Optik 126 (2015) 795–798

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Improving transmission efficiency of Cassegrain antenna

Mingyin Yu, Ping Jiang*, Huajun Yang, Yuchun Huang, Xiaojun Ma, Bing wang

School of Physical Electronics, University of Electronic Science and Technology of China, Sichuan Province 610054, China

ARTICLE INFO

Article history:
Received 5 February 2014
Accepted 13 February 2015

Keywords:
Cassegrain antenna
Transformation efficiency
Conical lens
Photonic crystal

ABSTRACT

A special conical lens and photonic crystal reflector are used to increase transmission efficiency of the Cassegrain antenna. Gauss beam is shaped into a hollow beam which could avoid the loss of energy caused by the subreflector center reflection in the Cassegrain antenna, and the transmission efficiency in the space optical communication system will be greatly enhanced. A one-dimensional (1D) photonic crystal reflector is designed to reduce energy absorption. Thus transmission efficiency of the whole system can be almost close to 100% in theoretical aspects. It is pretty significant for space optical communication of transmission long distances.

1. Introduction

With the development of communication technology, the inter-satellite optical communication and single-pulse radars technology have been developed rapidly. The Cassegrain antenna, which has advantages such as large aperture, free of chromatic aberration and wide range of available band, is widely used in those systems. While using the aspherical lens, the aberration can be greatly eliminated, and Cassegrain antenna can function as a transceiver. The transmission efficiency is an important parameter of the Cassegrain antenna, which plays a key role in the space optical communication. The loss of energy caused by the subreflector center reflection greatly depresses the transmission efficiency in the space optical communication system. Some researchers had adopted off-axis antenna structures to increase transmission efficiency [1,2]. But the transmission efficiency can increase very little [3,4], or even reduced [5–8].

In this work, a special conical lens is designed to shaping the Gauss beam into a hollow beam which could avoid the loss of energy caused by the subreflector center reflection in the Cassegrain antenna. A 1D photonic crystal reflector is also designed to reduce energy absorption. The transmission efficiency of the whole system could be greatly enhanced. The investigation results lend a significance of theoretical and application perspectives for long distance space optical communication.

* Corresponding author. Tel.: +86 02884406784.
E-mail address: jiangp@uestc.edu.cn (P. Jiang).

http://dx.doi.org/10.1016/j.ijleo.2015.02.068
0030-4026/© 2015 Published by Elsevier GmbH.

2. Energy loss analysis of Cassegrain antenna

A classical Cassegrain antenna comprises of two parabolic mirrors, namely the primary mirror and secondary mirror (as shown in Fig. 1). The focal lengths of the primary and secondary mirror are assumed as f_1 and f_2, respectively. The receiving and the launching antennas are assembled symmetrically. While calculating the transmission efficiency of the antenna, only launching antenna is taken into consideration.

A Gauss beam with most of the energy concentrated in the center is incident into the launching antenna and then reaches the secondary mirror. Light reflection from center of the secondary mirror into the hole of the primary mirror causes huge loss of energy (as shown by the red line in Fig. 1), thus greatly depresses the transmission efficiency in the space optical communication system.

Suppose the aperture radius of primary mirror is A. The radius of obscured part as the following

$$b = A\frac{f_2}{f_1} \tag{1}$$

Since the incident beam is a Gaussian beam, the electric field distribution can be described as

$$E(z) = \frac{C}{\omega(z)} \exp\left(-\frac{r^2}{\omega^2(z)}\right) \times \exp\left\{-i\left[k\left(z+\frac{r^2}{2R}\right) - \arctan\left(\frac{\lambda z}{\pi\omega_0^2}\right)\right]\right\} \tag{2}$$

The energy density of the beam in the cross section is

$$\left|E(z)\right|^2 = \frac{C^2}{\omega^2(z)} \exp\left(-\frac{2r^2}{\omega^2(z)}\right) \tag{3}$$

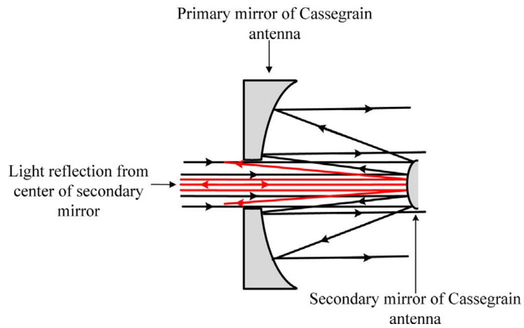

Fig. 1. Launching system of Cassegrain antenna. (For interpretation of the references to color in this figure citation, the reader is referred to the web version of this article.)

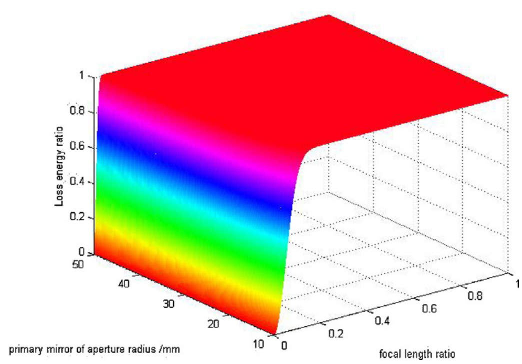

Fig. 2. Reflected energy efficiency curve.

where $\omega(z)=\omega_0\sqrt{1+\left[\lambda z/\pi\omega_0^2\right]^2}$, when $z<(\pi\omega_0^2\eta/\lambda)$, $\omega(z)\approx\omega_0$, $\pi\omega_0^2\eta/\lambda$ is Rayleigh length, λ is wavelength of light, and C is a constant.

