Abstract - The optical system proposed in this paper is developed from double reflector cassegrain antenna with parabolic contour for the main dish and a hyperbolic contour for the sub-dish. Due to the enhancement of obscuration of secondary mirror, the large amount of transmitted power is blocked, hence diffractive optical elements (DOE) are added. Even though the pre-collimator used for magnification, adaptive optical system need additional diffractive phase corrector and beam shaper which can diffract the obscured part of transmitted beam into the domain unobscured by the secondary mirror and improve beam quality. In the Design of DOEs, Phase profile of DOEs are calculated using GS algorithm. The beam divergence is unchanged and peak intensity of receiver plane increased, so nearly hundred percent emission efficiency of new figuration is achieved.

Keywords - Fonts, formatting, margins

I. INTRODUCTION

The future of communications depends largely on the development of free-space inter-satellite laser communication. This technology in turn depends on a reliable way to direct a laser beam from one satellite to another, requiring extremely high pointing accuracy, low power, and sufficient bandwidth to reject satellite disturbances. It includes acquisition, pointing and tracking in addition with beam shaping which is required to enhance the system performance.

Traditional optical communication systems employ mechanically steered mirrors to point and track laser beams. The standard approach has been to use a corner mirror for beam return and a two-stage (coarse-fine) dual-detector concept. This approach, however, is complex, involves moving parts, and limits the efficiency with which the signal is fed to the terminal’s fiber.

Laser beam shaping methods are divided into two categories such as external shaping to apply any existing laser, internal cavity shaping to enhance the performance of the laser while providing also the desired beam shape. Among the available redistribution of the irradiance under the beam profile techniques say absorption, beam segmentation, reflection or refraction of beam fluxes, or diffraction of energy, last one considered as energy efficient, flexible and relatively simple from the point of view of practical realization. In many applications, the laser beams with flat-top is desired in many applications, such as laser fusion, laser radar, laser heat treatment, etc. Unfortunately, the laser device operated in TEM mode delivers a laser beam with Gaussian profile. Therefore beam shaping that reshapes a laser beam from Gaussian profile, into flat-top is very important. With the development of laser fusion, the high-power laser beam with highly spatial coherence is transformed into the beams with low spatial coherence by induced spatial incoherence, random phase shifts and optical fibers. By using a lens with negative spherical aberration (SA), one can reshape a partially coherent light beam with Gaussian profile into flat-top.

In this proposed system, first two-mirror cassegrain optical antenna is designed strictly to get point to point laser communication and it is added with new aspheric pre-collimation lens system as a passive system because according to the traditional division method, the optical system includes active and passive system. Then basic configuration is improved by adding DOEs for beam quality [3].

II. BASIC OPTICAL SYSTEM

In the optical antenna system, we selected catadioptrics antenna. It uses a combination of mirrors and lenses to fold the optics and form an image. There are two popular designs: the Schmidt-Cassegrain. The light enters through a thin aspheric Schmidt correcting lens, then strikes the spherical primary mirror and its reflected...
back up the tube and intercepted by a small secondary mirror which reflects the light out in the rear of the instrument where the image is formed at the eye piece[1]. The cassegrain system consist of two reflecting surfaces a concave parabolic main dish and a convex hyperbolic secondary dish. Cassegrain telescope has shorter main reflector focal lengths, and hence is more compact than conventional parabolic reflectors as shown in fig1. This kind of optical telescope can get much higher gain than other. The magnification of the telescope serves to decrease the divergence of the beam, thus making it spread out less.

III .IMPROVED OPTICAL SYSTEM

For inter-satellite optical communication transmitter, a considerable amount of the beam energy is lost for central obscuration of secondary mirror. Hence, emission efficiency of inter-satellite optical communication transmitter and beam power density in far-field will be both decreased.

Different approaches have been proposed to avoid the secondary mirror obscuration. Generally, they can be classified into two groups according to whether secondary mirror positioned on axis or not. One can find that many existing optical elements or devices have been introduced in the former group, such as axicon optical element, dual-secondary mirror, cone reflecting mirror, prism beam slier and beam-splitter/beam combiner, etc. Low transmission efficiency is mutual defect of these schemes, and most of them have extraordinary drawbacks such as overfull optical elements, low flexibility or difficult to manufacture. In the latter case, the secondary mirror on-axis is replaced by more than one off-axis fold or turning mirrors, and the off-axis tertiary reflective surfaces will be structured to avoid central obscuration[2,3]. To improve transmitted beam quality with intrinsic bulk, mass, and power consumption we represent a method adopting two DOEs, which rearrange the transmitted beam with Gaussian intensity profile into a hollow Gaussian beam [4,5] to avoid the secondary mirror obscuration.

![Figure2.Schmidt cassegrain antenna with DOEs](image)

The two diffractive elements are placed between collimator and optical antenna along axis, and they act as a beam shaper and a phase corrector, respectively. Different from the typical scheme, in this configuration, the central portion of collimated Gaussian beams in plane P1 will be diffracted to annular domain beneath solid blue line in plane P2, which is the focal plane of diffractive beam shaper. Afterwards, the transmitted beam will be rearranged to a plane wave by diffractive phase corrector positioning in plane P2. Thus a hollow Gaussian beam(HGB) is achieved prior to secondary mirror. Since an afocal reflective telescope is usually considered as a linear beam expander, consequently a magnified HGB will be obtained in plane P3. The transmitted beam won’t be blocked by secondary mirror when a proper inner diameter of HGB in Fig.2 is selected.

