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A FUNCTIONAL MICROSTRIP CIRCUIT MODULE FOR ANNULAR SLOT ANTENNA

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Abstract—A functional microstrip circuit module for annular slot antenna is proposed. This module consists of an annular microstrip line component, two PIN diodes and a DC bias circuit. Reconfigurable circular polarizations can be simply controlled by this functional module. Axial ratio is adjustable by changing the clip angle of the notch made by the annular microstrip line component. Simulated and experimental results have shown good impedance bandwidth for return loss and antenna gains in circularly polarized states.

1. INTRODUCTION

Reconfigurable patch antenna with multiple polarizations can optimize system performance [1–6]. Offering improved effectiveness in receiving communication signals and reducing multipath fading were reported as the advantages for reconfigurable circularly polarized states [7–9]. Wilkinson power divider and branch microstrip line have been used very often in reconfigurable polarization antenna as tuners to modify the orthogonal radiation modes [10–14]. However, the most disadvantage is that the complicated DC bias circuit must be carefully considered to compensate the inefficient feed structure for

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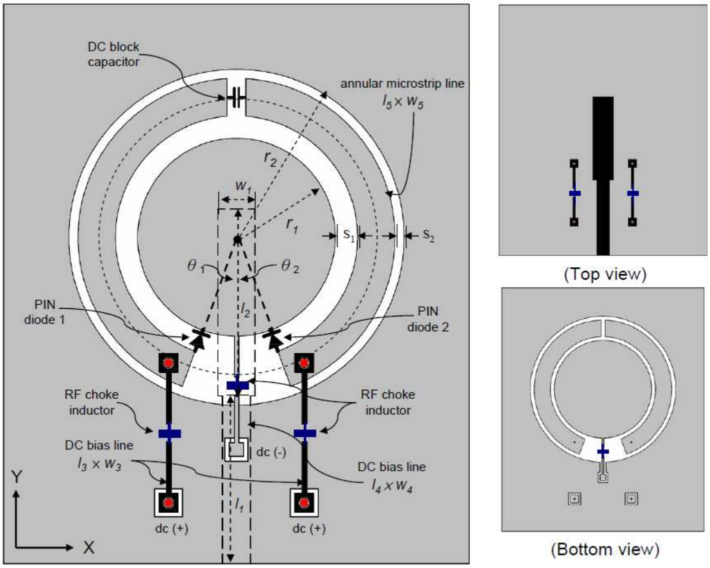
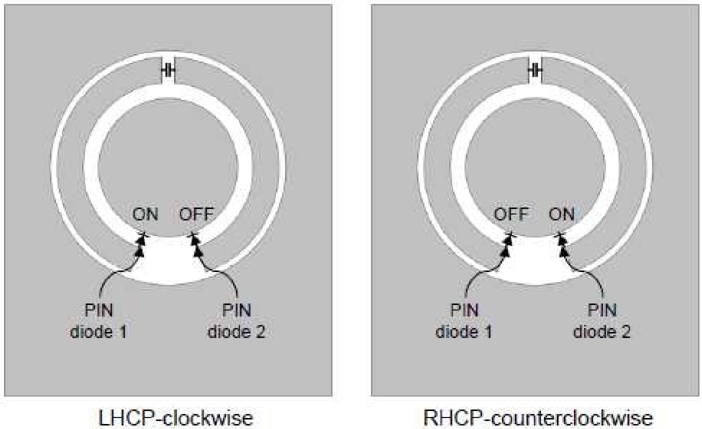
manipulating circular polarization [15, 16]. Basically, the slot antenna embedded with a single probe feed structure can always create circular polarization [17–19], for instance, printing slot line at locations of 45° and 135° [20, 21], adding stubs to couple with the excited orthogonal modes [22, 23] etc. As embedded the PIN diode into the patch antenna to reconfigure the circularly polarized states was reported before [24–26], controlling the modes of PIN diode to adjust the surface current on radiator could be an alternative way to modify the polarization of the antenna. In this study, with improving the operational convention of the circular polarization for the annular slot antenna, we propose a more effective design for reconfiguring circularly polarized states by using a single probe feed structure with a functional module.

