

Clubs-shaped Antenna with Reconfigurable Radiation Pattern for Wideband Wireless Applications

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Abstract—A clubs-shaped wideband antenna with reconfigurable radiation pattern is proposed. This antenna is composed of two tapered slots of mirror symmetry, embedded with two PIN diodes and fed by a $50\ \Omega$ coplanar waveguide (CPW). By controlling states of PIN diodes, two tapered slots can be shut down or opened. Consequently, the proposed antenna works in three radiation modes: one monopole pattern with a simulation frequency band (3.93–5.55 GHz) and two end-fire patterns with an identical band (3.29–6.13 GHz). The antenna is fabricated and tested. Measured results show good agreement with the simulation, which denotes that it is suitable for wideband wireless communication systems.

1. INTRODUCTION

The demand of high quality of wireless communication systems requires higher operating flexibility such as effective switching at different frequencies, patterns and polarizations. Meanwhile, there is also a trend of miniaturization and low cost. A reconfigurable antenna can be designed to be reusable at characteristics such as frequency, radiation pattern and polarization without increase of antennas [1–4], and has been a promising solution to meet these conflicting requirements [5, 6]. Meanwhile, wideband pattern reconfigurable antenna has attracted significant attention for its flexibility and large capacity. Several methods have been adopted in the research of pattern reconfiguration [7–9]. In [7, 8], a few PIN diodes are loaded into parasitic patches, which play the role of directors or reflectors when the diodes' states change. In [9], controlling off-on states of four PIN diodes to achieve the switch between a tapered slot and a monopole structure results in one end-fire radiation pattern and one omnidirectional pattern. But the antenna has only two radiation modes, which limits its scope of application. To further increase the number of radiation modes, the design of [9] is improved. In this paper, two back-to-back tapered slots, embedded with two diodes placed across the narrow gaps, are combined to achieve a clubs structure with a CPW feeding line connected to the common limb. By controlling states of PIN diodes, three radiation patterns are realized: one monopole pattern with a simulation frequency band of 3.93–5.55 GHz radiated at YOZ plane and two end-fire patterns with an identical band of 3.29–6.13 GHz radiated at about $\Phi = 45^\circ$ and $\Phi = 135^\circ$, respectively.

2. ANTENNA DESIGN

The geometry of the proposed antenna and some details on component configuration are illustrated in Fig. 1. Fig. 1(a) shows the overall size while Fig. 1(b) shows details of the PIN biasing configuration. DC1–DC3 are direct current (DC) biasing pad; RFC1–RFC3 are 18 nH Murata RF choking inductance of 0805 package; C1–C5 are 47 pF DC blocking capacitor of 0603 package. D1 and D2 are PIN diodes. The antenna is designed based on Vivaldi antenna method. First, an exponential curve was created

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under the XOY coordinate system. Then a patch was formed with the curve's mirror image by rotating φ . Finally, after being duplicated by rotating ± 90 degrees around Z axis and tailored, a clubs-shaped patch is generated. The exponential function is shown as in Eq. (1) while Formulas (2) and (3) give the expressions of $c1$ and $c2$ in Formula (1) [10].

$$y1 = c1 \cdot e^{ra \cdot x} + c2, \quad x \in [x1, x2] \quad (1)$$

$$c1 = \frac{y2 - y1}{e^{ra \cdot x2} - e^{ra \cdot x1}} \quad (2)$$

$$c2 = \frac{y1 \cdot e^{ra \cdot x2} - y2 \cdot e^{ra \cdot x1}}{e^{ra \cdot x2} - e^{ra \cdot x1}} \quad (3)$$

In order to reduce the increment of size in y direction caused by DC3, a slot of $Wc2$ in width and $Lc2$ in length is loaded into the common limb, and the DC bias line (DC3) is inserted into the slot. Some comb slots are loaded into the ground to compress the beam width.

The parameters are simulated and optimized by commercial software Ansoft HFSS V15. The final optimized variable values are set as follows: $y1 = 1.6$, $y2 = 14$, $x1 = 4.3$, $x2 = 32.6$, $ra = 0.1$, $\varphi = 46$ degrees, $Wc1 = 0.3$ mm, $Lc1 = 7.7$ mm, $Wc2 = 2.5$ mm, $Lc2 = 14$ mm, $W1 = 1.5$ mm, $W2 = 1.7$ mm, $W3 = 12$ mm, $W4 = 14.4$ mm, $W5 = 1$ mm, $W6 = 1.5$ mm, $L1 = 2$ mm, $L2 = 3.5$ mm, $L3 = 1.2$ mm, and overall size is $W = 60.8$ mm in width and $L = 36.2$ mm in length.

