Abruptly Autofocusing Beams Based on Phase Modulated Zone Plate

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***Abstract* — In this paper, we introduce a phase modulated zone plate to generate the circular symmetric Airy beam (CSAB) with abruptly autofocusing characteristic at 30GHz. This phase modulated zone plate is a phase combination form of a radial phase plate and a lens, which would make the conventional generation system of CSAB more compact. Based on full wave simulation, the unique abruptly autofocusing is explored in the field of millimeter wave. Even if the metal plate is placed in front of the phase modulated zone plate, the focusing can still be well obtained, which provides a potential advantage in millimeter-wave sensing.**

Index Terms — airy beam, abruptly autofocusing, phase zone plate, millimeter-wave sensing

I. Introduction

Airy beams [1-3] with the diffraction free, self-healing and self-acceleration properties have attracted much attention in the last decade. Although most research of the Airy beams is focused primarily on the versatile applications in the optical field, it is still of great practical significance to explore the potential applications of the Airy beams in the millimeter-wave field. As a specific type of Airy beams, circular symmetric Airy beam (CSAB) has a unique focusing property, namely, abruptly autofocusing. The propagation of the CSAB can be defined in cylindrical coordinate by a Hankel-transform integral [4].

$$u(r,z) = 2\pi \int_0^\infty r u_0(r) J_0(kr) dr \tag{1}$$

where k is the radial spatial frequency. J_0 is the first kind of Bessel function. u_0 is the electric fields of the initial CSAB, and expressed as [4]

$$u_0(r) = Ai(\frac{r_0 - r}{w}) \exp\left[\alpha\left(\frac{r_0 - r}{w}\right)\right] \tag{2}$$

where w is the scale factor. α is the decay factor. Ai represents the Airy function. r_0 is the radius of primary ring.

The circular symmetric Airy beam [5-7] can naturally focus their energy at the focal spot without any focusing lens or other device, while maintaining a low-intensity ring distribution during free-space propagation as shown in Fig.1(b). The electric intensity can be suddenly increased by several orders of magnitude at the focal plane. This unique property allows the beam to be focused at the intended area without causing extra damage to other areas, which provides a potential advantage in millimeter-wave sensing and imaging.

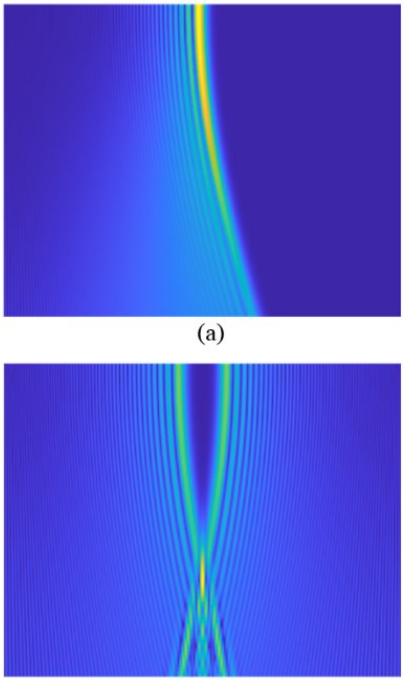

Fig. 1. The schematic view of free-space propagation of Airy beam and circular symmetric Airy beam. (a) The property of self-bending for Airy beam. (b) The property of abruptly autofocusing for circular symmetric Airy beam.

In this paper, we utilize a phase modulated zone plate to achieve the abruptly autofocusing beams. Based on the full-wave simulation, this unique focusing property is conformed. Even if the metal plate is placed in front of the phase modulated zone plate, the focusing can still be well obtained.