2. ANTENNA CONFIGURATION

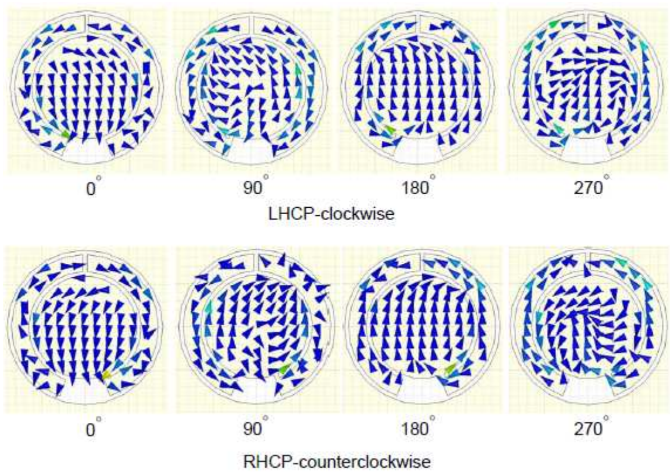
The geometry structure of the proposed antenna is depicted in Figure 1(a). It consists of two parts. Part 1 is a passive annular slot [20–23] implemented on FR4 substrate ($\varepsilon_r = 4.4$) with the overall size of $50 \times 60 \times 1.6\,\text{mm}^3$, and Part 2 is an active functional module. The functional module is composed of an annular microstrip component and a DC bias circuit. The annular microstrip line component, $l_5 \times w_5$, was printed on the opposite side of the substrate that the annular



(a)



(b)



(c)

Figure 1. (a) Geometry of the proposed antenna. (b) Configurable polarizations. (c) Simulated surface currents (by Ansoft HFSS) on the radiator of the proposed antenna.

slot was printed. The DC bias circuit components consist of two PIN diodes, three chokes and a DC block capacitor. Through the gap coupling (S_1 and S_2) and the microstrip circuit components, the functional module connected to the circular patch (radius r_1) can be used to manipulate the circularly polarized states of the antenna. By calculating the quarter wavelength via the operation frequency shown in Equation (1), we determined the size of the annular slot. The degrees of angles θ_1 and θ_2 shown in Figure 1(a) can regulate the axial ratio of circular polarization. The length of microstrip transmission line l_1 is $50\,\Omega$ impedance matching to the rectangular microstrip line $l_2 \times w_1$. DC bias is provided via the microstrip $l_3 \times w_3$ and $l_4 \times w_4$ to adjust the states of PIN diodes shown in Figure 1(a). The proposed antenna is excited through the single probe feed. In Figures 1(a) and 1(b), it is shown that PIN diode 1 connects left annular microstrip component to the circular patch. Meanwhile, PIN diode 2 connects right annular microstrip line component to the circular patch. The operation frequency was found at 2.4 GHz with the impedance bandwidth 20% of the return loss at -10 dB down. Simulation software Ansoft HFSS was used to optimize the parameters of the proposed antenna and are listed in Table 1.

Table 1. Parameters of the antenna structure.

Parameters	Dimensions	Parameters	Dimensions	Parameters	Dimensions
r_1	12 mm	l_1	18 mm	$l_3 \times w_3$	17×0.65 mm^2
$\theta_1 = \theta_2$	20°	l_2	20 mm	$l_4 \times w_4$	22×0.65 mm^2
w_1	4 mm	$S_1 = S_2$	1 mm	$l_5 \times w_5$	87×4 mm^2

