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Proceedings of 2014 International Conference on Electrical Engineering and Computer Science, ICEECS 2014

Country	United States - SIR Ranking of United States
Subject Area and Category	Computer Science Computer Networks and Communications Computer Science Applications Engineering Electrical and Electronic Engineering
Publisher	
Publication type	Conferences and Proceedings
ISSN	-
Coverage	-
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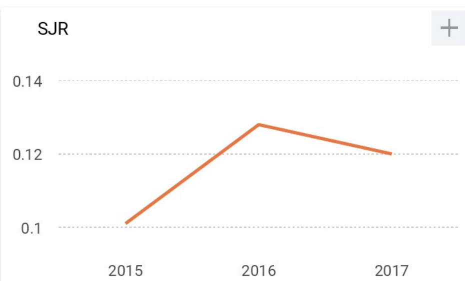

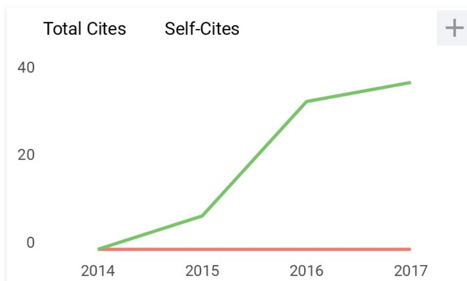

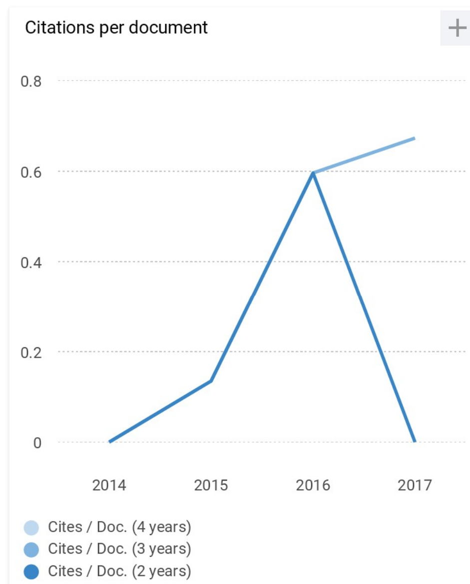

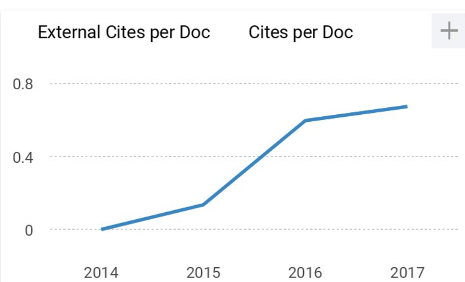

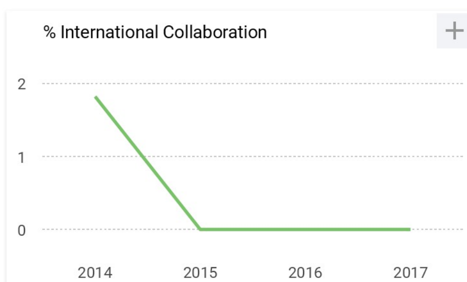

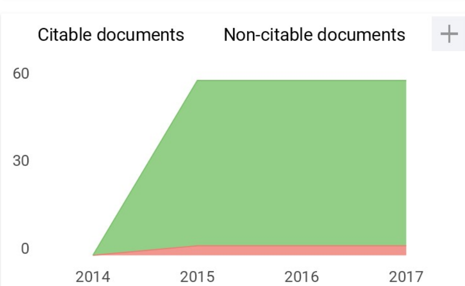

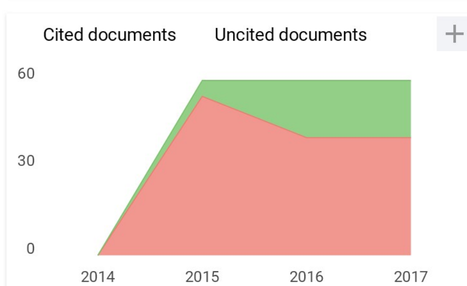

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Proceedings of

2014 International Conference on Electrical Engineering and Computer Science (ICEECS)

24-25 November, Denpasar, INDONESIA

ISBN 978-1-4799-8477-0
IEEE Catalog Number : CFP14A95-CDR

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TABLE OF CONTENTS

2014 IEEE International Conference on Electrical Engineering and Computer Science
24-25 November 2014, Bali, Indonesia

Characteristics of S-bend Optical Waveguides Based on Back-to-Back and Sinusoidal Structures

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***Abstract*—Bending waveguide is used to connect two separated optical waveguides. But the bend will produce a huge loss. The bending loss can be reduced by designing effective refrative index for the core and cladding, the radiatur curvature bend, and S-shaped bend design. In this paper, we will compute radiation loss between two geometris structure waveguide bend, a back-to-back and sinusoidal on symmetrycal slab waveguide. From the simulation result, we can obtain the radiation loss depends on Δn in slab waveguide. Radiation loss will decrease when Δn and length of the waveguide increase. Then we obtain the comparison characteristics of radius curvature and radiation loss of S-bend optical waveguides bend based on back-to-back and sinusoidal.**

