A Millimeter-Wave Phased Array Fed Biconvex Lens Antenna

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***Abstract*—Dielectric lens antennas have been applied in many modern advanced communication systems, in order to achieve beam scanning and high gain with conventional single feed. However, these lens antennas usually need mechanical beam tracking system, which are usually inconvenient for some applications. Consequently, small phased arrays are utilized as the feeds of lens antennas. This paper presents a biconvex lens antenna with a small phased array feed, which is transformed from spherical luneburg lens to reduce the antenna profile. The designed lens antenna operates at 39GHz. By using phase conjugation technology, the excitation amplitudes and phase distributions of the phased array are obtained. Numerical results show that the lens antenna can scan up to ±30° and maintain a maximum aperture efficiency of about 74%.**

Keywords—biconvex lens, beam scanning, high aperture efficiency, phased array feed, phase conjugation technology

I. Introduction

Over the past few decades, conventional dielectric lens antennas with the advantage of wide beam scanning ranges [1], wideband and high aperture efficiency have been widely studied, especially for radar systems, point-to-point, and multiple-beam satellite communications systems. However, these lens antennas are usually mechanical scanning with large antenna profile, where only part of feeds take effect [2] and the speed of scanning is slow. Importantly, there is almost no decrease of the gain at every scanning angle. In this way, conventional dielectric lens antennas with mechanical scanning usually require more time and cost to achieve the desired scanning angle and high gain.

As for phased array, it allows multiple feeds work at the same time and can be used to achieve some special scanning angles more easily by optimization algorithm such as GA, PSO, DE and so on. Eventually, the electronic beam scanning capability can be realized more quickly. However, the gain of the phased array is not sufficiently high. The problem can be solved easily, when a phased array is illuminating a low-profile biconvex lens antenna.

In this paper, a biconvex lens antenna (or the anamorphic spherical luneburg lens [3][4]) with low profile is proposed and designed, which is operated at 39GHz. The permittivity of each layer is in consistent with that of a spherical luneburg lens antenna. An 8×8 phased array feed is used to illuminate the biconvex lens antenna. The dielectric substrate for the phased array is the Taconic TLX. By using the commercial simulation software (HFSS), numerical results show that good performances of beam scanning and high gain are accomplished concurrently. The designed lens antenna is able to achieve a moderately wide scanning angle up to ±30°. Moreover, the directivity of the antenna is 27dB and the aperture efficiency at main direction is 74%. Details of this lens antenna are as follows.

II. Design of the Antenna

A. Biconvex lens antenna

The topology of the biconvex lens antenna is shown in Fig. 1. There are five layers of the biconvex lens antenna and each layer consists of different dielectric [5]. The thickness of the lens is 35mm (about 4.55 operating wavelength) and the diameter is 54.82mm (about 7.13 operating wavelength). The permittivity of each layer from inner to exterior is 1.9, 1.82, 1.73, 1.65, 1.59, respectively.

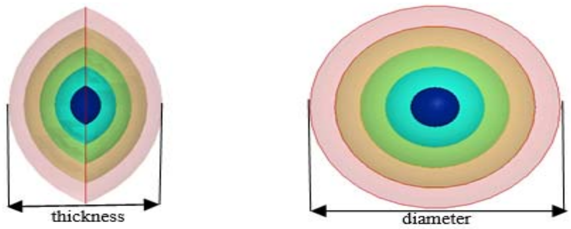

Fig. 1. Side and front views of the biconvex lens antenna.

B. Phased array feed

The construction of the phased array feed is depicted in Fig. 2. The phased array consists of 8×8 microstrip patch units. Taconic TLX dielectric substrate is used with permittivity of 2.55 and thickness of 0.508mm. The distances between neighboring patches are 0.65 working wavelength at two directions and each patch is fed by a 50Ω coaxial to acquire good impedance matching.

III. Design Methodology

In order to realize the beam scanning at special angles, the phase and amplitude excitations of the phased array should be selected properly. In this paper, the phase and amplitude excitations can be realized with phase conjugation technology [6]. Although this method is always used to form the focused array antennas [7], it can also be applied to tackle the problems of high gain and accurate scanning in this work. A concise set of design guidelines are as follows.

