A Pattern Reconfigurable Antenna Featuring Large Tilted Angle for 5G Applications

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***Abstract*-A novel pattern reconfigurable antenna based on quasi-Yagi principle is proposed in this paper. The proposed antenna consists of four arc-shaped radiators, a parasitic patch and a pair of reconfigurable feeding networks. By switching the operating states of four PIN diodes in the feeding network, the surface current distribution of four arc-shaped radiators can be controlled respectively. In such way, the pattern reconfigurable characteristic is obtained. To further improve the antenna gain, a parasitic patch is added. Moreover, based on the Yagi operating principle, the parasitic patch acts as the director, which greatly increases the antenna tilted angle. The simulation results show that the antenna gain is 3.77dBi-4.29dBi and the tilted angle is increased from 50° to around 70°. Moreover, eight radiation modes with different beam directions and good impedance matching from 2.4 GHz to 2.5 GHz are achieved, which is suitable for 5G indoor applications.**

Index Terms—Pattern reconfigurable antenna, large tilted angle, Yagi structure.

I. INTRODUCTION

In the face of increasingly complex communication environments, single-mode or fixed-mode antenna cannot meet the high demand of communication quality in 5G and B5G systems. Therefore, pattern reconfigurable antennas have attracted considerable interests, because of their multi-beam switching ability that can greatly enhance the channel capacity and improve the anti-interference ability [1].

Different kinds of beam reconfigurable antennas have been proposed over the past decade. The first is to load a switchable parasitic structure around the omnidirectional antenna. The beam direction is changed by controlling each switch. However, such antennas suffer from large size and high loss [2],[3]. Another approach is to change the direction of antenna beam by switching the excitation of different ports by using multi-port structure, which needs complex feeding network [4],[5]. The third is the use of the liquid metal radiator with low loss, requiring costly servo system [6]. A final approach is based on the mode synthesis technology. The beam-scanning performance is achieved by the combination of different antenna modes. However, it requires a complex feeding network [7]. Although different methods of beam scanning/control antennas have been studied, there are still some shortcomings, such as large size, low gain, and small tilted angle. The tilt Angle of directional reconfigurable antenna is closely related to its anti-interference strength, so people pay more and more attention to how to increase the tilt Angle of directional reconfigurable antenna.

In this paper, a novel pattern reconfigurable antenna based on the quasi-Yagi principle with large tilted angle is proposed. The proposed antenna uses four arc-shaped radiators as the radiating structure. The pattern reconfigurable characteristic is achieved by controlling the proposed reconfigurable feeding network. A parasitic patch is introduced between the ground and the arc-shaped radiator, which effectively enhances the antenna gain and the tilted angle. Moreover, the proposed antenna can realize eight pattern modes in the 360° coverage range.

II. ANTENNA CONFIGURATION AND OPERATING PRINCIPLES

A. Antenna Configuration

Fig. 1 shows the structure of the proposed pattern reconfigurable antenna. As shown in Fig. 1(a), The antenna is composed of four arc-shaped radiation patches, a parasitic patch, metal columns, metal ground, and a pair of feeding networks. Three substrates are used to constructed the proposed antenna, among which three substrates are all FR4 (ε_r = 4.4 and tanδ = 0.02) substrate with a thickness of 0.5 mm. The air gap between each two substrates is 5 mm. Each arc-shaped radiator is angled at 75° and separated from each other by 15°. The spacing angle of the fan area in the parasitic patch is also 15°, and the angle of the arc gap etched in the fan area is 55°.

The arc-shaped radiation patches and the metal columns constitute two pairs of the electric monopole. The proposed simple feeding network loads four PIN diodes, which can be used for switching radiation beam. To further improve the antennas gain and the tilted angle of the antenna beam, a parasitic patch is loaded on the middle of antenna, which is utilized as the guide. Also, the parasitic patch can be viewed as the combination of two pairs of sector patches and a round patch, and arc grooves etched into the sector patch. The curved groove not only acts as a barrier between the metal column and the parasitic patch but also concentrates energy on the edge of the parasitic patch. It is noted that the feeding metal column is connected to the feeding network and the parasitic patch at the same time.

