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An Omnidirectional and Directional Pattern Switchable Antenna Using Characteristic Mode Analysis

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***Abstract*-In this paper, an omnidirectional and directional pattern switchable antenna operating at 2.5GHz is proposed. Characteristic mode analysis (CMA) is utilized to design the proposed antenna. Based on the CMA, certain kinds of modes can be excited to generate an omnidirectional pattern or a directional beam. To verify this, a ring patch antenna with four slots and four feeding ports is analyzed by the CMA. By changing the phase difference among the four ports, different modes are excited, resulting in varying radiation pattern. Simulation results demonstrate that the omnidirectional and directional pattern switchable characteristic is obtained by the proposed ring patch antenna. With this feature, the proposed antenna can be used in a multi-functional system.**

***Index Terms* - Characteristic mode analysis, directional pattern, omnidirectional pattern, switchable antenna.**

I. INTRODUCTION

The omnidirectional antennas radiate electromagnetic waves with 360° beamwidth coverage in the horizontal plane. Due to its omnidirectional pattern, it is widely applied in mobile communication systems, and the wireless local area network (WLAN) systems [1]. On the other hand, the directional antennas can form the radiation beam at a certain angle. It is generally applied in the scenario of small coverage, high target density and high-frequency utilization. There are several ways to design a directional antenna. For instance, by the combination of an electric dipole and a magnetic dipole, a directional radiation pattern using the complementary antenna concept was obtained [2-3]. With the development of various wireless systems, it is highly desirable that a single antenna can achieve different radiation patterns for multi-functional applications. However, the antenna with such features is normally hard to achieve and generally of high complexity. To design such an antenna with simplified structure, the characteristic mode analysis (CMA) is utilized in this work.

The CMA gives an insightful physics understanding of the antenna radiating mechanism. The information of current distribution and resonant characteristics of different modes can be provided by the CMA. Thus, by placing inductive or capacitive elements in suitable positions and changing the phase difference among them, the desired modes can be excited [4-8]. In [9], two promising modes and three attached modes are selected to synthesize the up-tilt beam by analyzing current distribution and modes pattern of the patch. With the help of the CMA, the calculation of the electric field superposition and cancellation is intuitively understood, which helps design antenna with a desired radiation pattern.

In this paper, a ring patch antenna with switchable pattern is proposed. By utilizing the CMA, the current distribution and modes of the proposed antenna are well understood. Moreover, by simply changing the phase difference among the four ports, an omnidirectional and directional pattern switchable antenna is obtained.

II. ANTENNA DESIGN AND OPERATING PRINCIPLE

A. Antenna Design

The geometry of the proposed antenna is shown in Fig. 1. As shown, a circular ring patch with four slots is etched on the top layer of a RO4003C substrate. The relative dielectric constant of the substrate is 3.55 and the thickness is 0.4mm. Table I lists the optimal dimension parameters of the proposed antenna.

