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Propagation and properties analysis of inclined optical antenna

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The optical antenna possesses an aspheric surface collimation lenses system, and a con-focal parabolic-hyperbolic structure has been optimally designed. It is made up of one-dimensional photonic crystal material structure to make it achieve a high reflection. Laser beam propagation properties for the optical antenna with inclined optical axis have been analyzed in details. The curve of power attenuation are obtained for the off-axes situations. And the three-dimensional power distribution of laser beam for the received optical antenna is simulated for different deflection angles. The power attenuation ratio of optical antenna system correspond to some special inclined angles have been tested.

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1. Introduction

Space laser communication system possesses a tiny beam divergence of the laser beam, and its optical systems must have the function of acquisition, tracking and pointing(ATP)[1].

Many researches for optical axes are assumed aligned in the ATP. While in practical applications, precise optical axes alignment are difficult[2]. When the optical axis misalignment occurs, the corresponding antenna gain, antenna coupling efficiency, communication distance will be affected, so the research for optical antennas with inclined optical axis is necessary[3,5].

2. Structure for optical antenna

Optical antenna possesses a collimation lenses system and a con-focal parabolic-hyperbolic structure , which is shown in Fig.1. Where 1: semiconductor; 2: collimation lenses system;3:Primary Mirror; 4:Secondary mirror. The optical antenna includes two reflecting surfaces, a convex hyperbolic secondary mirror and a concave parabolic primary mirror. It is made up of one-dimensional photonic crystal material structure to make it achieve a high reflection.

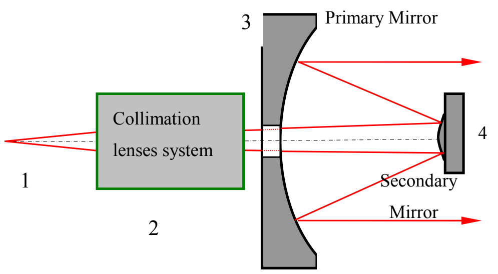


Fig.1 The structure of optical antenna system

The collimation system is shown in Fig.2, its structure parameters has been optimally designed by CODE-V. Meanwhile, as we design the structure parameters , we have synthetically considered the real fabrication situation for the optical lenses , and the minimum wave aberration.

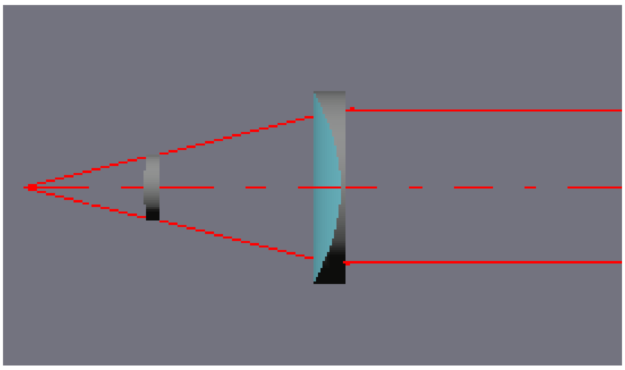


Fig.2 The structure of collimation lenses system

3.Theoretical analysis for optical antenna

3.1 Theoretical model for optical antenna

We assume the emitted laser beam of the semiconductor as Gauss laser beam, its wavelength is λ=830nm .By theoretical analysis, the electric field distributing of Gaussian beam can be described as [6]

$$E(z)=\frac{C}{\omega(z)}\exp\left(-\frac{r^2}{\omega^2(z)}\right)\exp\left\{-\mathrm{i}\left[k\left(z+\frac{r^2}{2R}\right)-\arctan\frac{z}{f}\right]\right\} \quad (1)$$

The power of the beam in the cross section is

$$|E(r)|^2=C^2/\omega^2(z)\exp[-2r^2/\omega^2(z)] \quad (2)$$

$$|E(x,y)|^2 = C^2/\omega^2(z)\exp[-2(x^2+y^2)/\omega^2(z)] \quad (3)$$

Where $\omega(z)=\omega_0\sqrt{1+[\lambda z/(\pi\omega_0^2)]^2}$, and C is a constant coefficient.

