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# Optimum design of aspheric collimation lenses for optical antenna system

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ABSTRACT

Three kinds of aspheric collimation lenses for optical antenna have been design by optimization. The aspheric cylinder collimation lenses with aspheric surfaces (such as elliptic, hyperbolic and parabolic marginal profiles) have been researched for the semiconductor laser beam with the characteristic of dot emitting source. Based on genetic algorithm and the optimization toolbox of MTLAB, the divergence angle has been optimized. The collimation divergence angle is less than 115 μrad has been measured by laser beam analyzer. This optimum design laser beam collimation lenses as a pre-collimation system can be used for optical antenna system. And it can be widely used in modern space laser communication.



## 1. Introduction

Because of several unique characteristics, such as small dimension, low cost, high input-to-output conversion efficiency, high-speed, and direct modulation, semiconductor are considered advantageously used as a light source in space laser communications [1,2]. There are two major application areas for space laser communications [3,4]. One is space communication for long distance (more than 100 km) and the other is infrared wireless communication for short distance (up to several kilometers) on ground.

The main shortcoming of semiconductor is the astigmatic beams with elliptically shaped mode profiles due to the shape and the waveguide properties of their active areas [5]. For high-precision applications such as space laser communication, optical interconnections and high power fiber coupling, nonastigamtic and spherical laser beams are desirable [6]. Therefore, collimation technology is important to deal with the different divergence property of laser beam space laser communication system possesses a tiny beam divergence of the laser beam [7], and its optical systems must have the function of acquisition, tracking and pointing (ATP).

Especially for the long distance space laser communication, the laser beam divergence angles are need to be collimated both in meridional plane (i.e., fast axis direction) and in sagittal plane (i.e., slow direction). In general, the divergence angles $\alpha_x$, $\alpha_y$ are different, which is shown in Fig. 1.

Optical design of laser beam shaping system has evolved considerably from the early work of Frieden and Kreuzer during the 1960's to the contemporary work of many summarized in Refs. [8–11]. Frieden computed the shaping of an aspherical refracting surface that would re-collimate the output beam parallel to the optical axis and also to the input beam. Keuzer imposed the constant optical path length condition for all rays passing through the beam shaping optics to control phase variation of the output beam. Unfortunately, optical design and fabrication technologies were generally not adequate until recently.

Optical design of beam shaping systems can be achieved using either physical or geometrical optics [8,9]. Based on the researched rules [10,11], we will discuss collimation lenses by geometrical optical principle. And consider the real manufacture, the cross section margin curves for aspheric lenses, such as ellipse, hyperbola and parabola cylinder lenses have been discussed in this paper.

## 2. Optical antenna structure

Optical antenna, such as reflective telescopes can be widely used in the fields of laser communications and remote sensing technology [3,4,12].

The optical antenna is the most important component of the laser communication, and the pre-collimation technology (collimation lenses design) is a key for optical antenna system.

We design optical antenna system structure is shown in Fig. 2. It includes collimation lenses system and Cassegrain telescope system. The Cassegrain system consists of two reflecting surfaces, i.e., a concave parabolic primary mirror and a convex hyperbolic

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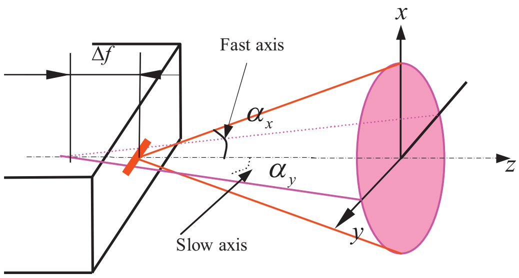


**Fig. 1.** Laser beam emission character for semiconductor.

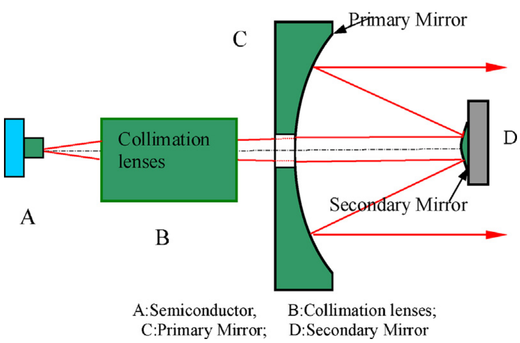


**Fig. 2.** Optical antenna (includes collimation lenses).

secondary mirror. Each part (A, B, C, D) has been listed in the following Figure. In this paper, we will mainly research the collimation lenses for the optical antenna system.

