Three Methods to Generate Orbital Angular Momentum Beams in Microwaves

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***Abstract*—This paper reviews three methods to generate orbital angular momentum (OAM) beams in microwave region. Circular patch array, Vivaldi connecting array and microstrip ring antenna are the potential candidates. The first two utilizes phased array technique, which needs complex feeding network, while the later method uses the higher modes of microstrip ring. Vortex OAM beams can be observed in all the methods.**

***Keywords*—Orbital angular momentum; patch antenna array; Vivaldi connecting array; microstrip ring antenna.**

I. Introduction

In 2007, Thide introduces the concept of orbital angular momentum (OAM) from optics to microwave region [1]. Ever since, there is a growing interest in generating OAM beams in microwaves. Various prototypes have been proposed in the last decade. One straightforward method is rescaling the devices in optics to microwaves. For example, spiral phase plate (SPP) has been applied to millimeter waves [2]. However, the device becomes bulky, if the frequency is in GHz band. Uniform circular array (UCA) is another widely used device in microwaves. In this scheme, the antenna elements are fed with equal amplitudes, but with a successive phase delay from element to element such that the phase increment after a full turn is an integer multiple of 2π [3].

In this paper, three prototypes including circular patch array [4], Vivaldi connecting array [5], and microstrip ring antenna [6] are designed to produce OAM beams.

II. Array Antenna Design

The array factor of UCA can be calculated by using Eq. 1, if the elements are fed with equal amplitudes and relative phase delay of $\psi_n = 2\pi nl/8$.

$$F_{array}(\theta,\varphi) = \sum_{n=1}^{N} e^{-j\vec{k}\cdot\vec{r}_n + jl\psi_n} \approx Nj^{-l}e^{jl\varphi}J_l(ka\sin\theta) \qquad (1)$$

Where N is the number of elements, l is the OAM state of the array. A clear azimuth phase dependency, $\exp(jl\varphi)$, is observed in the expression. However, this equation does not take the polarization of element into consideration. As shown in Fig.1, the polarization of UCA has two possible configurations. In Fig. 1(a), all the elements have the same polarization. The array is linearly polarized. In Fig. 1(b), the polarization of the elements is sequentially rotated.

Based on the two configurations, Fig. 2 and Fig. 3 present two practical antenna arrays [4]-[5]. In Fig. 2, 8 patch elements are placed uniformly in a circle, and are printed on a FR4 substrate board. All the elements have the same polarization. In

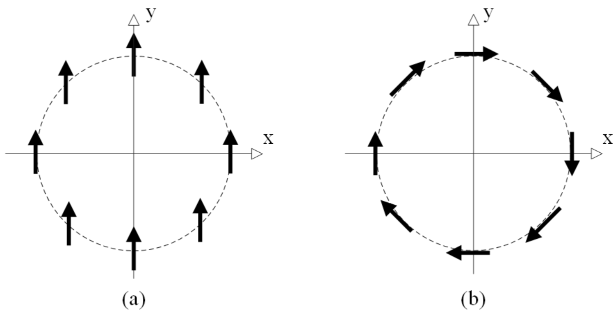

Fig. 1 Polarizations of the UCA. (a) Linear polarization. (b) Sequentially rotated polarization.

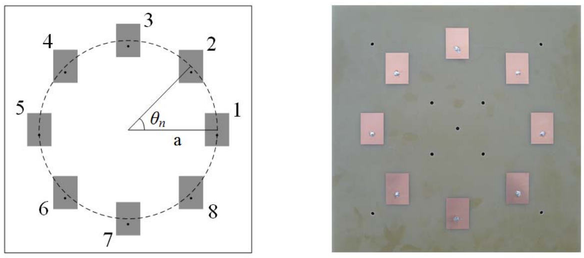

Fig. 2 Circular patch array and the fabricated prototype.

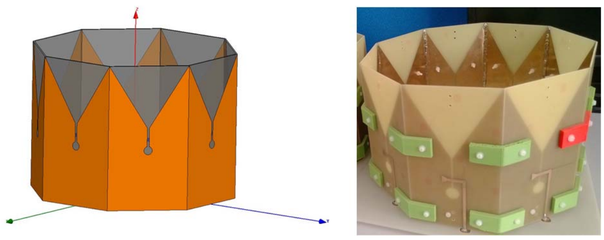

Fig. 3 Vivaldi connecting array and the fabricated prototype.

Fig. 3, 8 Vivaldi antenna elements are connected to form a connecting array. All the elements share the same ground plane. The polarization of each element has an angle rotation of 45°, compared with its adjacent elements.

The transversal electric field distributions of the two arrays are observed at an axial distance of 0.8λ. Fig. 4 compares four OAM states of the two arrays. Two, four, and six anti-clockwise helical beams are observed at the +1, +2, and +3 states of both arrays, although the polarizations of the two arrays are different. There are significant differences between the +0 state and +1 state. In patch array, the intensity in the center is strong at the +0 state and weak at the +1 state. However, this behavior is opposite in Vivaldi array.