Two SMP1345-079LF PIN diodes, of which the working frequency cover up to 6 GHz with about 0.19 pF capacitance at off-state and 1.5Ω resistance at on-state, are embedded into the narrow end of two tapered slots. When two diodes D1, D2 are both in off-state, the common limb becomes a monopole patch, and other limbs of the two tapered slots serve as ground, whereas the antenna works as a quasi Vivaldi antenna when one diode is in off-state and the other in on-state. Table 1 gives the operation states for different radiation modes.

Figure 2 shows the simulated magnitude of surface current distribution of the proposed antenna at 5 GHz.

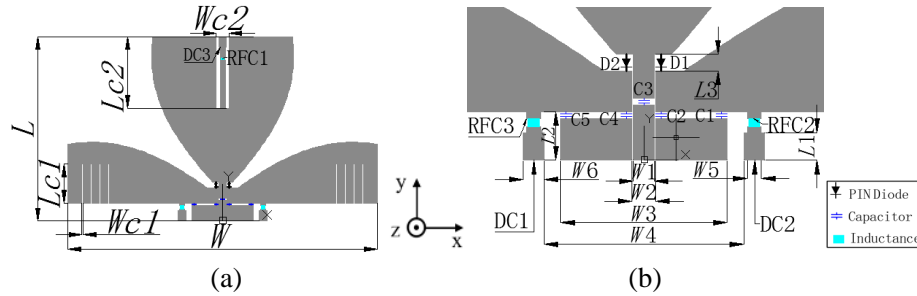


Figure 1. Geometry of reconfigurable antenna and biasing structure: (a) Overview and (b) PIN biasing and components configuration.