3.2 Optical antenna with off-axes situations

Supposing the optical axes for two optical antenna are out of alignment, i.e., off-axes situation, and we assume that the rest subsystem optical axes are all aligned. As shown in Figure 3, the received antenna deflection angle is γ , and we assumed the distance between the primary mirror and the secondary mirror is l .

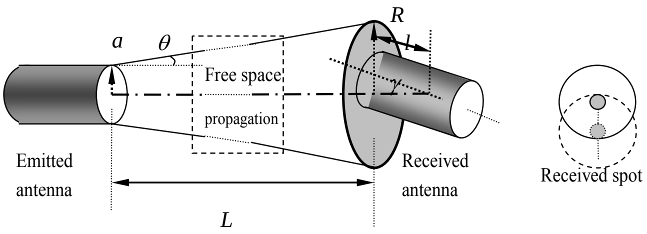


Fig.3 Optical antenna inclined situation.

Based on the theory of laser beam propagation, the receiving power through the receiving antenna are the two laser beam overlaps (include emitted antenna and received antenna). The elliptical laser beam is obtained in the case of the off-axes, circular laser beam is obtained for the optical axis is of alignment. The influence of the off-axes to the optical antenna properties is usually represented by power attenuation in different deflection angles.

We assume the axis of emitted antenna is the same as the standard axis, and the emitted power can be described as

$$P=\int_0^{2\pi}\mathrm{d}\theta\int_b^a |E(r)|^2 r\mathrm{d}r \quad (4)$$

where a ,b are the radius of primary mirror and secondary mirror respectively.

We assume the optical axis of received antenna is inclined at same deflection angle, it can be described as

$$P_r=\int_{x_1}^{x_2}\mathrm{d}x\int_{y_1}^{y_2}|E(x,y)|^2\mathrm{d}y \quad (5)$$

where x_1,x_2,y_1,y_2 are decided by integration region, which can be obtained by the off-axes real situation.

4. Simulation analysis for laser beam propagation for deflection optical antenna

4.1 Simulation for all overlap of laser beam

(1) If $\gamma \ge \arcsin(2a/l)$

There is no overlaps area for the focus spots of two laser beams for emitted and received optical antenna, therefore the transmission power of antenna system is zero.

(2) If $\arcsin[(a+b)/l] < \gamma < \arcsin(2a/l)$

It's overlaps beam can be approximately as a ellipse, whish is shown in Fig4(a),and its three-dimensions power distribution for the received optical antenna is shown in Fig5(a).

(3) If $\arcsin(2b/l) < \gamma \le \arcsin[(a+b)/l]$

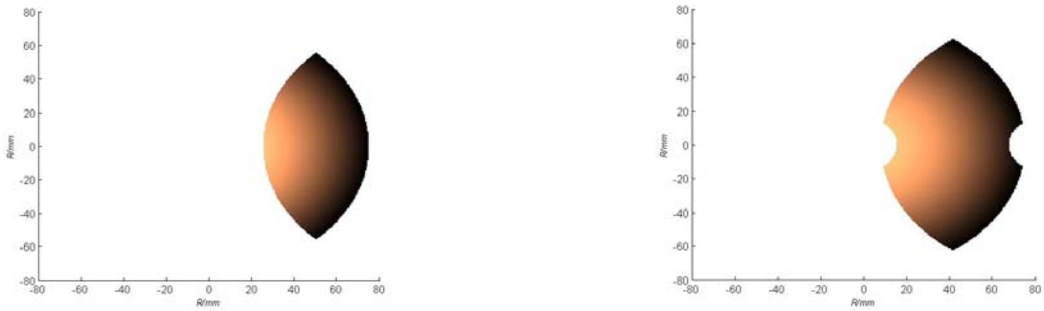
It's overlaps beam is shown in Fig4(b) ,and its 3_D power distribution is shown in Fig5(b).