The PIN diode used in this paper is MA4AGP907. The PIN diodes in the feeding network are arranged in counterclockwise order, which are called Diode1(D1), Diode2(D2), Diode3(D3) and Diode4(D4).

The optimized antenna dimensions are shown in Table I.

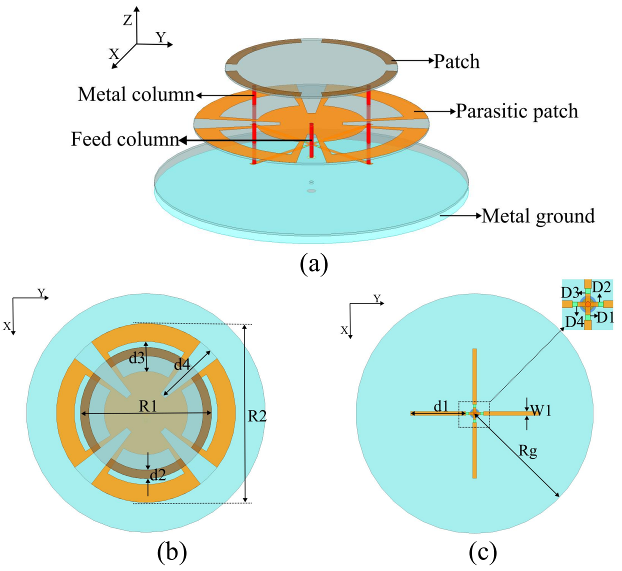

Fig. 1. Configuration of the proposed antenna. (a) Perspective view. (b) Top view. (c) Bottom view.

TABLE I
Dimensions of the Proposed Antenna (Unit: mm)

R1	R2	Rg	W1
44	60	40	1.33
d1	d2	d3	d4
18.57	2.87	10	22

B. *Operating Principles*

Fig. 2 shows the evolution process of the proposed antenna. First, only the arc radiator and the metal floor are used. The feeding network is loaded on the upper surface of the lower substrate. By controlling the ON/OFF state of the PIN diode in the feeding network, the tilted beam function similar to the Yagi operating principle can be obtained and beam-scanning performance can be realized. It is called Case 1, which is shown in Fig. 2 (a). Then, a parasitic patch is introduced based on Case 1. The parasitic patch is loaded on the upper surface of the medium substrate, as illustrated in Fig. 2 (b), called Case 2. Different from Case 2, a feeding metal column is added in the middle of feeding network for the proposed antenna.

Fig. 3 shows the simulation reflection coefficients,peak gain and the radiation patterns of two cases and the proposed antenna. As shown in Fig. 3, although the operating frequency band of Case 1 is from 2.33GHz to 2.51GHz, the tilted angle is small (50°), and the gain range is 3.11dBi-3.62dBi. As for Case 2, the tilted angle is effectively increased (80°). However, the value of $|S_{11}|$ is around -4 dB in the interesting frequency band, and the gain is reduced to 1.86dBi-2.96dBi. Compared with case 2, the proposed antenna has a good impedance matching, while the tilted angle is no changed a lot (10°), and the gain range is 3.77dBi-4.29dBi. In the proposed antenna, the parasitic patch is excited by the feeding metal column, and the electric field direction on its surface is the same as that on the surface of the arc radiator. Therefore, the parasitic patch plays the role of the guide based on the Yagi operating principle. On the contrary, in Case 2, the parasitic patch is stimulated by the arc-shaped radiation patch, and the direction of its surface electric field is affected by the arc radiator. Although it can also act as a guide, it will greatly deteriorate the impedance matching of the antenna.