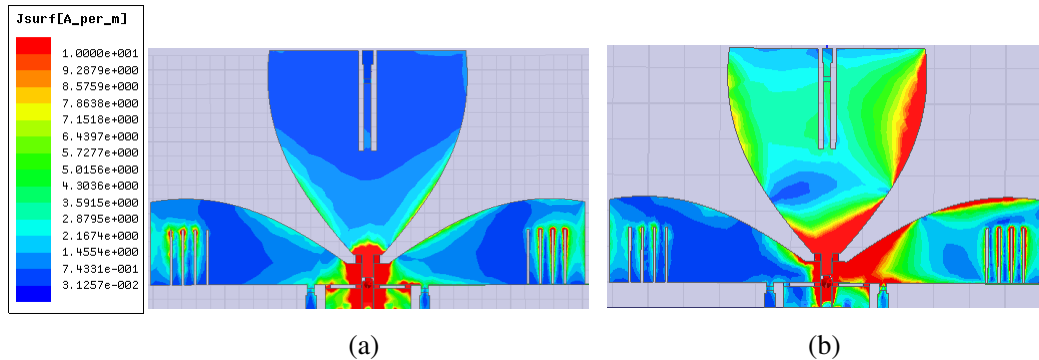


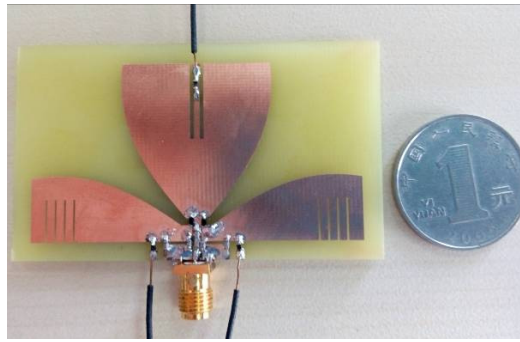
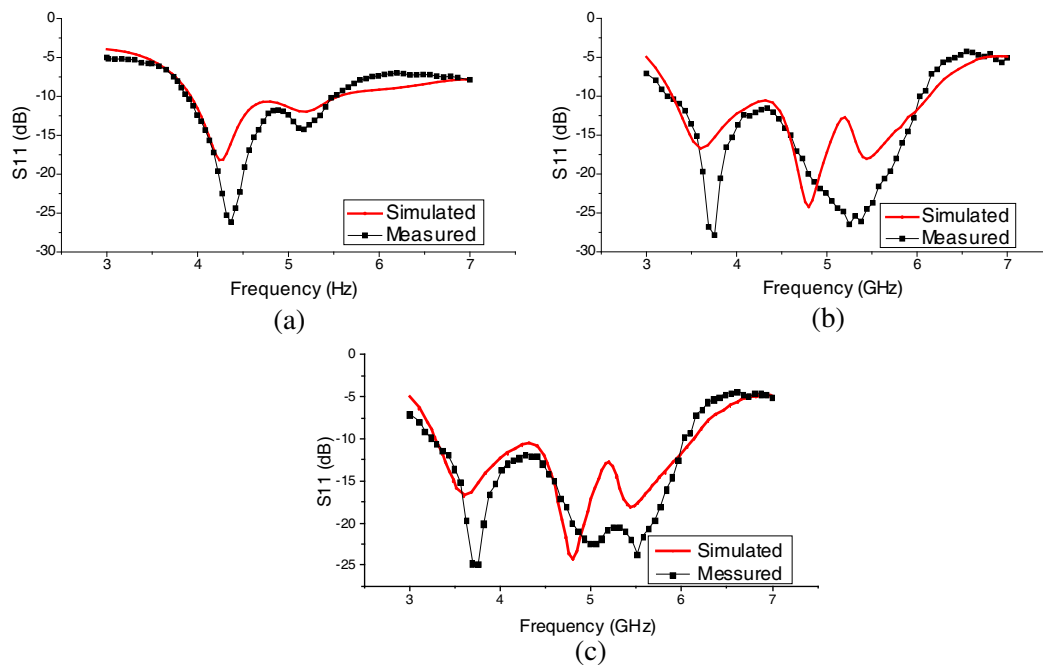
Figure 2. Magnitude of surface current distribution at 5 GHz. (a) Monopole mode, (b) end-fire mode.

Table 1. Operation modes.

	DC1	DC2	DC3	
$S1$	High	High	High	D1 off, D2 off, Monopole antenna
$S2$	Low	High	High	D1 on, D2 off, End-fire antenna1
$S3$	High	Low	High	D1 off, D2 on, End-fire antenna2

3. RESULTS AND DISCUSSION

Based on the optimal dimensions, a prototype of wideband pattern reconfigurable antenna is designed, fabricated and experimentally investigated. Fig. 3 shows a photograph of the fabricated antenna printed on an FR4 substrate with a relative permittivity of 4.4 and thickness of 2 mm. The DC biasing lines are welded on the DC pads.

**Figure 3.** Photograph of the fabricated reconfigurable antenna.**Figure 4.** S_{11} of the reconfigurable antenna. (a) S_{11} of state $S1$ (Monopole mode), (b) S_{11} of state $S2$ (End-fire mode), (c) S_{11} of state $S3$ (End-fire mode).

The S_{11} of the proposed clubs-shaped antenna is measured by an Agilent E8363B vector network analyzer. Measured and simulated results are plotted in Fig. 4 and listed in Table 2. For state $S1$, measured impedance bandwidth for $|S_{11}| \leq -10$ dB is about 1.58 GHz (3.90–5.48 GHz), and for $S2$ and $S3$, the bandwidth of test is respectively 2.84 GHz (3.26–6.03 GHz) and 2.77 GHz (3.25–6.01 GHz). According to Fig. 4(a), the measured impedance bandwidth of monopole antenna mode agrees well with simulation, whereas $S2$ and $S3$ are slightly drifted compared to the simulated bandwidth of 2.84 GHz (3.29–6.13 GHz) according to Fig. 4(b) and Fig. 4(c), which is mainly because components error especially the parametrics of SMP1345-079 PIN diode adopted in simulation have some deviation and drift along with frequencies. Moreover, welding error and external DC lines also impact the antenna radiating performance.