(4) If $0 < \gamma \le \arcsin(2b/l)$

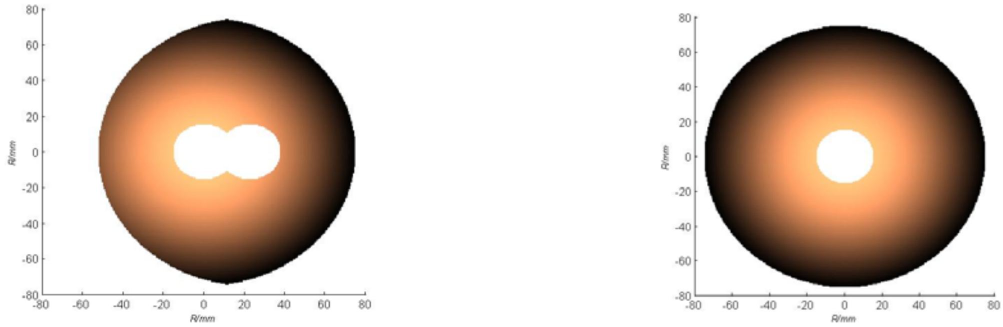
It's overlaps beam is shown in Fig4(c) ,and its 3_D power distribution is shown in Fig5(c).

(5) If $\gamma = 0$.

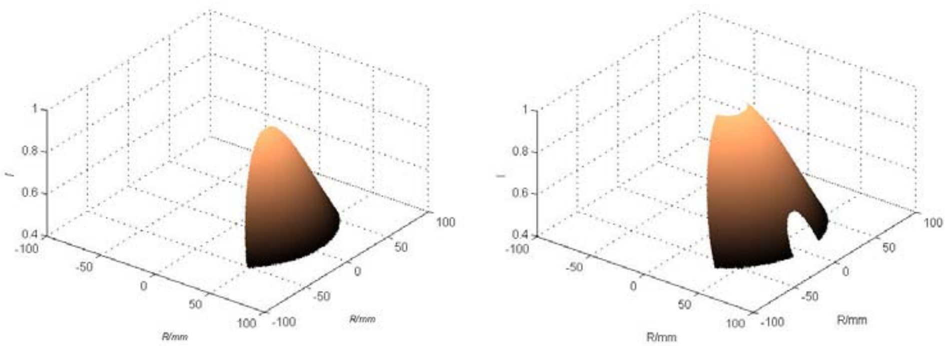
It's overlaps beam is shown in Fig4(d) ,and its 3_D power distribution is shown in Fig5(d).



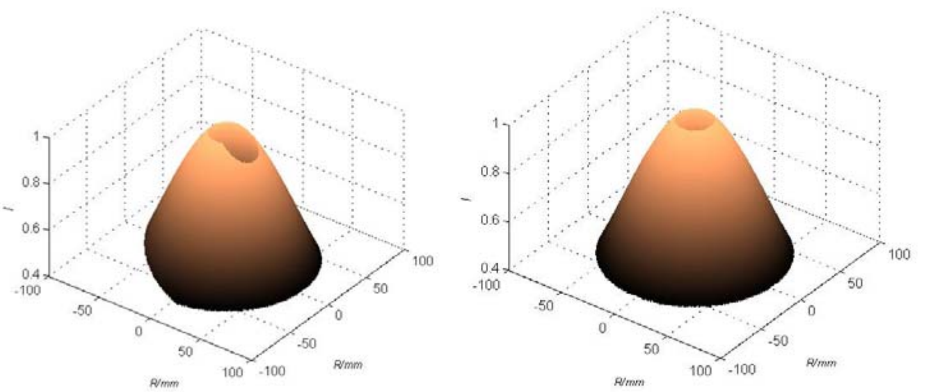
(a) (b)



(c) (d)



(a) (b)



(c) (d)

Fig.5 Three-dimensions power distribution for the received optical antenna

4.2 Power attenuation versus the deflection angle

Power attenuation ratio for the optical antenna system can be defined as

$$\frac{P_r}{P} = \frac{P_r}{\int_0^{2\pi}\int_b^a c^2/\omega^2(z)\exp[-2r^2/\omega^2(z)]rdr} \quad (6)$$

It will be changed with the optical axis of the receiving antenna misalignment occurs. The power attenuation ratio of the system varies with the change of deflection angle γ is shown in Fig.6. If γ more than 0.45rad, it indicates that the power attenuation quickly reduce to zero.