***Keywords*—back-to-back bend; bending waveguide; sinusoidal S-bend; radiation loss**

I. INTRODUCTION

When a number of optical components integrated in a system, bending waveguide required to interconnect the dielectric waveguide pathways [1]. Bends is the basic form of the various optical components such as the MZI (Mach-Zehnder interferometer), coupler, microring resonator, and so forth. But, the bending waveguide can cause effects that lower the performance of a guided wave system, such as radiation loss.

It can occur because the power on the waveguide will be less than the power absorbed out from the waveguide. Radiation loss can be reduce by decreasing the curvature of the bend and design optical waveguide. There are several geometries to design S-shaped bending waveguide such as back-to-back curvature and sinusoidal S-bend.[2]

II. THEORY

In this paper we used a simple bends configuration and applied to a number of two different waveguide bend geometries, which is they have a different curvature. In back-to-back bending waveguide, we used two back-to-back circular arc section of constat radius of curvature to calculate the loss. In sinusoidal S-shaped bend, to find the loss in bend is describe by a 'shaped function' $y = f(x)$, where $f(x)$ is continuous in its first derivative. [2] Fig. 1 shows a schematic diagram picture of back-to-back structure.

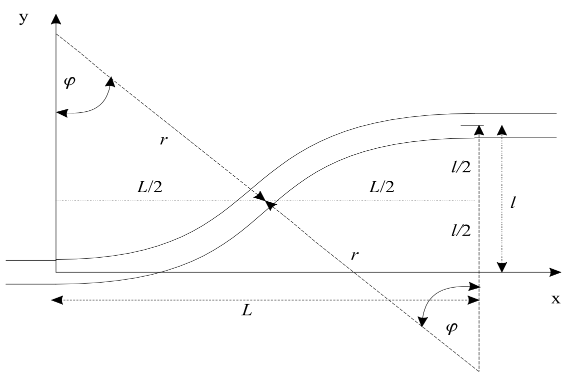


Fig. 1. Schematic diagram example of back-to-back and sinusoidal waveguide bend.[2]

Form fig. 1, the back-to-back waveguide bend geometry, we get the geometric relations,

$$r\sin(\varphi) = \frac{L}{2} \tag{1}$$

and,

$$r\left(1-\cos(\varphi)\right)=\frac{l}{2} \quad (2)$$

Where φ is the angle subtended by each of the arc section, L is the transition length, and l is the lateral offset. Assuming that $L >> l$, equation (1) and (2) can be arranged to obtain an approximate analytical relation for radius curvature r:

$$r=\frac{L^2}{4l}\left(1+\frac{l^2}{L^2}\right) \quad (3)$$

And the curvature $\frac{1}{r}$ can be written as:

$$\frac{1}{r}=\pm\left[\frac{L^2}{4l}\left(1+\frac{l^2}{L^2}\right)\right]^{-1} \quad (4)$$