Figure 5 shows the normalized radiation patterns of the presented antenna of state $S1$. Due to the

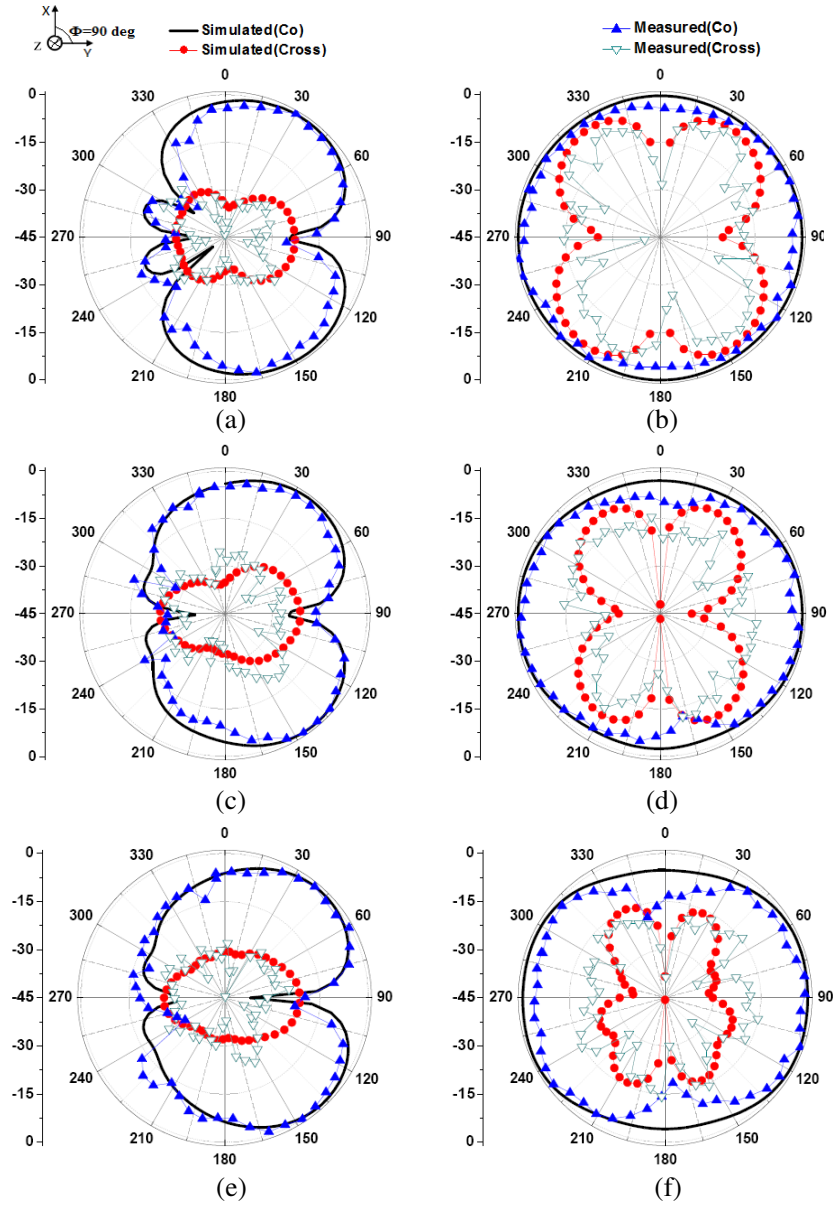


Figure 5. Normalized radiation patterns of state $S1$ (Monopole). (a) E -plane (XOY) at 4.5 GHz, (b) H -plane (YOZ) at 4.5 GHz, (c) E -plane at 5 GHz, (d) H -plane at 5 GHz, (e) E -plane at 5.5 GHz, (f) H -plane at 5.5 GHz.

existence of taper-shaped ground, the patterns of E -plane (XOY) are slightly tilted forward compared with conventional monopole antenna with flat ground, and H -plane (YOZ) are compressed at $\Theta = 0$ deg. Fig. 6 and Fig. 7 give the normalized radiation patterns of state $S2$ and state $S3$.

As shown in Figures 6 and 7, for states $S2$ and $S3$, antenna radiated at about $\Phi = 45$ deg and $\Phi = 135$ deg, respectively. It can be explained by that two ground arms of the antenna are formed by rotating common limb around Z axis for ± 90 degrees and then tailored. So the inner edges of two tapered slots are symmetrical with $\Phi = 45$ deg axis and $\Phi = 135$ deg axis in XOY plane, respectively. Consequently, the main beam of end-fire modes is skewed by around ± 45 degrees from Y axis in a wideband.

