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Analysis the wavelength for off-focus Cassegrain optical antenna with incident Gaussian beam

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ABSTRACT

Cassegrain antenna has excellent transceiver characteristics, it is widely used in inter-satellite communication. Most researchers are only based on the on-focus antenna system. But in fact, some unpredictable factors, like slight impact or thermal deformation may make the primary and secondary mirror cannot be exactly on-focus. Therefore, the off-focus Cassegrain optical antenna system with incident Gaussian beam are researched in the paper. We conclude that the far field transmission gain is more sensitive to the wavelength of the laser than the energy in off-focus system. So in practical application, we must mainly consider the influence of wave length to the transmission gain. If the secondary mirror is set off-focus by 0.05 mm, the gain will change 20.9474 dB with long wave 1550 nm, and 79.8526 dB with short wave 633 nm. So use long wave laser in off-focus system is better.

1. Introduction

With the development of the times, the optical fiber communication and the inter-satellite communication technology has been developed rapidly. The Cassegrain antenna has some characteristics, such as the aperture can be very large, no chromatic aberration and has wide range of available band. When using the aspherical lens, it can eliminate the aberration greatly, and it can be a transceiver [1]. So the Cassegrain antenna is widely used in satellite communication stations and single-pulse radars.

But up to now, most studies of the Cassegrain antenna are mainly based on on-focus system. In fact, due to some factors like thermal deformation, to get the exactly on-focus will be hard. In the circumstance, which kind of wavelength should we use? So it is necessary to study the off-focus system. Besides, the radiation field of the laser resonator, whose amplitude distribution of cross section is abide by the Gaussian function. So it is necessary to study the received optical field distribution with incident Gaussian beam. And in the received plane, the gain is an important aspect, so we also discussed the far field transmission gain.

2. Analysis of the received optical field distribution with incident Gaussian beam in off-focus system

2.1. Theory analysis

With incident Gaussian beam, we analyze the light beam waist, deflection and the optical field in the off-focus system. Shown in Fig. 1, at the point of left focus of the secondary mirror is the feed source. The beam I deflected by the secondary mirror is equivalent to the transform of lens system, so the waist of beam II must be at the right focus of the secondary mirror.

For the waist of beam II

$$\omega_{02} = \frac{f_2}{f_1}\omega_{01} = \frac{\omega_{01}}{M} \tag{1}$$

where $M = f_1/f_2$ is the magnification factor of the secondary mirror, ω_{01} is the value of the waist of the primary mirror, f_1 and f_2 are the left and right focus length of the secondary mirror, separately.

In matrix optics, we know that the transformational matrix from beam II to III is

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & l \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 1/f & 1 \end{bmatrix} \begin{bmatrix} 1 & -d \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 + l/f & d - l - dl/f \\ 1/f & 1 - d/f \end{bmatrix} \tag{2}$$

in which d and l are the distance from the waist of beam II and III to the apex of the primary mirror, separately.

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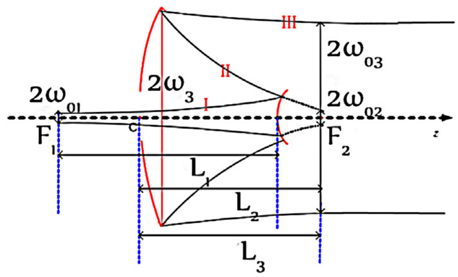

Fig. 1. Cassegrain antenna with Gaussian beam propagation.

From the knowledge of the matrix optics, we know that the compound curvature q from light beam II to III is

$$q = \frac{Aq_{02} + B}{Cq_{02} + D} \tag{3}$$

What's more, $q_{02} = i\pi\omega_{02}/\lambda$, $q = i\pi\omega_{03}/\lambda$. Substituting A, B, C, D to Eq. (3), we can yield that

$$l = \frac{f[M^4 d\Delta d - z_{01}^2]}{M^4 d(\Delta d)^2 + z_{01}^2} \tag{4}$$

$$\omega_{03} = \frac{Mf}{[z_{01}^2 + M^4(\Delta d)^2]^{1/2}}\omega_{01} \tag{5}$$

In which $z_{01} = \pi\omega_{01}^2/\lambda$, $\Delta d = f - d$.
If $d = f$, in on-focus system, we can yield that

$$\left|l\right| = f \tag{6}$$

$$\omega_{03} = \frac{Mf}{z_{01}}\omega_{01} = Mf\frac{\lambda}{\pi\omega_{01}} \tag{7}$$

