# A Study of Orbital Angular Momentum Generated by Parabolic Reflector with Circular Array Feed

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***Abstract*** **– This paper discusses the generation of orbital angular momentum (OAM) produced by a parabolic reflector with a circular array (CA) feed. Simulated electromagnetic (EM) field verifies the behavior of OAM. Design parameters are numerically optimized for both the parabolic reflector and the circular array feed, in term of beam divergence associated with different OAM modes. Primitive estimations suggest that a few low-order-OAM modes can be transmitted simultaneously up to 100 meters in the mm-wave bands.**

***Index Terms*** **— orbital angular momentum (OAM), parabolic reflector, circular array (CA), millimeter-waves.**

## 1. Introduction

Orbital angular momentum (OAM) of the electromagnetic (EM) fields has drawn attentions of researchers and engineers since its recently found practical uses in the field of optics [1] and radio communications [2]. Theoretically, orbital angular momentum (OAM) can create a new degree of freedom for mode multiplexing, thanks to its mutually orthogonal characteristics between modes [3]. This novel characteristic can be exploited to transfer large amount of information by using multiple OAM modes [4].

It is noted that for all but OAM mode 0, the equi-phase plane of the radio beam is twisted and its energy disperses according to the travelling distance. Therefore, to make use of the non-zero-order modes, it is necessary to increase the travelling distance by employing antennas with larger apertures in term of wavelength. Consequently, the trade-off between increasing link distance and compactness of the system has to be considered carefully. In this paper, we propose a parabolic reflector antenna with a circular array (CA) feed excited by a Butler matrix for multiplexing and demultiplexing multiple OAM modes.

## 2. Antenna Structure

In our design, OAM modes are created by an array of N elements equidistantly placed on a circular ring of diameter $\Phi$. To generate the *l-th* OAM mode, each element is excited by the same amplitude and progressive phase:

$$\varphi = \frac{2\pi nl}{N} \qquad (n = 0, 1 \ldots N-1) \qquad (1)$$

, where n is the index of antenna element of the CA arranged in a clockwise manner. The progressive phase that excites the CA's elements can be created by a N×N Butler matrix.

TABLE I
Antenna Design Parameters

| | |
|---|---|
| Frequency [GHz] | 150 |
| Reflector diameter [mm] | 600 |
| Ratio of focal length to reflector diameter (F/D ratio ) | 1.0 |
| Feed type | Circular array |
| | 8 elements |
| | Diameter $\Phi = 2\lambda_0$ |

Using this structure, data can be encoded on multiple OAM modes at the transmitter-Tx side, simultaneously transferred, and accordingly decoded at the receiver-Rx side [4].

In comparison with its counterparts such as helicoidal parabolic reflector [2] or the spiral phase plate (SPP) [5], the CA is superior in term of degree of freedom of OAM modes. Nevertheless, receiving and decoding these modes is a real challenge since the radiating field is only received at discrete points where the array's elements are located.

To deal with this issue, we introduce a parabolic reflector fed by a CA with phase controlled by a Butler matrix. On the Rx side, the same antenna structure is employed to receive and decode the transmitted OAM modes. Here, high gain characteristic of the parabolic reflectors also can contribute to the link budget positively. The antenna structure is illustrated in Fig. 1, and its optimal design parameter is nominated in Table I.

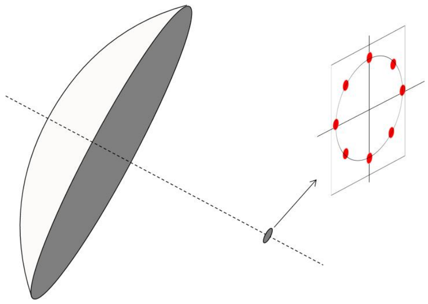


Fig. 1. Parabolic reflector feed by a circular array.

## 3. Simulation Results

At first, we confirm the OAM behavior by studying the EM field of the beam radiated from our proposed antenna structure at the distance *d* of 100m. The patterns of modes 1, 2, 3 can be observed from Fig. 2, which agree with ones calculated by the Laguerre polynomial [1].

Antenna design parameters are numerically optimized in term of beam divergence i.e. the angles of which the OAM beams diverge from the normal axis of the antenna aperture. Fig. 3 shows the radiation pattern with several combinations of *F/D* ratio and the diameter $\Phi$ of the CA. From these patterns, we observe that the diverged angle increases when *F/D* decreases or the CA's diameter $\Phi$ becomes larger. The combination $F/D = 1$ and $\Phi = 2\lambda_0$ (free space wave length), gives us the optimum patterns considering mode 0, 1, 2, and 3. The diverged angles are 0, 0.15, 0.22, and 0.29 degrees for $l = 0$, 1, 2, and 3, respectively. This result suggests that in case the same antenna with $\Phi = 0.6$m placed 100m away is used to receive the OAM beams, at least mode 0 and ±1 can be utilized since their main beams fall inside the receiving antenna aperture. Here, coverage angle of 0.172 degrees is geometrically calculated from antenna diameter $\Phi = 0.6$m and link distance $d = 100$m. Primitive estimations also suggest that OAM mode ±2 and ±3 could be transmitted and received for links up to 78m and 60m by Tx and Rx antennas of 0.6m in diameter. Coverage angles associated with 0.6m antennas and link distances 100m, 78m, and 60m are added to Fig. 3 by the dashed lines.