In the range of Rayleigh length, energy loss rate can be written as

$$\eta_r=\frac{\int_0^{2\pi}\int_0^{b}\left|E\right|^2 rdrd\theta}{\int_0^{2\pi}\int_0^{A}\left|E\right|^2 rdrd\theta}=\frac{1-e^{-(2b^2/\omega_0^2)}}{1-e^{-(2A^2/\omega_0^2)}}=\frac{1-e^{-(2\gamma^2A^2/\omega_0^2)}}{1-e^{-(2A^2/\omega_0^2)}} \tag{4}$$

Let $\gamma=f_1/f_2$.

It can be obtained

$$\frac{d\eta_r}{d\gamma}=\frac{4\gamma A^2}{\omega_0^2(1-e^{-(2A^2/\omega_0^2)})}e^{-(2\gamma^2A^2/\omega_0^2)}\quad \text{where}\quad \gamma\in(0,1) \tag{5}$$

Let $d\eta_r/d\gamma=0$, we can work out $\gamma=0$. So η_r has minimum when $\gamma=0$, but $\gamma\in(0,1)$. While $\gamma\neq 0$, η_r would not gain minimum, and transmission efficiency does not also reach maximum. Therefore, it is not able to increase transmission efficiency by means of reducing γ. Little γ is very difficult to manufacture; at the same time, it is not useful actually.

Due to this, it could not be obtained $\gamma=0$, so the most of energy is reflected. Loss efficiency curve is shown in Fig. 2.

Obviously, γ is very sensitive to the transmission efficiency.

3. Design a conical lens to produce a hollow beam

Since small γ is very difficult to manufacture, a special conical lens is designed to increase transmission efficiency. The cross section of the conical lens is shown in Fig. 3.

When ray passing across a parallel plate lens, it will generate an off-axis distance d. The incident light and refract light are also

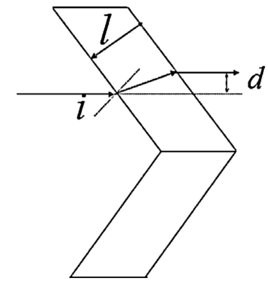

Fig. 3. The cross section of the conical lens.

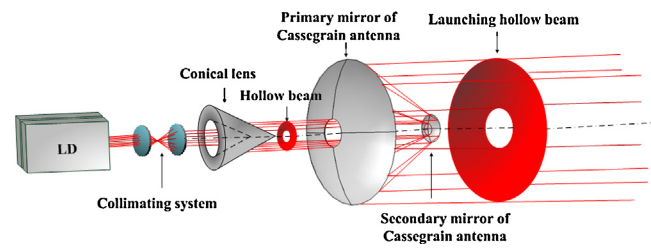

Fig. 4. The structure of the launching antenna system.

parallel. With the knowledge of geometrical optics, it is easy to obtain

$$d=l\left(\sin i-\frac{\sin i\cos i}{\sqrt{n^2-\sin^2 i}}\right) \tag{6}$$

where n is refractive index, i is incident angle, and l is the thickness of the parallel plate part of the conical lens.

By 360° rotation of this model, a conical lens is formatted, and a hollow beam could be produced, which could avoid the loss of energy caused by the subreflector center reflection in the Cassegrain antenna, thus improve the transmission efficiency of the launching system. Corresponding structure is shown in Fig. 4.

The structure should be satisfied

$$b=d=l\left(\sin i-\frac{\sin i\cos i}{\sqrt{n^2-\sin^2 i}}\right)=\gamma A \tag{7}$$

and

$$b+a=A \tag{8}$$

where a is radius of the incident light beam and b is inner radius of the hollow beam. It is easy to obtain that $a=(1-\gamma)A$ by Eqs. (1) and (8), thus the hollow inner radius satisfied

$$b=l\left(\sin i-\frac{\sin i\cos i}{\sqrt{n^2-\sin^2 i}}\right)=\gamma A \tag{9}$$

It is easy to obtain a series of n, l and i which satisfied Eq. (9), thus incident beam could be shaped into a hollow beam. There are a large number of combination of n, l and i which satisfied Eq. (9) in general.

The electric field distributing of beam can be described as

$$E'=\begin{cases}\dfrac{C}{\omega_0}\exp\left\{-i\left[kz-\arctan\left(\dfrac{\lambda z}{\pi\omega_0^2}\right)\right]\right\} & r=0\\ 0 & 0<r<b\\ \dfrac{C}{\omega_0}\exp\left(-\dfrac{r^2}{\omega_0}\right)\exp\left\{-i\left[k\left(z+\dfrac{r^2}{2R}\right)-\arctan\left(\dfrac{\lambda z}{\pi\omega_0^2}\right)\right]\right\} & b\le r\le A\end{cases} \tag{10}$$

The energy distribution of hollow beam is shown in Fig. 5.