II. Phase Profile of Phase Modulated Zone Plate

Generally, the generation system of the CSAB consists of two parts, namely a radial phase plate and a lens. The radial

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phase plate represents desired phase pattern for generating CSAB. The lens performs the function of Fourier transform (FT). Here, a phase modulated zone plate combined the profiles of these two parts is utilized to generate the abruptly autofocusing CSAB, and defined as follows [5],

$$\phi_{CSAB} = \alpha r^3 + \beta r - k_0 r^2/(2f). \quad (3)$$

where $k_0 = 2\pi/\lambda$, and λ is the wavelength. f is the focal length of lens. In our case, the diameter of design phase modulated zone plate operating at 30 GHz is 153 mm. Fig.2 shows the phase profile of designed phase modulated zone plate with the size of 51×51. The size of each grid is 3 mm.

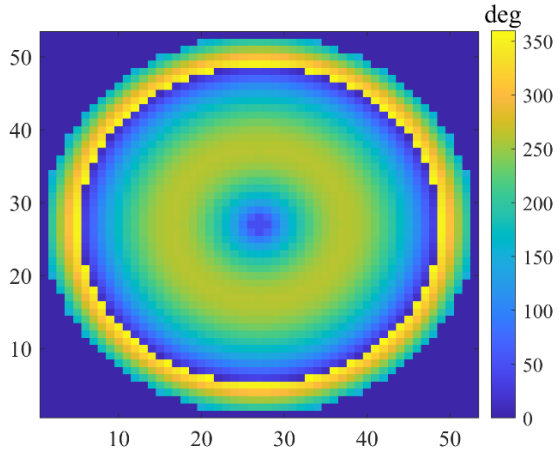

Fig. 2. The phase profile of designed phase modulated zone plate.

The phased profile can be realized by using the rectangular dielectric columns with different heights, as shown in Fig.3. The dielectric material has a relative permittivity of ~2.75. Besides, the designed 3-D model can be easily fabricated by 3-D printing.

Here, the Ka-band horn antenna is utilized as feeding source. Based on full-wave simulation in CST Microwave Studio, the power flow distribution for the generation antenna system of the CSAB is shown in Fig.4.The generated beam follows a curved parabolic trajectory, and is finally focused.

In the extreme case as shown in Fig.5, a metal plate with size of 60 mm × 60 mm is placed in the front of designed phase modulated plate. However, it has little effect on the performance of focusing, which provides a great advantage in obtaining the depth information of target.

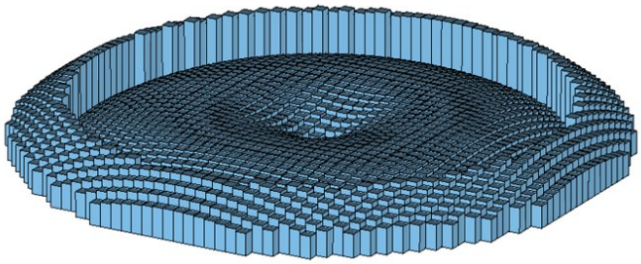

Fig. 3. The 3-D model of designed phase modulated zone plate with the relative permittivity of ~2.75.