While, for the lateral position function for sinusoidal bending waveguide geometry is [8],

$$y(x)=\frac{xl}{L}-\frac{l}{2\pi}\sin\left(\frac{2\pi x}{L}\right) \quad (5)$$

Then the radius curvature for sinusoidal bend when $L >> l$ is given by:

$$\frac{1}{r}\approx\frac{2\pi l}{L^2}\sin\left(\frac{2\pi x}{L}\right) \quad (6)$$

Bending waveguide loss can calculated using analytical approximation, to construct a smooth S-shaped transition connecting two parallel slab waveguides. We can use Lee's theory to find C_1 and C_2 which is a parameter that will not be affected by the waveguide radius.

Lee's equation of C_1 and C_2 coefficients is [1]:

$$C_1=\frac{2\gamma^2}{k_0 n_2(\gamma h+2)}cos^2\left(\frac{\kappa h}{2}\right)e^{\gamma h} \quad (7)$$

and,

$$C_2=\frac{2\gamma\left(n_{eff}-n_2\right)}{n_2} \quad (8)$$

Where γ is propagation constant in cladding, k_0 is wave in vacuum, h width of core, and κ is propagation constant in core.

A. Radiation Loss of Back-to-back Bending Waveguide

To find the radiation loss of back-to-back bending waveguide, first we find the attenuation coefficient (α). It will increase exponentially according to the decrease of radius and will be constant for a fixed radius curvature. Using (7) and (8), we can compute the value of α. It will affect the radiation loss of bending waveguide [3].

$$\alpha=C_1e^{-C_2 r} \quad (7)$$

The value of α mostly depends on C_2. After we get the value of attenuation coefficient (α), we can calculate the loss occuring in bending waveguide. The total loss (dB) is [3]:

$$Loss(dB)=\frac{10}{log_e(10)}(\alpha s) \quad (8)$$

We can subtitute $\frac{10}{\log_e(10)}$ = (4.34), so we can calculate loss (dB) become:

$$Loss(dB)=(4.34)(\alpha s) \quad (9)$$

Where, $s=\varphi r$

B. Radiation Loss of Sinusoidal Bending Waveguide

The radiation loss of sinusoidal bending waveguide is:

$$Loss(dB)=\left\{\frac{10}{\log_e(10)}\right\}\int_0^L C_1 e\left(-C_2 r\right)dx \quad (10)$$

We subtitute the value of r in (10) with (6). To obtain the following equation [2]:

$$Loss(dB)=\left\{\frac{10}{\log_e(10)}\right\}C_1\int_0^L e\left\{-\left(\frac{C_2L^2}{2\pi l}\right)\frac{1}{\left|\sin\left(\frac{2\pi x}{L}\right)\right|}\right\}dx \quad (11)$$

Equation (11) shows the loss of sinusoidal bend waveguide.

III. Results and Discussion

The loss of bending waveguide can be computed analytically. In this chapter we will obtain the comparison of radius curvature and radiation loss between two S-bend geometries. In back-to-back structure the radius curvature is higher than sinusoidal structure. Fig. 2 show the comparison of radius curvature between back-to-back and sinusoidal structure.