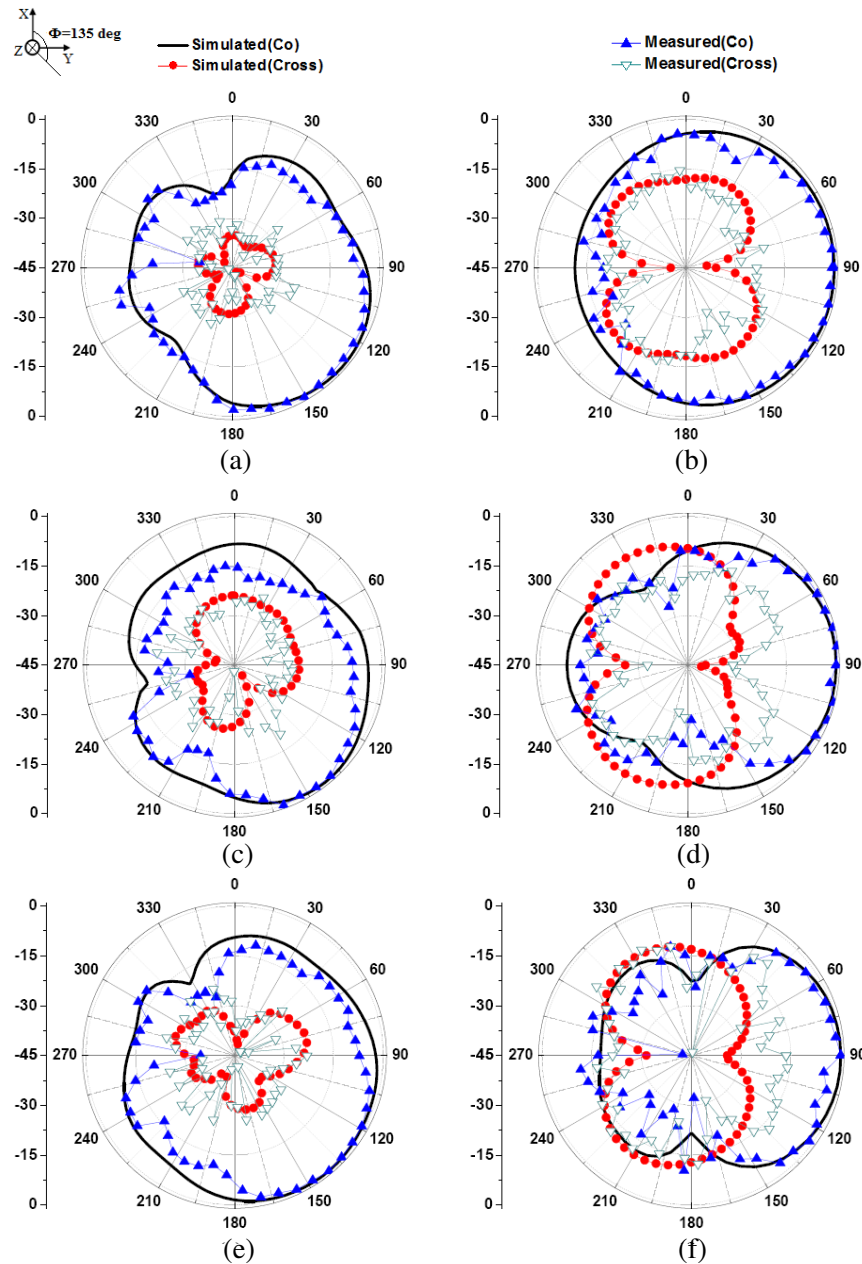


Figure 6. Normalized radiation patterns of state $S2$ (End-fire mode). (a) E -plane (XOY) at 3.5 GHz, (b) H -plane ($\Phi = 135$ deg) at 3.5 GHz, (c) E -plane at 4.5 GHz, (d) H -plane at 4.5 GHz, (e) E -plane at 5.5 GHz, (f) H -plane at 5.5 GHz.

