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Characteristics of Coupling Degradation Tolerances for Single-Mode Optical Fiber

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Abstract

The coupling tolerances is considered as an important parameters for the optical designer and it can not be ignored. Since the coupling efficiency is affected by the displacement of the optical components during the thermal expansion and the assembling processes, so, the coupling tolerances are just as important as coupling efficiency in the assessment of the optical coupling system. In this research the coupling tolerances for laser source to single mode optical fiber have been analyzed, these tolerances include: lateral offset, angular misalignment (tilt) and longitudinal offset for the optical fiber, also the tolerances values have been limited, our criteria is (-4dB) as coupling loss to point the tolerance of the coupling efficiency versus the misalignment in the optical coupling system.

Keywords: Coupling Efficiency, Misalignment Fiber Tolerances, Coupling Tolerances

خصائص سماحيات انحدار الاقتران لليف بصري أحادي النمط

الخلاصـــــــة

تعتبر سماحيات الاقتران من العوامل المهمة للمصمم البصري ولا يمكن إهمالها. ولان كفاءة الاقتران تتأثر بإزاحة المركبات البصرية بسبب التمدد الحراري وعمليات التجميع, لذا فان سماحيات الاقتران لا تقل أهمية عن كفاءة الاقتران عند تقييم منظومة الاقتران البصرية. تم في هذا البحث تحليل سماحيات اقتران مصدر ليزر مع ليف بصري أحادي النمط، وتتضمن هذه السماحيات: الإزاحة الجانبية، الإزاحة الزاوية (الانحناء) و الإزاحة الطولية لليف البصري. وتم كذلك تحديد قيم هذه السماحيات, وأعتمد المعيار في ذلك (-4dB) كخسائر اقتران لتعيين سماحية كفاءة الاقتران مقابل فقدان الترصيف في منظومة الاقتران البصرية.

1.Introduction

In response to rapid advances in optical fiber technology, workers around the world are developing a wide variety of passive optical components, such as couplers, switches, and wavelength multiplexers, for manipulating and processing the signal in fiber; and significant interest in single-mode fiber (SMF) and long-wavelength laser diodes (LD) has created a need for such components that can be used with SMF. Most of these components include some form of optics, such as lenses or mirrors, for collecting light from a source fiber or a laser and concentrating it on a receiving fiber or fibers.

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These components always exhibit optical coupling loss, which is completely determined by the degree to which the optics depart from ideal, that is, by the aberrations and misalignment tolerances of the optical system. This means that a component designer, in the process of optimizing coupling efficiency (CE), can make beneficial use of the enormous body of knowledge that already exists concerning classical optical imaging systems[1].

However, because butt joints provide poor coupling efficiency, numerous technologies have been proposed for reducing coupling loss at the LD-SMF joint. These coupling technologies can be divided into four categories, Microlens technology of extremely short focal length, large lens technology, such as a hemispherical gradient-index (GRIN) rod lens, confocal two lens technology, where two relatively large lenses are positioned in a nearly confocal arrangement, lenses and virtual fiber technology, where the virtual fiber is formed by attaching a GRIN rod lens to the input end face of the SMF. This results in a virtual fiber spot size, which is larger than the SMF spot size[2,3].

This paper describes all of the misalignment fiber tolerances for large convex coupling lens. The maximum CE and misalignment fiber tolerances are compared and discussed for same LD, SMF. Three lens selected with different focal number F# (0.8, 0.81 & 0.82), to focusing the light on the fiber.

2. Coupling Scheme

To improve the coupling of a laser diode to a single-mode fiber, an elliptical laser diode emitting spot must be transformed by a lens circuit to match a circular single mode fiber mode profile. For a single lens circuit, an optical focal length f_{opt} is [4]:

$$f_{opt} = p w_1 w_0 / l \qquad \ldots\ldots\ldots\ldots..1$$

Where, w_1 and w_0 are spot sizes of laser diode and a single-mode fiber, respectively, and l is a wavelength.

The general configuration for the large lens coupling technology and the misalignment fiber tolerances are shown in Fig. 1. in this technology a convex large lens positioned between the LD and SMF.

3. Results & Discussion

Figures (2,3 and 4) represent the power coupling loss in (dB) as a function of the lateral offset, angular misalignment and axial misalignment for three different convex lenses. In the following discussions, the measured values correspond to a -4dB coupling loss. The calculated fiber tolerances values are summarized in Table-1.

a- Lateral Offset

Figures (2a-c) demonstrate the power coupling loss as a function of the lateral offset tolerance. From these figures one can see that the tolerance different in the X- axis than in the Y-axis, where these directions represent the location of the fiber with respect to the exit pupil of the lens, since the intensity distribution in Y-direction is grater than that in the X-axis at the exit pupil (far-field pattern), the lateral or displacement tolerance in the Y-axis (10.004µm) is higher than that in the X-axis(6.7µm), Table-1.