The reconfigurable circularly polarized states of the proposed antenna are shown in Figure 1(b). Consequently, the PIN diode makes a good RF (radio frequency) switch. When the PIN diode 1 is kept in short (short circuit) and the PIN diode 2 is in open (open circuit), left hand circular polarization (LHCP) is obtained. In contrary, when the PIN diode 1 is kept in open and PIN diode 2 is in short, right hand circular polarization (RHCP) is obtained.

$$r_2 = \frac{\lambda_0}{4}, \quad \lambda_0 = \frac{C}{f\sqrt{\varepsilon_{eff}}} \tag{1}$$

The calculated current distributions of the proposed antenna are shown in Figure 1(c) to demonstrate the radiation characteristics of circular polarization. If the maximum currents are located at the phase angles of 0°, 90°, 180°, and 270°, the current flows counterclockwise to produce RHCP radiation. In contrary, the current flows clockwise to produce LHCP radiation.

In Figures 2(a) and 2(b), the equivalent circuits of the states of open and short circuit for the PIN diodes are demonstrated. Based on the BAR64-04W data sheet of the diode [27], an equivalent short state should have a forwarded resistance R_f ($\sim 1\,\Omega$) and an inductor

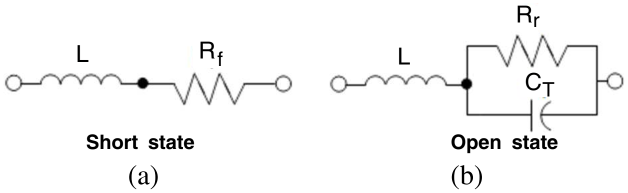


Figure 2. The equivalent circuits of PIN diode are (a) in short and (b) in open state.

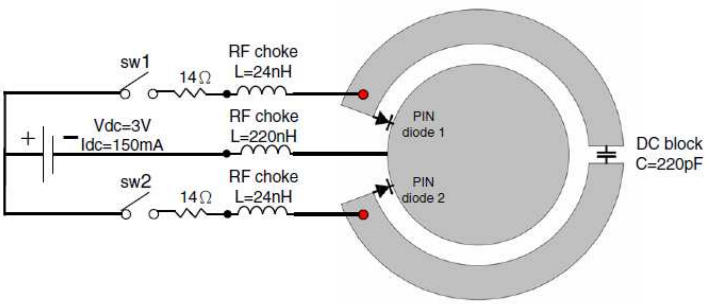
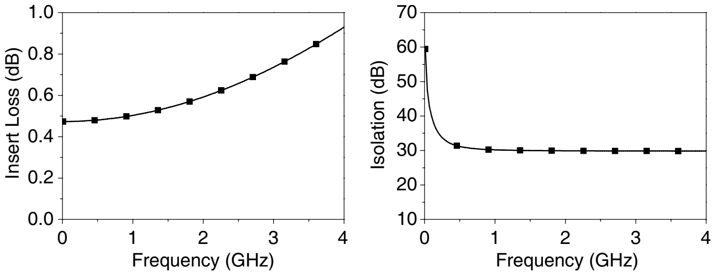


Figure 3. DC bias circuit of the switch.

L (= 1.4 nH). Besides, an open state should have a capacitor C_T (= 0.17 pF) parallel connected to a reverse resistance R_r at 3 kΩ.

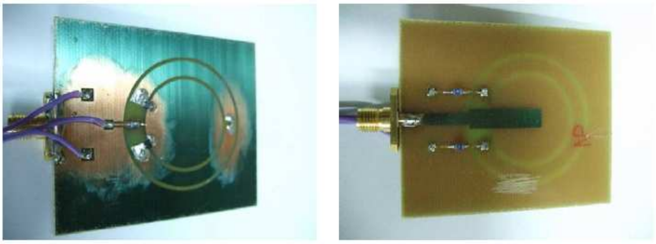
The series type of DC bias circuit is presented in Figure 3. It consists of three inductors used as RF choke where the capacitor is functioned as a DC block to avoid the DC current exciting another one of the PIN diodes. Two states of the circuit shown in Figure 3, sw1 and sw2 made by PIN diodes, are prepared for controlling the action. When sw1 is in short, the antenna is operated as LHCP antenna. If sw2 is short, the antenna can function as RHCP antenna. In our design, DC block includes a capacitor (C = 220 pF) with the impedance of $Z_C = -j0.3\Omega$. RF choke includes three inductors. Two of them are 24 nH for each, and another one is 220 nH functioned to avoid RF signals getting into the DC bias terminal.