To better understand the operating principle of the proposed antenna, Fig. 4 shows the surface electric field distribution of the arc radiation patch and the parasitic patch of the antenna at 2.45 GHz when D1 is turned on. It can be seen from the Fig. 4 that the parasitic patch acts as a director, the excited arc-shaped radiant patch acts as an active radiator, and the unexcited radiant patch acts as a reflector.

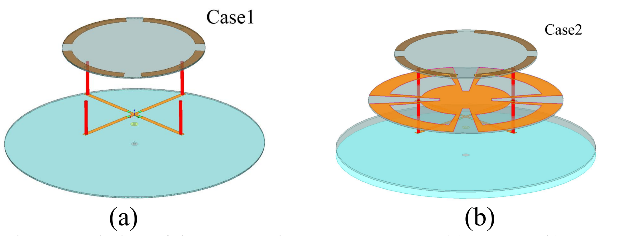

Fig. 2. Evolution of the proposed antenna structure. (a) Case 1. (b) Case 2.

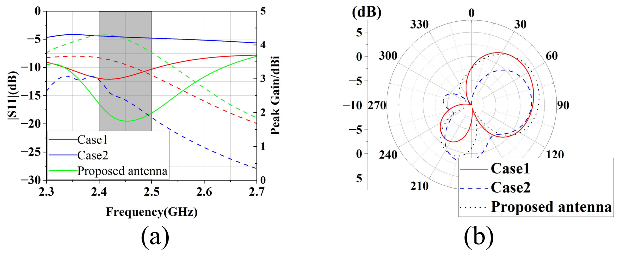

Fig. 3. Simulated reflection coefficients ($|S_{11}|$),peak gain and radiation patterns for the proposed antenna and two cases at 2.45GHz.

TABLE II
Radiation Pattern States of the Proposed Antenna

States	D1	D2	D3	D4	Beam direction
S1	ON	OFF	OFF	OFF	Phi=0°,Theta=70°
S2	ON	ON	OFF	OFF	Phi=45°,Theta=70°
S3	OFF	ON	OFF	OFF	Phi=90°,Theta=70°
S4	OFF	ON	ON	OFF	Phi=135°,Theta=70°
S5	OFF	OFF	ON	OFF	Phi=180°,Theta=70°
S6	OFF	OFF	ON	ON	Phi=225°,Theta=70°
S7	OFF	OFF	OFF	ON	Phi=270°,Theta=70°
S8	ON	OFF	OFF	ON	Phi=315°,Theta=70°

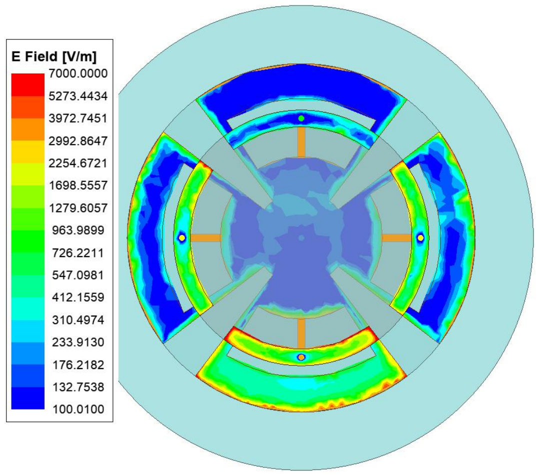

Fig. 4. Surface electric field distribution at 2.45GHz when the antenna is in S1 state.