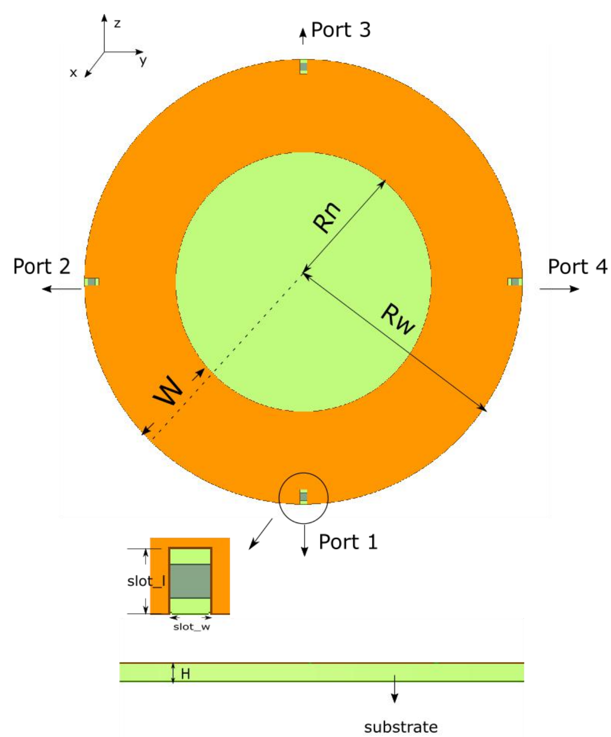


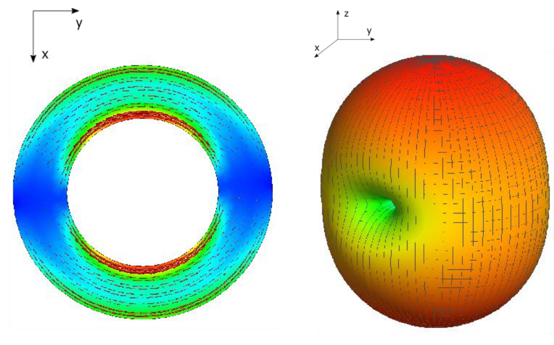
Figure 1. Geometry of the proposed antenna

TABLE I
DIMENSION PARAMETERS OF THE PROPOSED ANTENNA
(UNIT: MM)

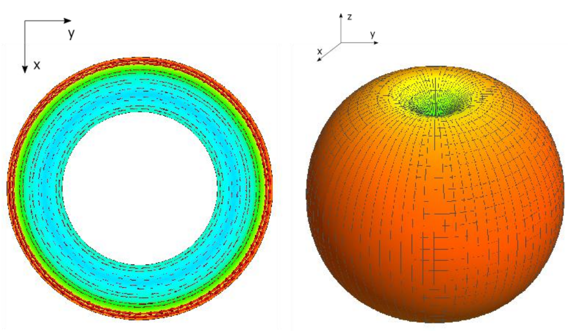
Rw	Rn	W	H	slot_l	slot_w
30	17.5	12.5	0.4	2	1

B. *Operating Principle*

Simulated results of the CMA for the proposed antenna without slots are calculated by Feko. Fig. 2 shows the current distribution and radiation pattern of Mode 2 and Mode 3 at 2.5 GHz. As shown in Fig. 2(a), the radiation pattern of Mode 2 is similar to that of an electric dipole with the current polarized along y-direction. In addition, the ring current and omnidirectional beam shown in Fig. 2(b) illustrate that the radiation pattern of Mode 3 is analogous to that of a magnetic dipole.



(a)



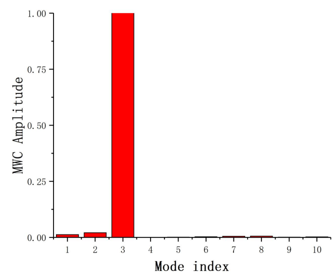
(b)

Figure 2. Current distribution and the corresponding modes radiation pattern of the ring patch without slots at 2.5 GHz. (a) Mode 2; (b) Mode 3.

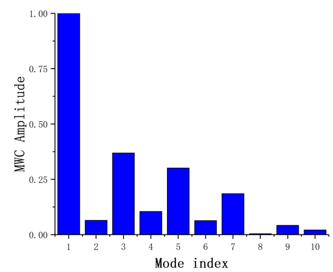
When the mode of the magnetic dipole is excited and other modes are suppressed, an omnidirectional antenna can be realized. According to the current distribution of the desired mode, four slots are etched in the ring patch and four feeding ports are placed in the four slots. Four slots are adopted as the inductive couplers elements (ICEs) at the proper position to selectively excite the desired modes. To avoid confusion, the n-th Mode of the new configuration is expressed as Mode n*. Mode 2 of the previous model turns to be Mode 1* of the structure with feeding. By changing the phase difference among the four ports, two different radiation patterns can be realized, which are illustrated below.

State 1): When feeding the four ports in equal power and equal phase, Mode 3* can be excited as the magnetic dipole and other unwanted modes can be suppressed effectively. Therefore, the proposed antenna can generate an omnidirectional radiation pattern. Fig. 3(a) shows the modal weighting coefficients (MWC) of State 1. It is clear that only Mode 3* can be excited.

State 2): When feeding three ports with identical phase and the other port with 180° phase difference, Mode 1* and Mode 3* can be excited simultaneously. Fig. 3(b) shows the modal weighting coefficients of State 2. As shown, although other modes are excited at the same time, considering the amplitude and phase of the MWC and amplitude and phase of the electric field, they have little impact on the expected design. Hence, it is not necessary to add extra ports to suppress these unexpected modes. As Mode 1* and Mode 3* are excited simultaneously, a directional radiation pattern is achieved.



(a)



(b)

Figure 3. Normalized MWC Amplitude of the ring patch with slots and ports at 2.5 GHz. (a) State 1; (b) State 2.