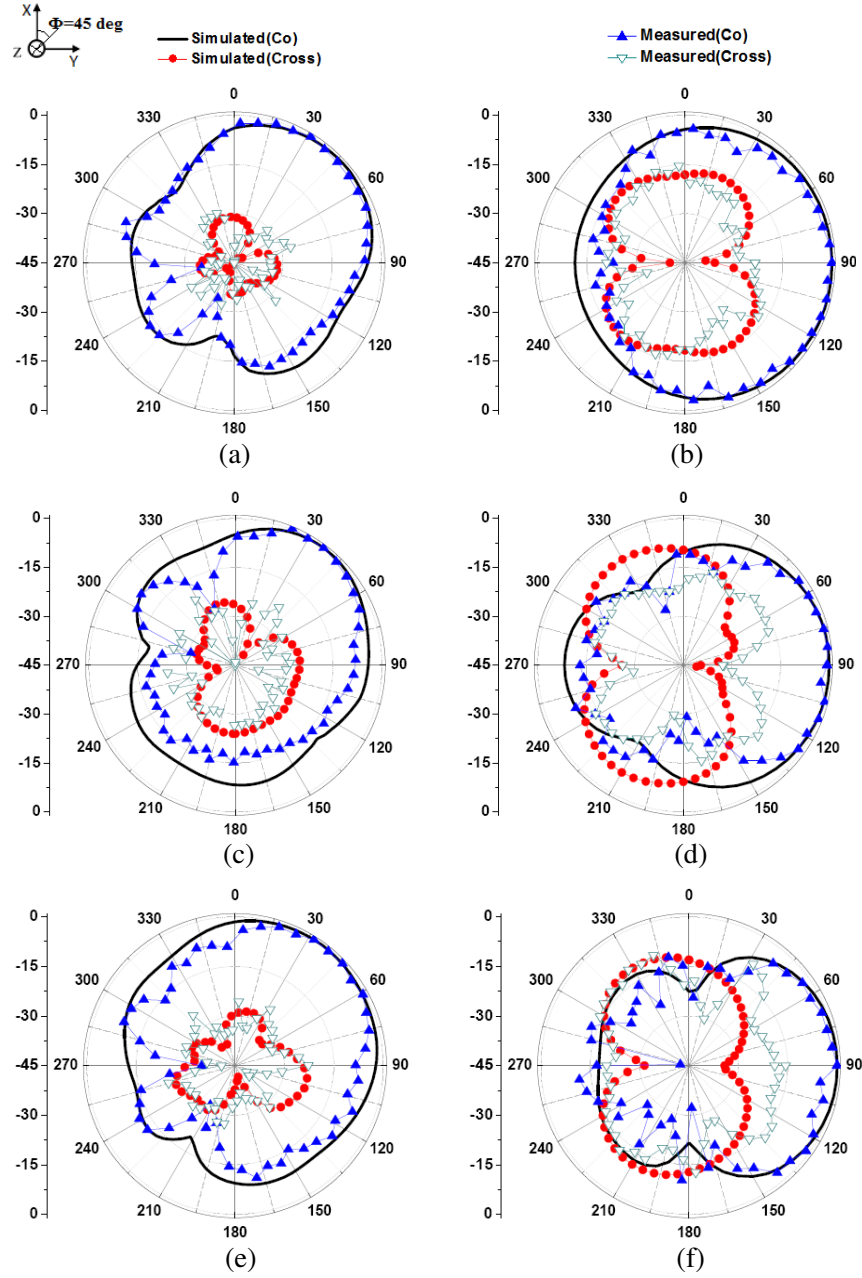


Figure 7. Normalized radiation patterns of state $S2$ (End-fire mode). (a) E -plane (XOY) at 3.5 GHz, (b) H -plane ($\Phi = 45$ deg) at 3.5 GHz, (c) E -plane at 4.5 GHz, (d) H -plane at 4.5 GHz, (e) E -plane at 5.5 GHz, (f) H -plane at 5.5 GHz.

Table 2. Measured and simulated impedance bandwidths of the proposed antenna.

	$S1$	$S2$	$S2$
	BW (GHz)	BW (GHz)	BW (GHz)
Measured	3.90–5.48	3.26–6.03	3.25–6.01
Simulated	3.93–5.53	3.29–6.13	3.29–6.13

4. CONCLUSION

A wideband clubs-shaped antenna with reconfigurable radiation pattern is presented. By changing the off-on states of two PIN diodes, the proposed antenna radiates at three pattern modes: one monopole mode with a bandwidth of 1.58 GHz (3.90–5.48 GHz) and two end-fire modes, with the bandwidths are respectively 2.84 GHz (3.26–6.03 GHz) radiated at $\Phi = 135^\circ$, and 2.77 GHz (3.25–6.01 GHz) radiated at $\Phi = 45^\circ$ approximately. Measured results match well with the simulation and show steady radiation across working band. Therefore, this antenna is suitable for wideband wireless communication applications.

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