That means the point of the waist of beam II and III is coincident.
Suppose the light beam from transmitting antenna is basal membrane Gaussian beam, that is [2,3]

$$E_0(r_0) = \sqrt{\frac{2}{\pi\omega^2}}\exp\left(-\frac{r_0^2}{\omega^2}\right)\exp\left(\frac{ikr_0^2}{2R}\right) \tag{8}$$

in which we do not care about diffraction, so

$$E_0(r_0) = \sqrt{\frac{2}{\pi\omega^2}}\exp\left(-\frac{r_0^2}{\omega^2}\right) \tag{9}$$

In Cassegrain antenna system, we use data below (Table 1)
Where f is the focal length of the primary mirror, D_1 and D_2 are apertures of the two mirrors. We suppose that the waist of the primary mirror $\omega_{01} = 2.578\ \mu$m to get the best $\alpha = D_1/2\omega_{03}$ parameter.
Choosing the view point is away from the apex of the primary mirror by 1 km, so waist radius of the view point is

$$\omega(z) = \omega_{03}\sqrt{1 + \left(\frac{z}{\pi\omega_{03}^2/\lambda}\right)^2} \tag{10}$$

Considering the shield effect of the secondary mirror, whose aperture is $D_2 = 30$ mm. Supplying it to Eqs. (9) and (10), when ω_{03} is decided by Eq. (7), we figured the Gaussian optical field in on-focus system and an of-focus system by moving 0.05 mm along the axis, shown in Fig. 2.

Table 1
Structure parameters of the antenna.

D_1, mm	D_2, mm	$\lvert M\rvert$	f, mm
150	30	3	300

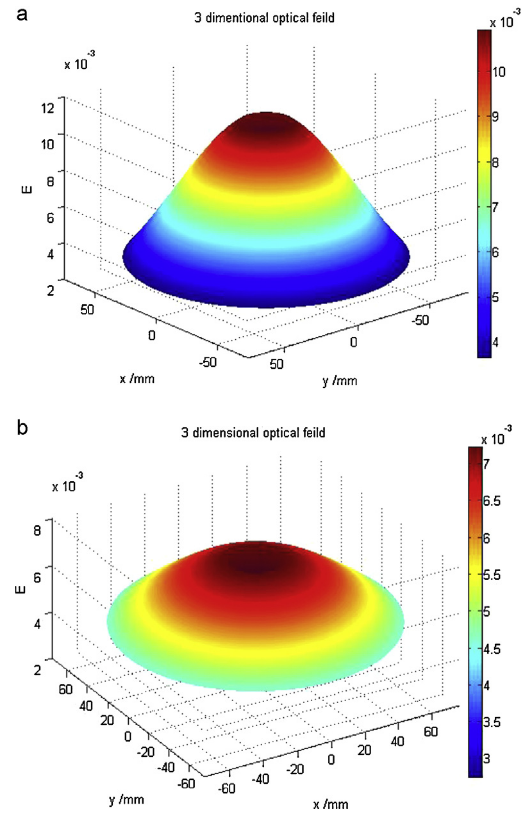

Fig. 2. (a) Gaussian received optical field in on-focus system. (b) Gaussian received optical field in off-focus system along the axis by 0.05 mm.

If the secondary mirror move along the axis, the received optical field will be changed, lower amplitude and even a little distortion, just as shown in Fig. 2(b)

2.1.1. *The limitation of the off-focus to show the image with no distortions*

Of course, the offset cannot be infinite, there is a limitation for it, if the offset is greater than that, there will be great distortion.

Considering the Strehl ratio: 80% is commonly known as the diffraction limit of an optical system. So the luminous power for an optical system below this limit is not assumed to have satisfactory performance. Then we calculate the luminous power which the receiving surface get, $P = \int_0^{2\pi}\int_0^{\infty}\left[\left|E(r)\right|\right]^2 r dr d\varphi$, in which E is given in Eq. (9), and we have found the cut off.

2.1.2. *Discussion with the cut off of* Δd

We use different wavelength of laser, including helium-neon laser ($\lambda = 632.8$ nm), and infrared laser ($\lambda = 1064$ nm and $\lambda = 1550$ nm), to get the relationship between E and Δd, shown in Fig. 3. Suppose $\Delta d = f - d$ is the off-set.

From Fig. 4, the line $E = 0.8$ is described in solid line, whose abscissa of the intersection points with the 3 curve are 0.053, 0.062, 0.068, separately. So we can yield that if we use helium-neon laser, while the secondary mirror move along the axis by 0.068 mm, the image cannot be distinguished. Or 0.062 mm and 0.053 mm for $\lambda = 1064$ nm and $\lambda = 1550$ nm. So if the system is off-focus, use short wave laser seems better. But we can know that it is not too much influence by the wave. Below we can see that the far field transmission gain is more sensitive. And the longer wave is better.