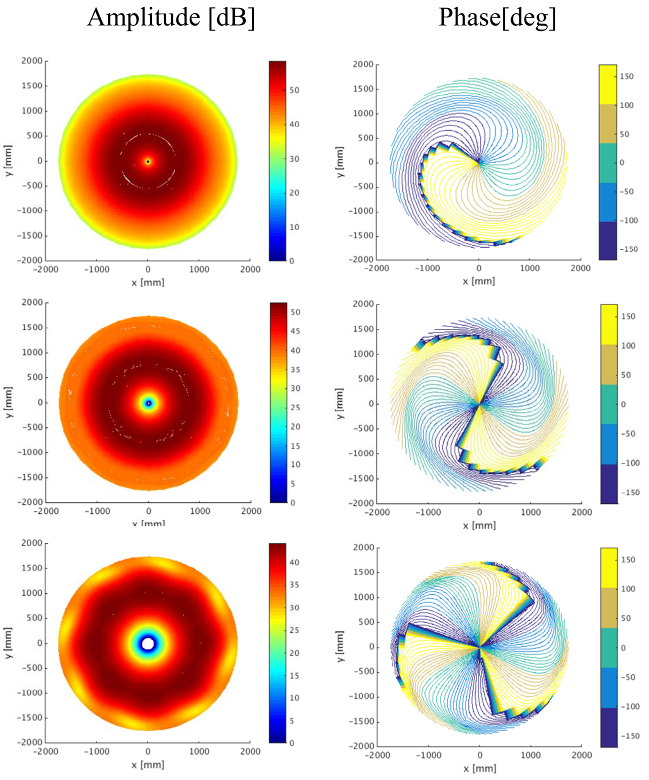
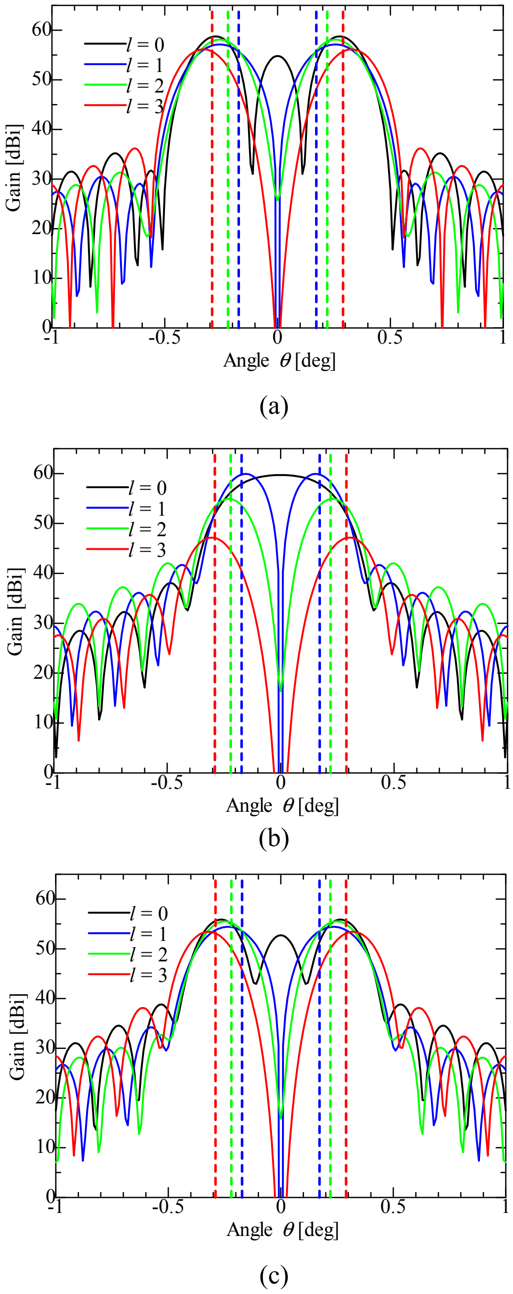


Fig. 2. 2 distribution of a field radiated from our proposed antenna, observed at a distance of 100m ($50000\lambda_0$).

## 4. Conclusions

A parabolic reflector with a circular array feed excited by a Butler matrix was studied for OAM mode multiplexing. We have demonstrated the OAM behavior of the EM field radiated from our proposed antenna structure. Simulation results have shown the evidence of utilizing a few low-order OAM modes for a practical link in the millimeter-waves.



(a)

(b)

(c)

Fig. 3. Radiation patterns of the parabolic reflector associated with different design parameters: (a) $F/D = 0.6$, $\Phi = 2\lambda_0$; (b) $F/D = 1$, $\Phi = 2\lambda_0$; (a) $F/D = 1$, $\Phi = 3\lambda_0$.

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