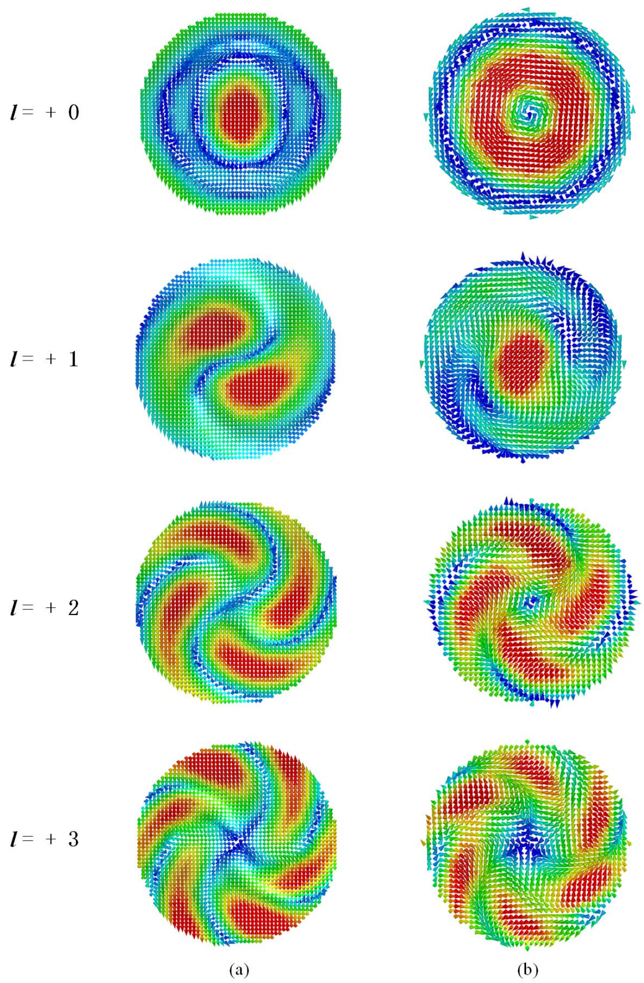

Fig. 4 Transversal field distributions. (a) Patch array. (b) Vivaldi array.

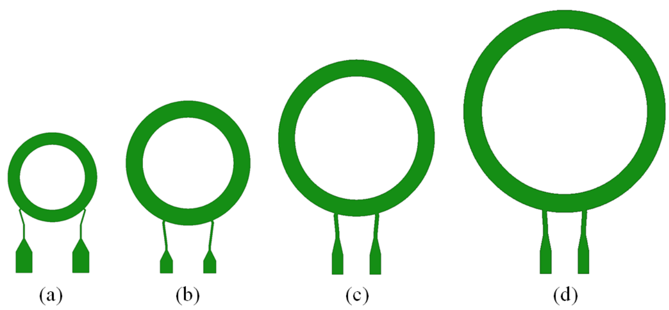

Fig. 5 Microstrip ring antennas. (a) TM_{11}. (b) TM_{21}. (c) TM_{31}. (d) TM_{41}.

III. Microstrip Ring Antenna Design

Considering that the feeding network of array is complex, single antenna is explored to produce OAM beams [6]. Fig. 5 shows the four designs that can excite the TM_{11}, TM_{21}, TM_{31}, and TM_{41} modes of microstrip ring. All the modes are fed by the same signals, where the two feeding ports have the same amplitudes but a relative phase delay of 90°. As the mode order increases, the radius of the ring should increase, while the angle between the two feeding ports (φ) should decrease, to generate different states of OAM beams at the same frequency point. The theoretical relation between φ and mode order n is given in the following equation:

$$\varphi = \frac{90^\circ}{n} \tag{2}$$

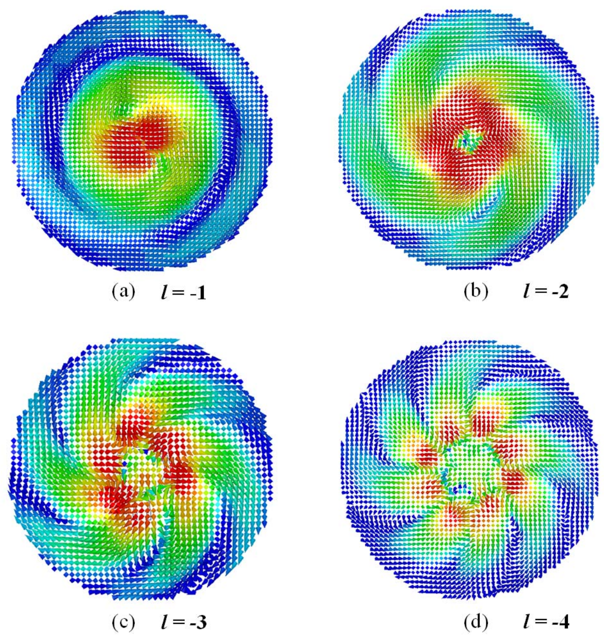

Fig. 6 Near-field intensity distributions of the four microstrip ring antennas. (a) TM_{11}. (b) TM_{21}. (c) TM_{31}. (d) TM_{41}.

Fig. 6 shows the transversal field distributions at an axial distance of 0.5λ. Helical beams are seen in the four states. There are two, four, six, and eight helical beams in the -1, -2, -3, and -4 OAM states. Positive OAM states can be obtained, if the phase difference between the two feeding ports is -90°.

IV. Conclusions

Three methods to generate OAM beams have been studied in this paper. Circular patch array and Vivaldi connecting array are used to produce OAM states with linear polarization and sequentially rotating polarization. Microstrip ring antenna are also investigated to produce OAM beams with single element.

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