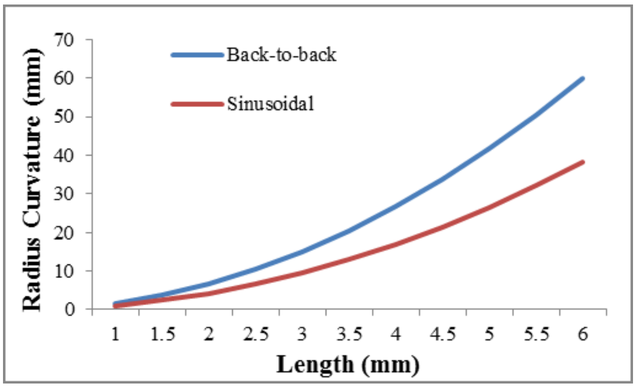
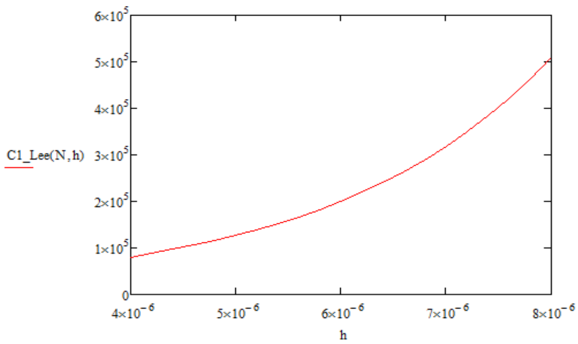


Fig. 2. The radius curvature comparison for back-to-back and sinusoidal structure

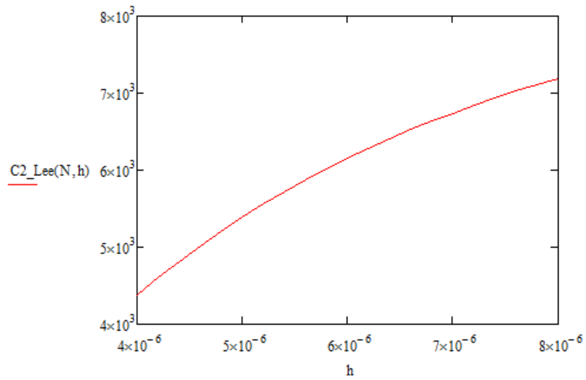
It is evident that sinusoidal structure have lower radius curvature than back-to-back structure. The difference radius curvature can affect to the radiation loss of bending waveguide for every value of L.

A. *Simulation Results of C_1 and C_2 Value vs Width of the Core*

To find C_1 and C_2 we use (7) and (8). The following graphics show the changes of value C_1 and C_2 versus width of the waveguide core which will increased exponentially while the width increased.



(a)



(b)

Fig. 3. Comparison of C_1 (a) and C_2 (b) value versus width of the core

The value of C_1 and C_2 as a parameter function that not affected by the radius curvature. For the radiation loss, it will more affected by the value of C_2.

B. *Bending Loss of Back-to-Back and Sinusoidal Structure*

The following is the result simulation to find loss of bending waveguide back-to-back and sinusoidal structure. For back-to-back bend, we used equation (5). In this calculation, the parameters are λ = 1.550 µm, h = 7 µm, $\varphi = 40^0$ assumed, and l is fixed at a value of 150 µm, while L is variable over the range of 1 mm – 6 mm, with different Δn .

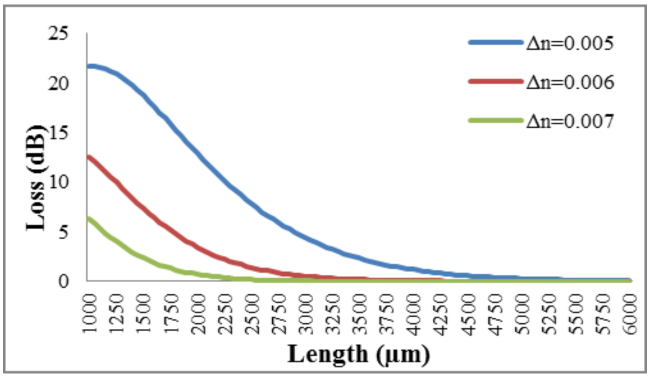


Fig. 4. Back-to-back bend loss as a function of radius curvature, for several values of Δn

Fig. 3 shows that significant reduction by increasing Δn in the bend loss. For example at Δn =0.005 µm, the loss is higher than Δn =0.006 µm, and Δn =0.007 µm. The radiation loss on back-to-back Δn =0.005 decreased to zero value with a curvature radius at 5500 µm. While on Δn =0.006 µm it will zero at 3500 µm, and on Δn =0.007 µm at 3000 µm. It means the higher value of length then the bend loss will decreased.