IV. DESIGN OF DOE AND BEAM TRANSFORMATION

DOEs mentioned above are classified as pure-phase elements, which can be described by phase functions, so the phase profiles of both beam shaper and phase corrector must be precisely determined to obtain a lossless output beam. In this paper, only design scheme of DOE for beam shaping is demonstrated, which enables beams with Gaussian intensity profile to hollow Gaussian intensity profile. Actually, the design for phase corrector is very simple, which can be reached only across a subtraction of phase functions between plane-wave and actual wave-front of plane P2. The design of DOE is similar to phase retrieval from intensity measurements. In fact, the intensity distribution of laser beam in plane P1 and the required hollow Gaussian intensity distribution in plane P2 are all measurable, and hence the generation problem of diffractive beam shaper can be referred as a phase construction from two known intensity information. Many optimization algorithms have been developed to compute phase profiles of DOE. Among those Gerchberg-Saxton (GS) algorithm [4] is used which depends on a Fourier Transform relation between the waves in plane P1 and plane P2. It is explained in the Appendix.

As mentioned above, when the transmitted beam has been transformed to a HGB in plane P2, the phase pattern of this HGB is modified by a phase corrector placed in this plane and form a new plane wave. Subsequently, this new plane wave with hollow Gaussian intensity pattern is magnified by optical antenna, and the emission efficiency of inter-satellite optical communication transmitter is increased with the absence of the secondary mirror obscuration[5]. In order to evaluate the performance of the improved scheme, we define the emission efficiency of inter-satellite optical communication transmitter as:

$$\eta_p = \frac{E'}{E} \times 100\%,$$

where $E$ represents the total beam energy emitting from light source, and $E'$ represents the beam energy emitting from the exit pupil. The HGB leave from inter-satellite optical communication transmitter and transmit to opposite inter-satellite optical communication receiver
apart from ten-thousands of kilometers via free space, and the complex amplitude function of receiver plane can be computed by Fraunhofer diffractive formula.

IV. NUMERICAL SIMULATION

In the design of inter-satellite optical communication transmitter, the design requirements includes the diameter of exit pupil, beam waist or beam divergence. Only when these parameters have been given, we can determine the magnification of optical antenna, which is defined as the diameter ratio between primary mirror and secondary mirror. The reciprocal of magnification is referred as obscuration ratio, which is denoted as $T$. Obviously, the inner diameter of HGB in exit pupil plane varies with $T$, so the intensity patterns of far-field are also varied with $T$. This variation prompts us to investigate the far-field intensity patterns with various obscuration ratio.

All parameters have been determined according to previous known conditions; the phase function of diffractive beam shaper can be computed by using GS algorithm. While the algorithm reaches a stable position, the Gaussian beam is transformed into a Hallow Gaussian Beam which shows that a good consistency between computed amplitude and desired amplitude. Improved beam quality is evaluated by using relative peak energy and relative peak energy increment [6]. Improved emission efficiency

$$\eta_P = \left( \frac{I_{\text{max}} - I'_{\text{max}}}{I_{\text{max}}} \right) \times 100\%$$  \hspace{1cm} (2)

where $I_{\text{max}}$ and $I'_{\text{max}}$ are the peak energy of far field with and without DOE, respectively. Obtained beam intensity distribution of the receiver plane with DOE and with out DOE is in figure 3.

V. CONCLUSIONS

General Optical system is optimum designed by using a cassegrain antenna with new aspheric pre-collimation system. Then improved beam quality of inter-satellite optical communication system is achieved by adding two diffractive elements into optical path along optical axis, and a lossless output beam was obtained with the same mass, volume, and power consumption. Hence this work can offer a useful reference for optimal design of optical telescope centrally obscured, and can also be a guidance for other applications of DOE in satellite optical communication system or other modern optical systems. Simulation result shows that the emission efficiency of inter-satellite optical communication transmitter is nearly 100%, which is higher than that of the condition without DOE greatly.

APPENDIX

The Gerchberg-Saxton (GS) algorithm is an iterative algorithm for retrieving the phase of a pair of light distributions (or any other mathematically valid distribution) related via a propagating function, such as the Fourier transform, if their intensities at their respective optical planes are known. It is often necessary to know only the phase distribution from one of the planes, since the phase distribution on the other plane can be obtained by performing a Fourier transform on the plane whose phase is known. Although often used for two-dimensional signals, the GS algorithm is also valid for one-dimensional signals.

Gerchberg–Saxton Algorithm

$$\phi_n+1 = \phi'_n$$

end Gerchberg–Saxton Algorithm

GS algorithm is an infinite loop of forward and backward transforms from input plane P1 to reconstruction plane P2, the known sampled amplitude function $A$ and $B$ are assigned to these two planes, respectively. To begin, a random phase distribution is generated to serve as the initial phase estimate and combined with the corresponding sampled amplitude function $A$ to form input wave function $Ein(x_1,y_1)$. Then, this synthesized complex discrete function is done by means of the Fast Fourier Transform algorithm. The phase portion of the complex wave function $E'_{\text{out}}(x_2,y_2)$ resulting from this transformation are computed and

Figure 3. beam intensity of the receiver plane with and without DOE
reserved, and it is combined with the corresponding sampled amplitude function $B$. This new complex function $E_{\text{out}}(x_2,y_2)$ is then done by Inverse Fast Fourier Transform (IFFT), the phases of the sample points are calculated and combined with the known sampled amplitude function $A$ to form a new estimate of the complex sampled input plane, and the iteration process is repeated. The phase mapping of two planes evolves through the iterations [7,8] and eventually comes to a stable position or stopped on the condition that the sum of squared error between the desired and computed amplitude function of the reconstruction plane, should be less than Fourier transform $\zeta$, which is an infinitesimal. Finally, the phase mapping representing the DOE data will be obtained across a subtraction between calculated phase mapping and initial phase of input plane-wave.

REFERENCES