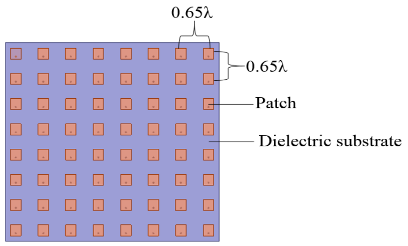

Fig. 2. An 8×8 phased array feed consisting of microstrip patch units.

A. Plane wave illuminate

By using a plane wave to illuminate the biconvex lens, it is able to obtain the desired phase and amplitude on a reference plane, which is on the other side of the lens antenna. In HFSS, the phase is acquired by setting the fields calculator and the amplitude is obtained by plotting Complex Mag_E. The reference plane should be placed in an appropriate distance to ensure that the entire phased array illuminates the biconvex lens antenna completely.

B. Conjugate phase

After getting the desired phase and amplitude distribution, the remaining thing to do is to set the phased array with conjugated phase and the same amplitude distribution. A vbs script file is used to set the phase and amplitude quickly for Ansoft HFSS full wave simulation. When the entire antenna consisting of the biconvex lens and phased array is simulated, the lens keeps still and the phased array takes place of the reference plane. As for other scanning angles, it only needs to change the angle of incident plane wave and follow the aforementioned steps. In this way, the desired scanning radiation patterns can be obtained.

IV. Antenna Structure and Simulation Results

Fig. 3 shows the whole lens structure and the thickness of the entire lens antenna is 46mm of about 6 operating wavelength from the outer edge of the lens to the phased array. The focal distance is 28mm from the phased array to the center of the lens. As displayed in Fig. 4 and Fig. 5, it is observed that the designed lens antenna achieves a scanning angle of 30° along H-plane. Besides, the gain of the lens at 30° decreases 1.8dB compared with that at 0° with the maximum gain of 25.7dB.

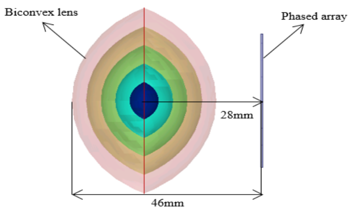

Fig. 3. The structure of biconvex lens with an 8×8 phased array feed.

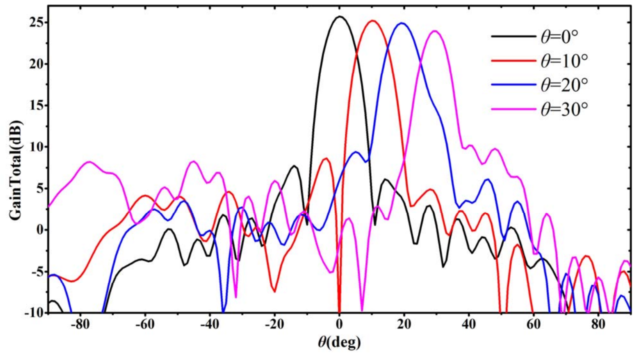

Fig. 4. Simulated H-plane beam scanning radiation pattern.

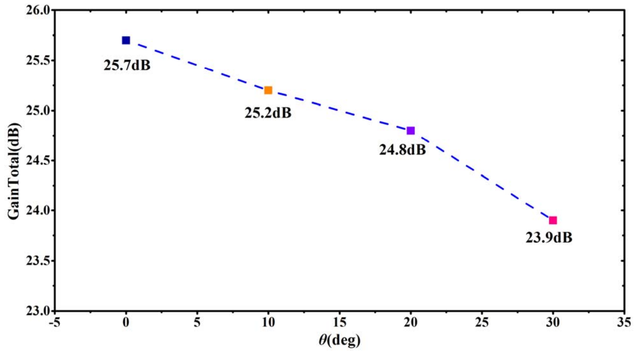

Fig. 5. Simulated H-plane scanning gain versus θ.

V. Conclusions

In this paper, a biconvex lens antenna with phased array feed is proposed and designed. It realizes the scanning goal up to ±30° with high aperture efficiency about 74% and a moderately low antenna profile of about 6 operating wavelength. The proposed antenna can be used for 2D scanning systems and 5G wireless communication technologies.

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