For sinusoidal bend, we used (11) and obtain the radiation bending loss using the same parameters as back-to-back and also the value of C_1 and C_2.

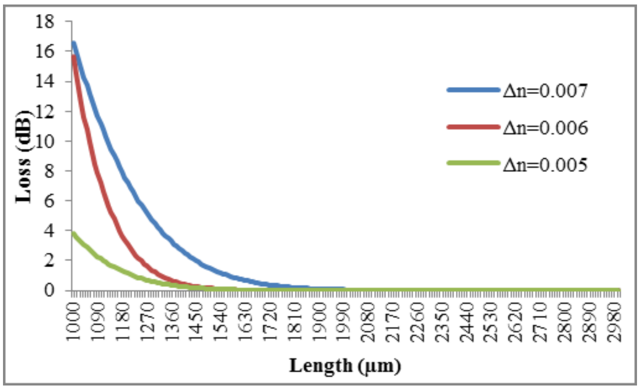


Fig. 5. Sinusoidal bend loss as a function of the transition length, for several values of Δn

Fig. 5 also shows that significant reduction by increasing Δn in the bend loss. When the value of transition length increased, the bend loss is decreased. At Δn =0.005 the radiation loss get zero value at transition length 1990 µm. While at Δn =0.006 it get the zero value on 1540 µm, and at Δn =0.007 on 1450 µm.

C. *Comparison Bending Loss of Back-to-Back and Sinusoidal Structure*

The following results will compare the bending loss for Δn=0.005 µm. It can be seen that the loss in back-to-back is higher than in sinusoidal structure. These simulation using same parameters.

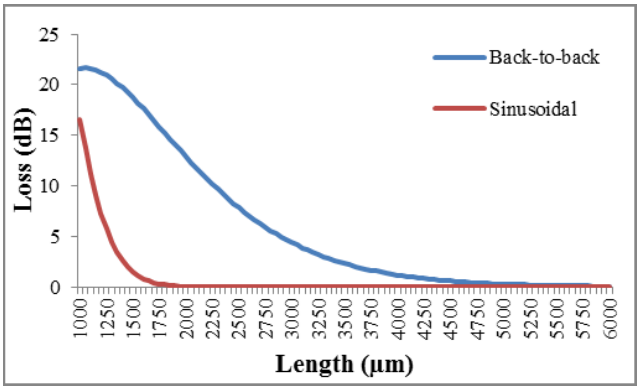


Fig. 6. Comparison between bend loss in back-to-back and sinusoidal structure

The loss still appear in transition length of 5000 μm for back-to-back structure, but in sinusoidal structure, it disappear at transition length of 2000 μm. The radiation loss in back-to-back structure will occured in more wider transition length value than sinusoidal structure.

IV. Conclusions

The radius curvature and the radiation loss in two different geometries is different. From the comparison of the radius curvature, we obtained that the changing value of radius curvature is higher in back-to-back than in sinusoidal structure for every increasing value of transition length. If we use back-to-back geometry which is the change of loss depends on curvature radius, then the radiation loss higher than sinusoidal bends that use a changing transition length to calculate its radiation loss. It happened because the sinusoidal structure is more smooth and continuous along the transition length. When the differences value of Δn is decreased, the radiation loss become higher. It can happen because the changing of Δn will affect effective refractive index, which will change the value of C_1 and C_2. The characteristics between back-to-back bend and sinusoidal bend different at the value of loss obtained. Acknowledgment

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IEEE Catalog Number : CFP14A95-CDR
ISBN 978-1-4799-8477-0