For a laser transmitter, the magnification of the telescope serves to decrease the divergence of the beam, thus making it spread out less. This kind of optical telescope can get much higher gain than other kinds. By this optical antenna, the laser light beam is transmitted in space. At last, the acquisition/tracking laser beam is focused onto a CCD camera sensor which tracks the spot and drives the gimbals system.

## 3. Theoretical analysis for collimation lenses

In optical communication system, we choose a semiconductor with wavelength 860 nm. It possesses an emitting source area (1 μm × 3 μm) laser beam character. The divergence angles of this semiconductor are asymmetric between in fast axis and in slow axis direction. It possesses the maximum divergence half angle for $\alpha_{x\max} = 14^\circ$, $\alpha_{y\max} = 9^\circ$, respectively.

A cylinder lenses collimation system with marginal profiles, such as ellipse, parabola or hyperbola have been designed, respectively. It is shown in Fig. 3. The first cylinder lenses are used to collimation the fast axis direction, and the second is used to collimation the slow axis direction.

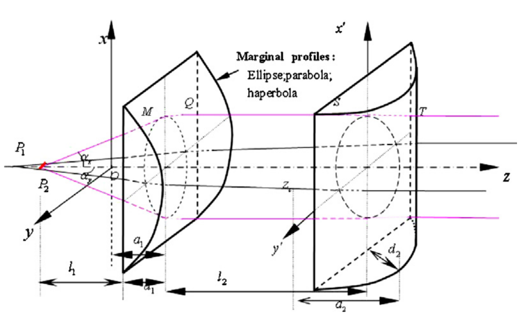


**Fig. 3.** Collimation lenses system.

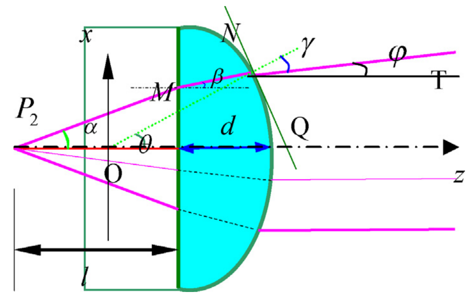


**Fig. 4.** Elliptical cylinder lenses collimation system.

### 3.1. Design for ellipse cylinder lenses collimation

The laser source emits beam from point $P_2$ for fast axis direction, and $P_1$ for slow axis direction. First, we design an aspheric cylinder lenses to collimation the divergence laser beam for meridional plane (i.e., fast axis direction). And then, the same theoretical analysis can be suitable for sagittal plane (i.e., slow direction).

The cylinder margin profiles is design as ellipse form to collimate the fast axis divergence laser beam, it is shown in Fig. 4 for meridional plane. Based on geometrical optics theory, we can trace the light rays such as $P_2M$, $MN$, $NT$.

The ellipse equation can be described as

$$\frac{z^2}{a^2} + \frac{x^2}{b^2} = 1 \tag{1}$$

Let

$$e = \frac{b}{a} \tag{2}$$

(It can be optimum design in simulation program). Especially, if $e = 1$, it can be degenerated to the circle situation.

We can obtain the straight line equation for PM:

$$x = (z - a + d)\tan\beta + l\sin\alpha \tag{3}$$

Please pay attention to the tangential line NQ of point $N$ is perpendicular to the normal line of N point for the curve, so we can obtain

$$\tan\theta = \frac{a^2}{b^2}\frac{x_N}{z_N} \tag{4}$$

By the formulas (1), (2), (4), we have

$$z_N = \frac{a}{\sqrt{1 + e^2\tan\theta}} \tag{5}$$

By the formulas (2), (3), (4), we have

$$z_N = \frac{l\tan\alpha + (d-a)\tan\beta}{e^2\tan\theta - \tan\beta} \tag{6}$$

Therefore

$$\frac{l\tan\alpha + (d-a)\tan\beta}{e^2\tan\theta - \tan\beta} = \frac{a}{\sqrt{1 + e^2\tan\theta}} \tag{7}$$

By Eq. (7), we can obtain

$$\tan\theta = \frac{-a^2\tan\beta \pm \sqrt{(a\tan\beta)^2 - (p^2 - a^2)[p^2 - a^2\tan^2\beta]}}{p^2 - e^2a^2} \tag{8}$$

where we have let $p = l\tan\alpha + (d-a)\tan\beta$.

According to the physical meaning, i.e., real situation, we can selection the plus or minus sign.

By the refraction law, we can obtain the refraction angle $\beta$ is the function of $\alpha$. i.e., $\beta = \arcsin[(\sin\alpha)/n]$. And $\gamma = \arcsin[n\sin(\theta - \beta)]$.