In this study, the power source is designed as $V_{dc} = 3$ V and $I_{dc} =$ 150 mA. In Figures 1, 2 and 3, R_f is designed 5.6 Ω to minimize the loss on the microstrip line. The reverse impendence $Z_r = 3k - j370\Omega$. The forward impendence $Z_f = 5.6+j21.1\,\Omega$ was calculated by Equation (2). The PIN diode with the insert loss and the isolation are calculated by using Equation (3) and shown in Figures 4(a) and 4(b). In Figure 4(a), the insert loss of the PIN diode is shown to be 0.64 dB at 2.4 GHz, and

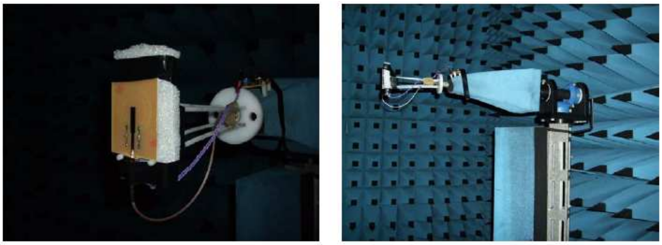


(a) (b)

Figure 4. Frequency dependent (a) insert loss and (b) isolation of the PIN diode.



(a)



(b)

Figure 5. (a) Prototype of the proposed antenna. (b) Set up of measuring radiations in anechoic room.

in Figure 4(b), the isolation of the PIN diode is shown to be 29.8 dB at 2.4 GHz. The DC bias circuit thus can have the greatest ratio on the off-to-on attenuation [27].

$$Z_d = \begin{cases} Z_r = R_r + j(\omega L_i - 1/\omega C_j) \\ Z_f = R_f + j\omega L_i \end{cases} \tag{2}$$

$$IL = -20\log\left|\frac{2Z_0}{2Z_0 + Zd}\right| \tag{3}$$

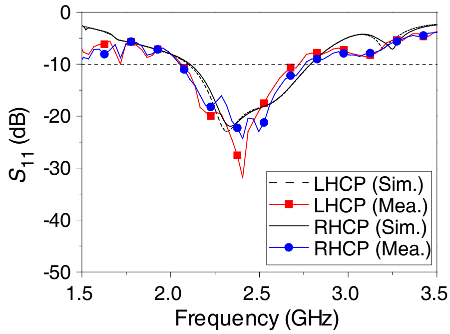


Figure 6. Simulated and measured return loss of the proposed antenna.

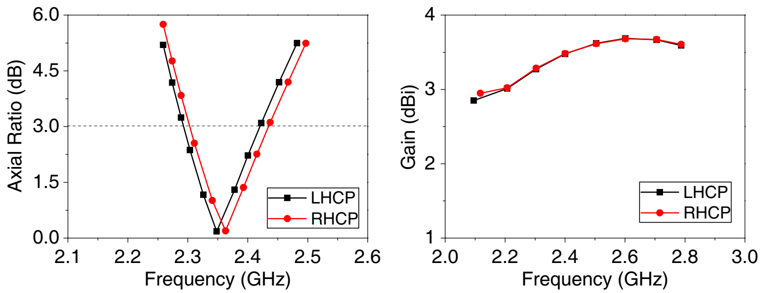


Figure 7. Measured results of the proposed antenna. (a) Axial ratio. (b) Antenna gains.

Table 2. Simulations and measurements of proposed antenna operated at 2.4 GHz.