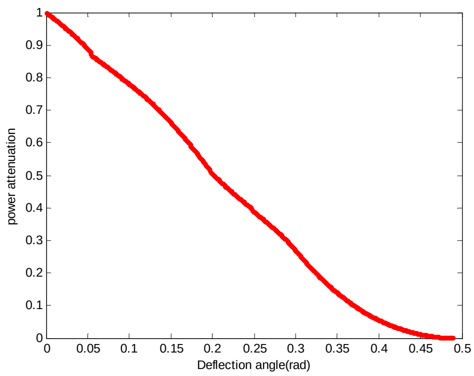


Fig.6 Power attenuation ratio versus angle γ

5. Test of the optical antenna system

5.1 Optical antenna experiment system

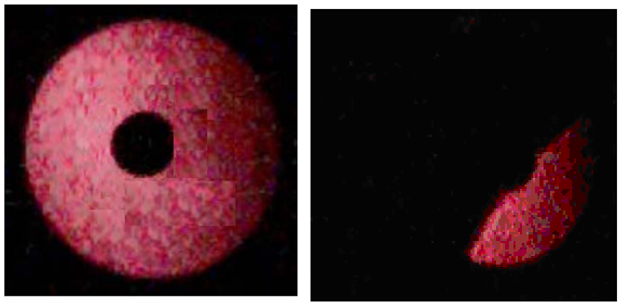
In accordance with the optimal design of the antenna structure, the optical antenna test system is shown in Figure 7. Attenuation plate has been designed for the experiment where the long distance 5000km is simulated as the short distance of 5m in Lab. The semiconductor laser, whose wavelength is 860nm and emitted power is 102.08mW tested by laser power indicator.

Fig.7 Optical antenna experiment system

5.2 Test for the laser beam in section surface

According to STREHL ratio, when the Power attenuation ratio is beyond 80%, the optical antenna system can be considered as in alignment, approximately. Experiment for the situation of optical axes alignment , the laser beam obtained by the receiving antenna is shown in Fig. 8(a). And in this case, the power attenuation ratio is tested as 80.97%, which correspond to γ = 0.091rad by simulation calculation.

In a inclined (i.e., misalignment) situation , the overlaps beam is tested. Which is shown in Fig.8(b).



(a) (b)

Fig.8 Test for the propagation of laser beam in section

In this misalignment situation, the power attenuation ratio is tested as 18.11%. According to the theory analysis , in this special case, the inclined angle of the receiving antenna is 0.342rad by simulation calculation. In practical optical communications , the optical axis should be adjusted until the power attenuation ratio P_r / P infinitely close to 1, which implements the precise alignment of the optical axis between transmitting and receiving antenna.

6. Conclusions

The optical antenna of space laser communication with one-dimensional photonic crystal material has been optimally designed. The three-dimensional power distributions of the laser beam for received optical antenna with inclined optical axis situation have been simulated. Power attenuation is changed with the deflection angle of received optical has been discussed .

By simulations, we can find that if the deflection angle increasing, the power attenuation reducing dramatically. When the deflection angle is more than 0.45rad, the receiving antenna could not receive any signal.

By experiments, the Power attenuation ratio of antenna system is obtained for some specific experiments. The power attenuation ratio of antenna system in one special case is 80.97%. According to the STREHL standard, we can judge that the optical axis is in alignment station , approximately .Of course, the misalignment situation should be prevented if possible. Which is useful in the application of optical communication system.

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