The Lens F# affects the fiber coupling tolerance which relate with focal length and this in turn related beam spot size, these can be expressed by the following well-known formulas[5]:

$$F\ \# = \frac{f}{D} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$w = \frac{l\, f}{D\, p} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where:

F# : lens F-number
D : lens diameter
f : lens focal length
w :spot size of the light beam

From table-1 it is clearly that the lateral offset tolerances increase as a function of lens F#, this relation can be seen clearly in figure (2-d).

This difference between the degradation characteristics of the power coupling loss caused by SMF offset can be expressed by the following equations[2, ,6,7]:

$$h = \exp-\left(\frac{x^2}{w^2}\right) \qquad \ldots\ldots\ldots\ldots\ldots(4)$$

Where, *X* is the offset of the SMF, *h* represent the coupling efficiency. As shown in equation.4, a large spot size can increase the lateral offset tolerance.

b- Angular Misalignment

Figures (3a-c) show the power coupling loss with respect to the angular misalignment. The angular misalignment tolerance expands around the X-axis while, it tight around the Y-axis. Since the larger lens F# (spot size) reduces the angular misalignment tolerance in accordance with the following equation[2,6,7]:

$$h = \exp-\left(\frac{p^2 w^2 q^2}{l^2}\right) \qquad \ldots\ldots\ldots\ldots(.5)$$

Where θ & λ are the angular misalignment and laser diode wave-length, respectively. Figure (3-d) show the relation between F-number & angular misalignment tolerance around X & Y-axis, and this relation can be seen in Table-1.

C- Axial Misalignment

Figures (4a-c) observed the relation between power coupling loss and axial misalignment tolerance at three different F-numbers. As shown in Table-1, the large lens F# relaxes the axial misalignment tolerance, as shown in the following equation[2,6,7].

$$h = \frac{1}{1 + \left(\frac{l\, z}{2\, p w^2}\right)^2} \qquad \ldots\ldots(6)$$

Where z designates the axial misalignment. Figure(4-d) shows this relation, where at the -4dB the axial misalignment tolerance have a direct relation with the lens F#.

4. Conclusions

The results shown a direct relation between the lens F# and the lateral offset, Axial misalignment tolerances, while the angular misalignment tolerance is proportional inversely with F#.

Also it is observed that the lateral misalignment tolerance in the X-axis is more sensitive to the optical alignment than the lateral misalignment in the Y-axis. While, in the angular misalignment tolerance in the Y-axis is more sensitive than in the X-axis.

The results shown that the lateral offset tolerance is more important in laser diode module fabrication than the angular misalignment tolerance.

However, it is important to note that the angular misalignment tolerances cause no problem in laser diode fabrication & construction processes, because the angular misalignment of the light beam can compensated by adjusting the other lens during the assembling process.

5.References

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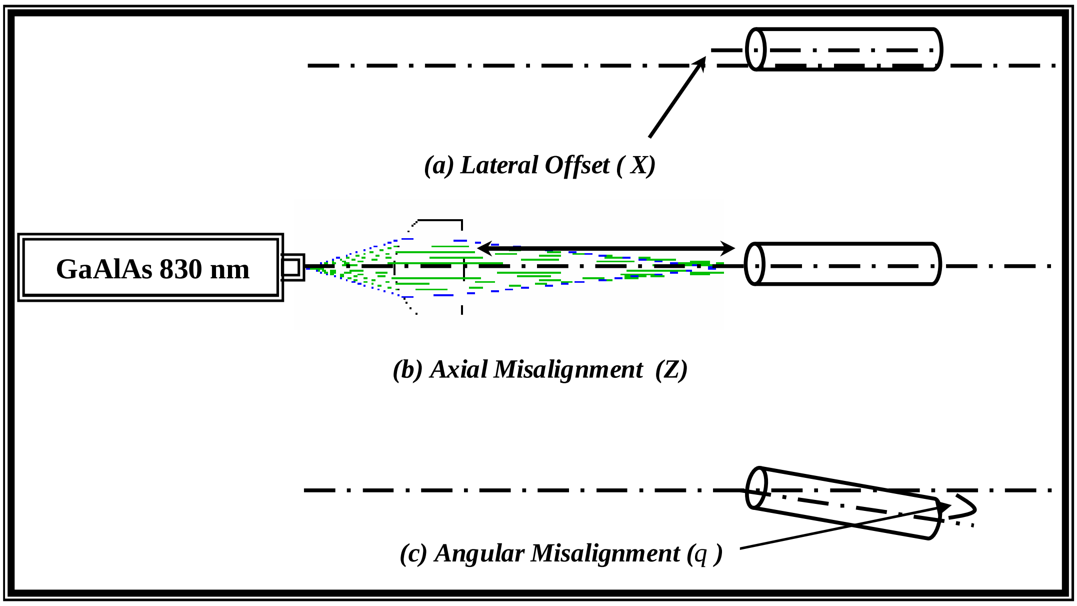
Table-1 Calculated Fiber Tolerances at -4 dB Power Coupling Loss