III. RESULTS AND DISCUSSION

The proposed antenna is also analyzed by the full-wave simulation tool HFSS to verify the design concept. Fig. 4 and Fig. 5 show the radiation patterns of the proposed antenna in the two main planes under state 1. As shown, an omnidirectional pattern is achieved by under this state.

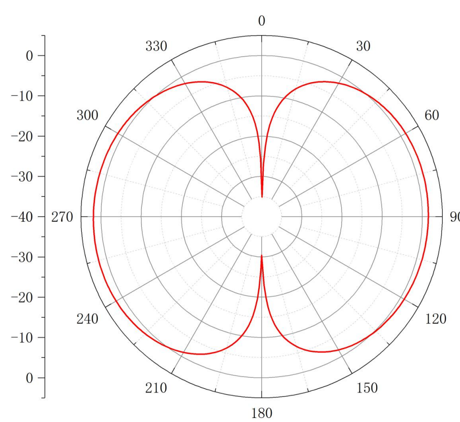


Figure 4. Full-wave simulation pattern at 2.5GHz in *yoz*-plane under state 1.

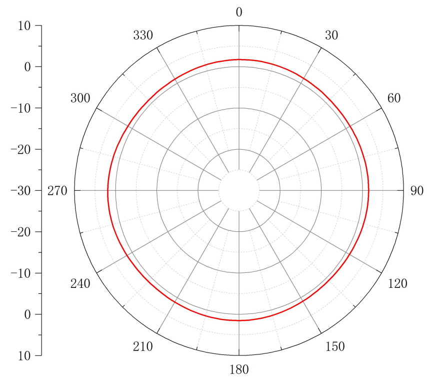


Figure 4. Full-wave simulation pattern at 2.5GHz in *xoy*-plane under state 1.

Fig. 6 and Fig. 7 show the radiation patterns of the proposed antenna in the two main planes under state 2. As shown, a good directional radiation pattern is realized with a peak gain of 4.67 dBi and the front-to-back ratio of 25 dB.

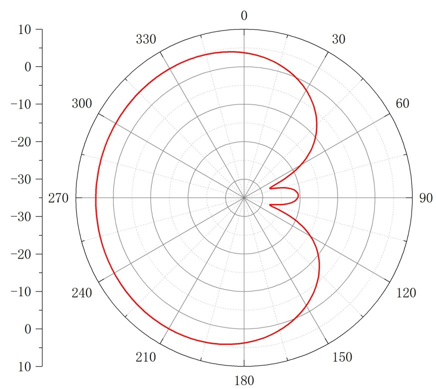


Figure 6. Full-wave simulation pattern at 2.5GHz in *yoz*-plane under state 2.

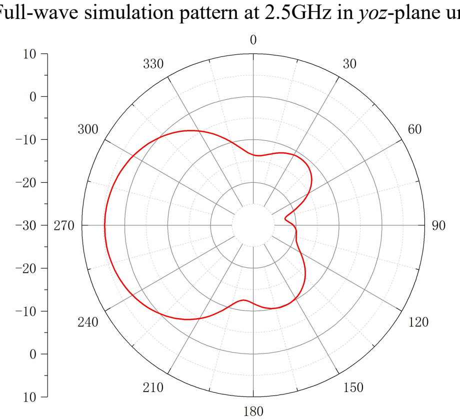


Figure 7. Full-wave simulation pattern at 2.5GHz in *xoy*-plane under state 2.

Based on the above results, it is apparent that by simply changing the phase difference among the four ports, the omnidirectional and directional pattern switchable antenna is achieved. The directional pattern can be used to cover a certain radiation range. When it turns to form the omnidirectional antenna, it can be utilized to realize a 360° radiation coverage in the horizontal plane. This feature makes it very appealing for multi-functional applications.

IV. Conclusion

A ring patch antenna with switchable patterns is proposed in this paper. The operating mechanism of the proposed antenna is analyzed by the CMA. By using the CMA, the superposition of the electric field of different modes can be intuitively considered. Based on the current distribution, the antenna design can be more efficient by setting feeding ports in the proper positions to excite the desired modes. By changing the phase difference among the four ports, the presented antenna can not only achieve a 360° radiation coverage in the horizontal plane, but also be able to form a directional pattern with large front-to-back ratio. With its switchable patterns, the proposed antenna can be a promising candidate for various applications especially for the multi-functional systems.

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