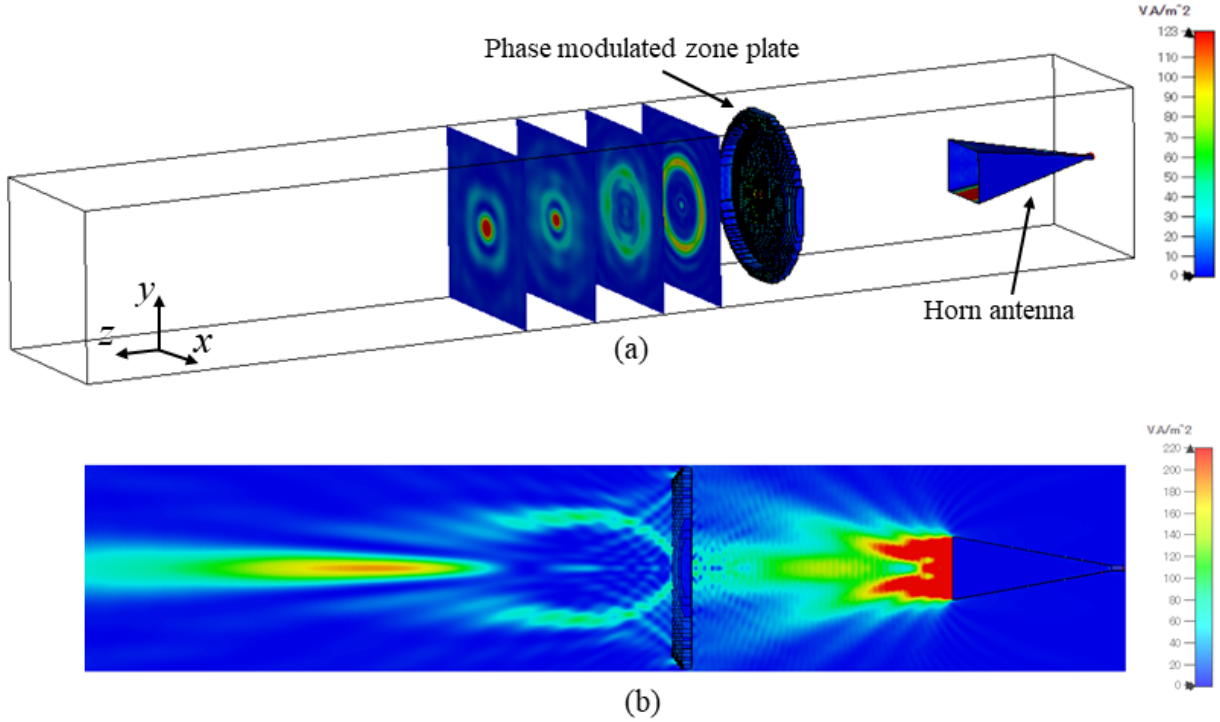

Fig. 4. The power flow distribution (a)along the propagation z-axis. (b) at yoz plane.

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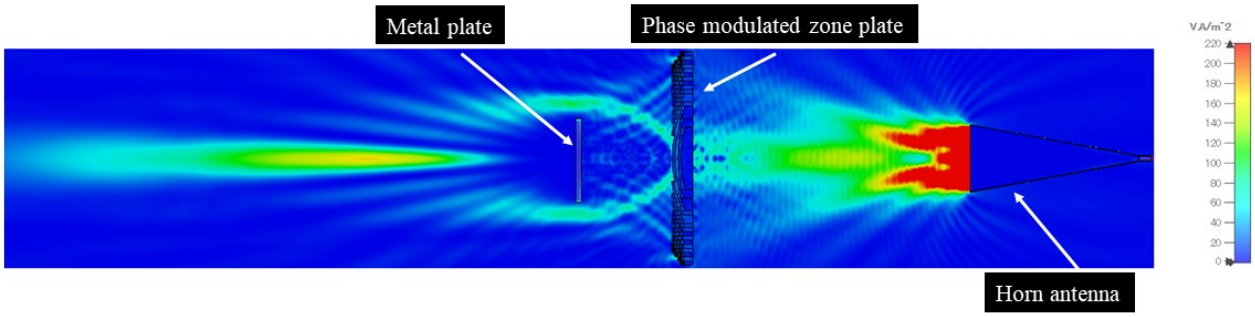

Fig. 4. The power flow distribution when a metal plate with a size of 60 mm × 60 mm is placed in the front of phase modulated zone plate.

III. Conclusion

A phase modulated zone plate with ka-band horn antenna as feeding source is introduced to generated the circular symmetric Airy beam at 30GHz. The characteristic of abruptly autofocusing is explored based on full wave simulation. Although a metal plate with suitable size is placed in the front of designed phase modulated plate, it has little effect on the performance of focusing, which provides a potential advantage in obtaining the depth information of target.

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