F-number	***Fiber Tolerances at -4 dB power coupling loss***				
	Lateral Offset (mm)		**Tilt (degree)**		**Axial Misalignment (mm)**
	X-axis	**Y-axis**	**X-axis**	**Y-axis**	
0.82	**6.7**	**10.004**	**0.951°**	**0.781°**	**833.6**
0.81	**6.6**	**9.668**	**1.076°**	**0.8 62°**	**676.8**
0.8	**6.3**	**8.907**	**1.14 2°**	**0.9005°**	**494.5**



Figure(1) The Coupling Schemes and Fiber Misalignment Tolerances

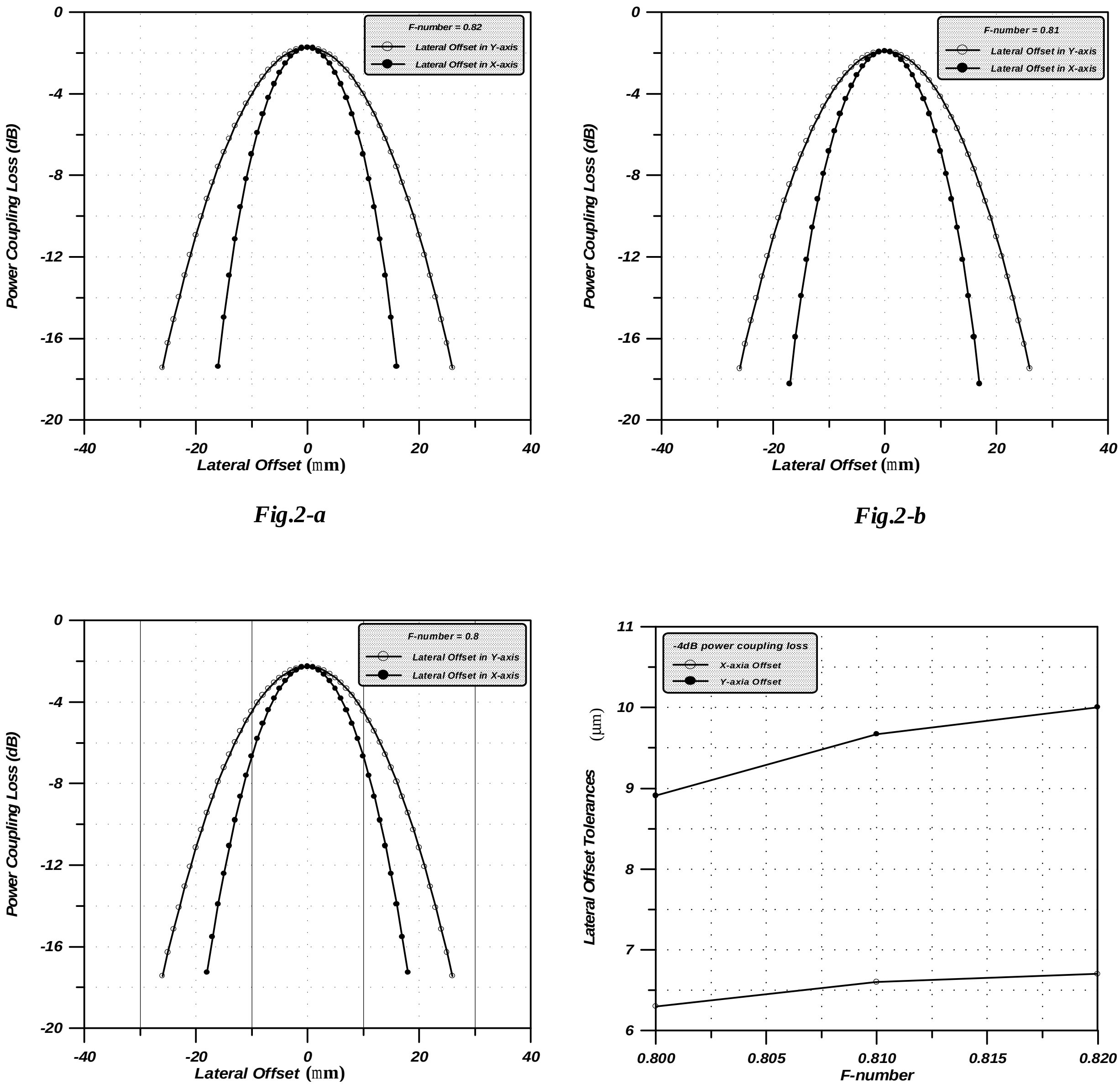


Fig.2-a

Fig.2-b

Fig.2-c

Fig.2-d

Figure -2 The lateral offset tolerance for three different F-numbers
a-for F-number = 0.82
b- for F-number = 0.81
c- for F-number = 0.8

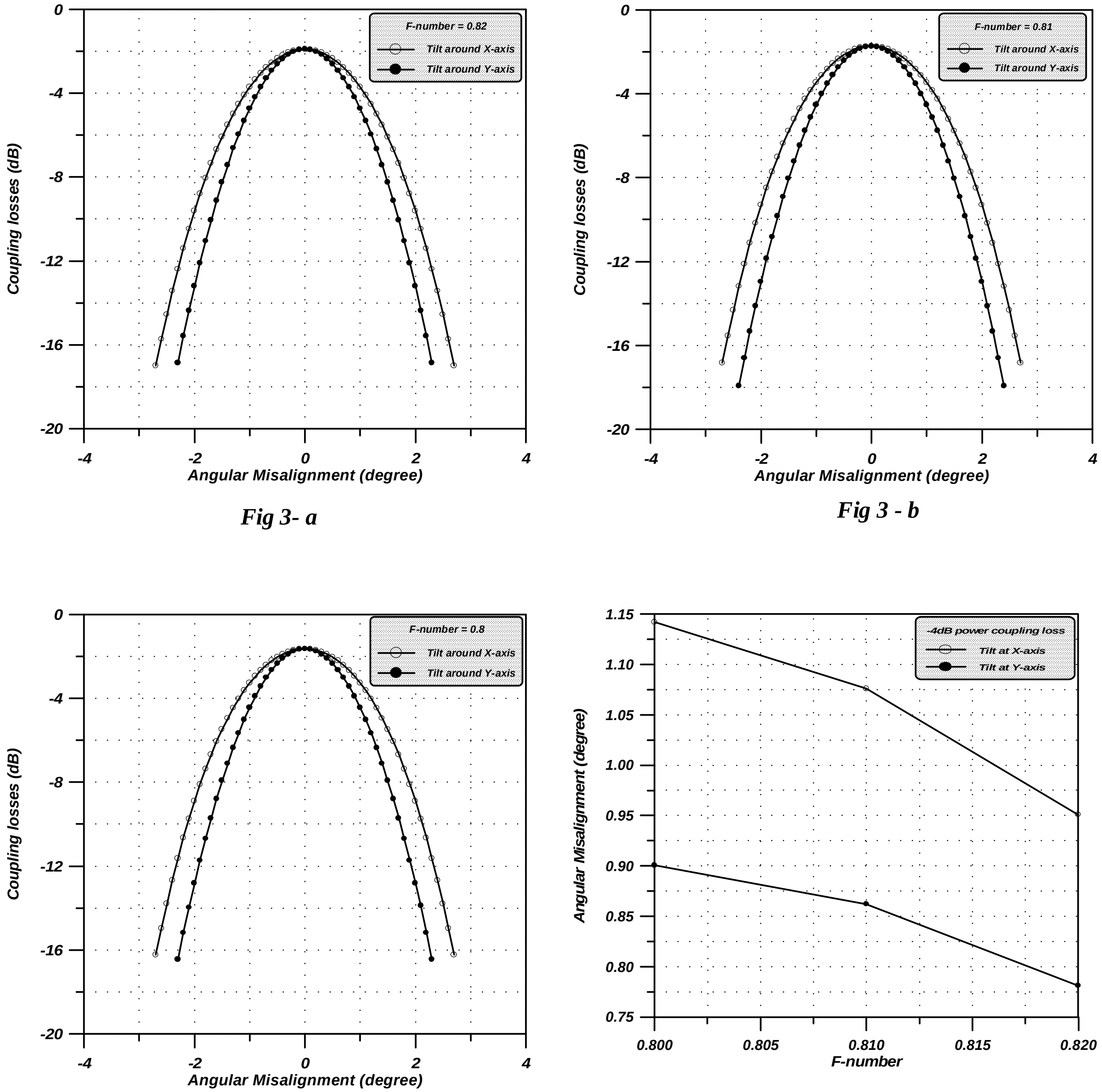


Fig 3- a

Fig 3 - b

Fig 3- c

Fig 3- d

Figure -3 The angular misalignment tolerance for three different F-numbers
a-for F-number = 0.82
b- for F-number = 0.81
c- for F-number = 0.8

