, S.** "Symmetric Three-branch Optical Power Divider with a Coupling Gap." *IEEE Journal of Lightwave Tech.*, Vol. 17, No. 9, (1999), 1693-1699.
- Yabu, T.; Geshiro, M. and Sawa, S.** "New Design Method for Low-loss Y-branch Waveguides." *IEEE Journal of Lightwave Tech.*, Vol. 19, No. 9, (2001), 1376-1384.
- Yong, Y.; Low, A.; Chien, S.; You, A.; Wong, H. and Chan, Y.** "Design and Analysis of Equal Power Divider Using 4-branch Waveguide." *IEEE J. of Quantum Electronics*, Vol. 41, No. 9, (2005), 1181-1187.

** *

*قسم الهندسة الكهربائية، كلية الهندسة، جامعة الملك سعود، ص ب ٨٠٠، الرياض ١١٤٢١، المملكة العربية السعودية
** شركة الاتصالات السعودية، الرياض، المملكة العربية السعودية

(قدم للنشر في ٢٠/٠٧/٢٠٠٥م؛ وقبل للنشر في ٠٥/٠٦/٢٠٠٧م)

: موزع ضوئي (٣X١)، موجه ضوئي، نمذجة، زاوية عريضة، منشور، فقد قليل.

. تم استخدام طريقة انتشار الحزمة الضوئية في هذا البحث لنمذجة تصميم مقترح لموزع ضوئي (٣X١) رقمياً. ولقد أظهرت نتائج النمذجة أن التصميم المقترح يمكنه توزيع الطاقة الضوئية بانتظام وبمعامل توزيع يساوي واحد وبزاويا توزيع عريضة تصل إلى ثمان درجات وبفعالية قدرة تزيد عن ٨٠٪. إن التصميم المقترح يتميز بسهولة التصنيع حيث يتم التوزيع على مرحلتين يستخدم في المرحلة الأولى منه منشور ضوئي بمعامل انكسار مناسب يوضع في منطقة التوزيع وذلك بهدف تقليل الفقد الإشعاعي والحصول على خاصية التوزيع المتساوي.