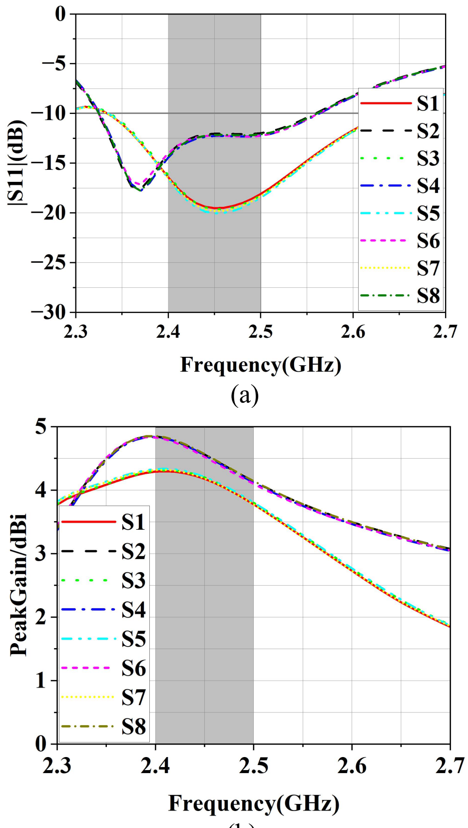

Fig. 5. (a) Simulated reflection coefficient (|S_{11}|) and (b) Peak Gain for the proposed antenna with different switch states.

By switching the ON/OFF states of the four PIN diodes, the proposed antenna can achieve beam scanning in the horizontal plane. The switching states of the eight modes of the reconfigurable antenna are shown in.Table II.

III. RESULTS AND DISCUSSIONS

The reflection coefficients and peak gain of the proposed antenna under different states are shown in Fig. 5. The impedance bandwidth of the designed antenna can cover the 2.4-2.5GHz band in all states, as shown in Fig. 5(a). Fig. 5(b) shows the gain of the proposed antenna under different states. As shown, the gain of the antenna under excitation of only one patch is smaller than that under excitation of two patches at the same time.

Fig. 6 shows the radiation patterns of the antenna in different states at the frequency of 2.45 GHz. As can be seen from Fig. 6, eight radiation modes covering 360° azimuth range are generated by the antenna at 45° step. It is worth noting that its tilted angle is greater than 70°. Combined with the multi-beam controllable characteristic, it can meet the requirements for indoor complex environment communication and 5G applications.

IV. CONCLUSION

Based on the operating principle of the quasi-Yagi structure, a low-cost large-tilted-angle, pattern reconfigurable antenna is proposed in this paper. The quasi-Yagi structure is formed by four arc-shaped radiators, a ground plane, and a parasitic patch, which generates a tilted beam with large tilted angle. By controlling the PIN

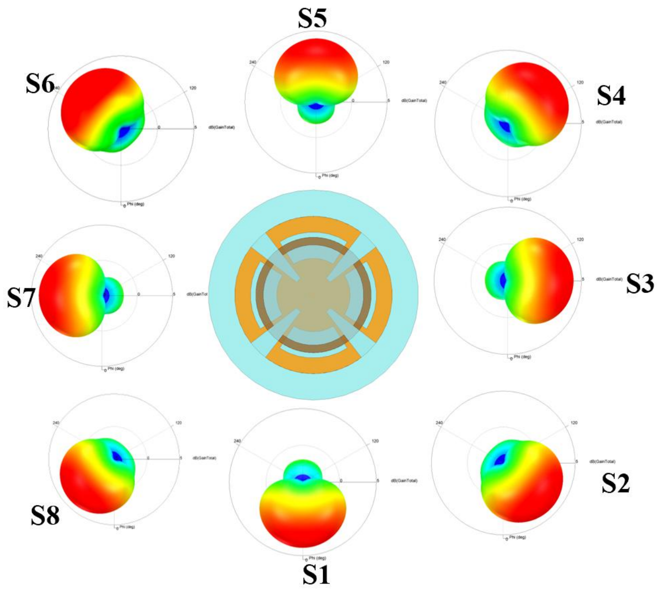

Fig. 6. Simulated pattern of the proposed antenna in different states at 2.45GHz.

diode loaded on the feeding network, the antenna can generate eight beams towards different directions with a 45° step. Because of its large covering range, simple structure, and low cost, the proposed antenna is suitable for various 5G applications.

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