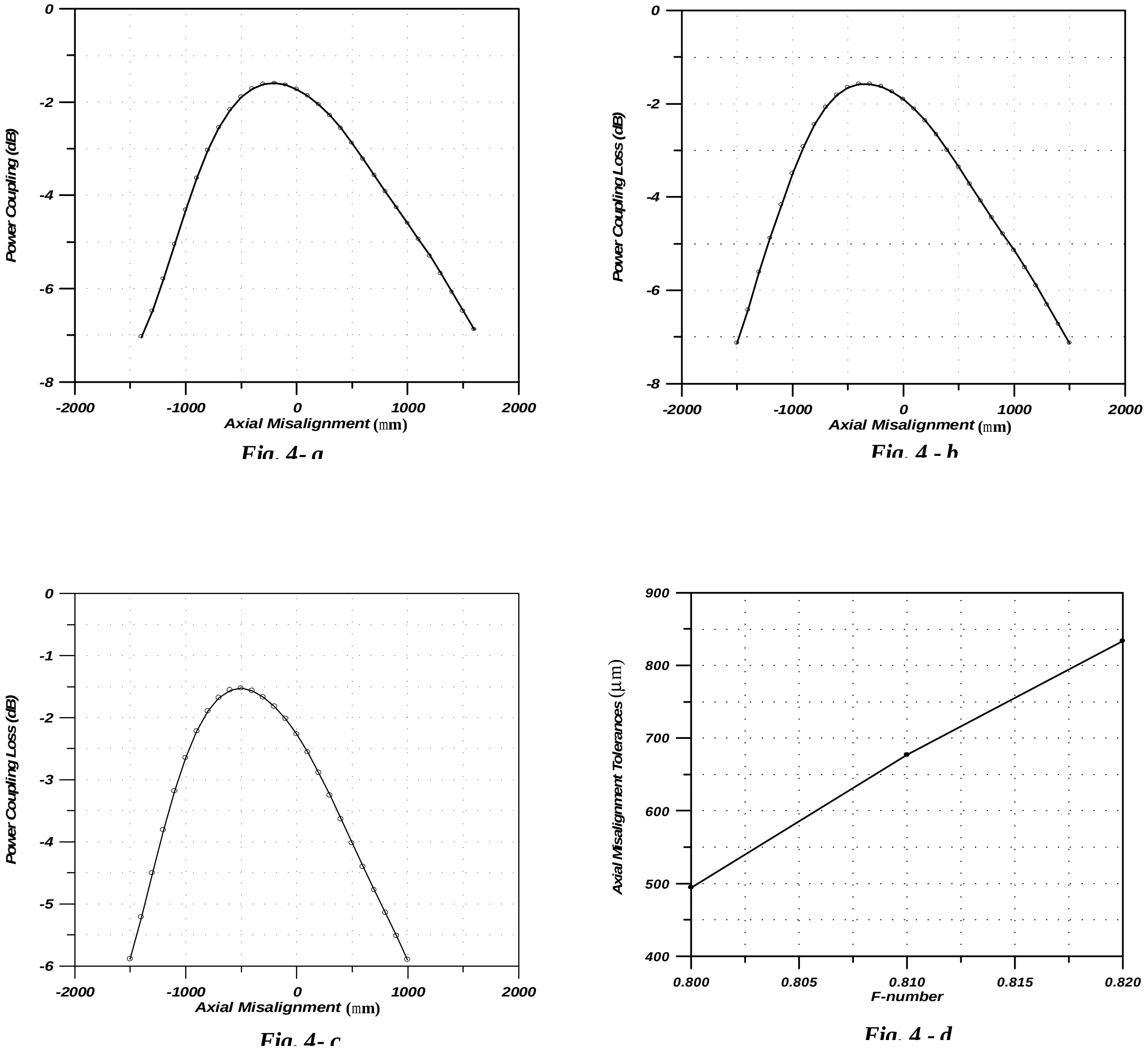


Fig. 4- a

Fig. 4 - b

Fig. 4- c

Fig. 4 - d

Figure-4 The axial misalignment for three different F-number
a-for F-number = 0.82
b- for F-number =0.81
c- for F-number =0.8