Polarization	Diode1	Diode2	S_{11} [dB]		Bandwidths [%]		3 dB Axial Ratio Bandwidths [%]	Gain [dBi]
			Sim.	Mea.	Sim.	Mea.		
LHCP	ON	OFF	-20.2	-31.9	29.2	29.1	5.5	3.47
RHCP	OFF	ON	-20.4	-24.4	28.7	30	5.9	3.48

3. MEASUREMENTS AND SIMULATIONS

The measured radiations for the proposed antenna are demonstrated in Figures 5(a) and 5(b). The return loss of the proposed antenna is shown in Figure 6. The measurements of bandwidths of the proposed antenna are demonstrated, 29.1% at LHCP and 30% at RHCP. The measurements of the axial ratio and antenna gains are shown in

Figures 7(a) and 7(b). For the mode of LHCP, the measured CP operating bandwidth, referred to 3 dB axial ratio, is 5.5% (130 MHz) with respect to the center frequency 2.4 GHz. For the mode of RHCP, the CP operating bandwidth is 5.9% (140 MHz) and centered at 2.4 GHz. In addition, the antenna gain for the operation frequency at 2.4 GHz was observed 3.47 dBi at LHCP and 3.48 dBi at RHCP. Details of the simulation and measurement are listed in Table 2.

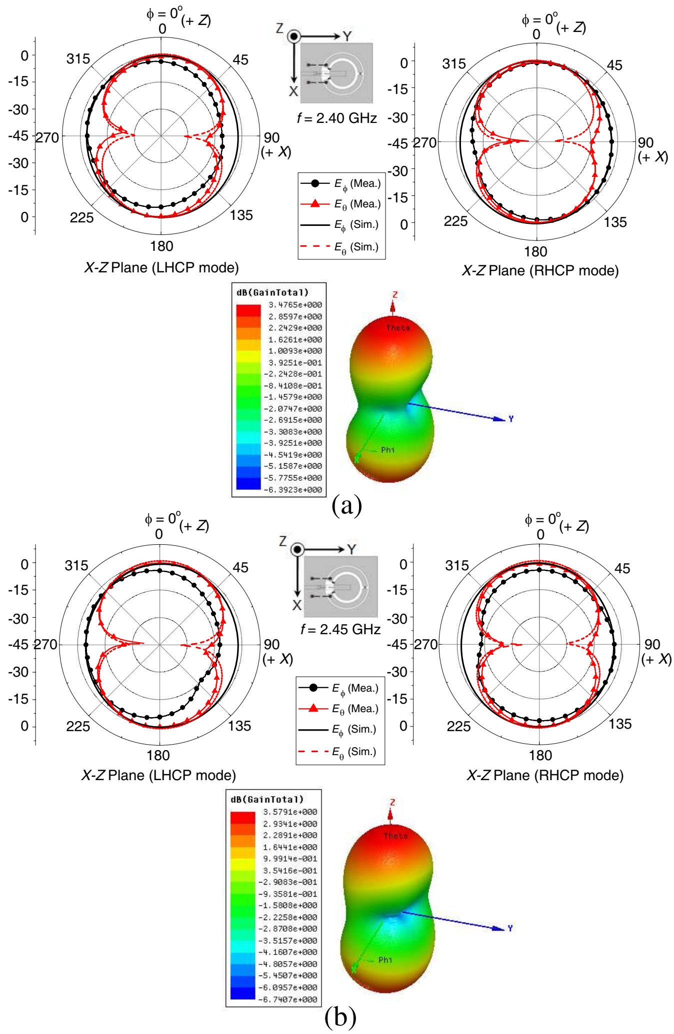


Figure 8. Measured (2D) and simulated (3D) patterns for the proposed antenna. (a) At 2.4 GHz, (b) at 2.45 GHz.

The measured two-dimensional patterns and the simulated three-dimensional patterns for the proposed antenna are shown in Figures 8(a) and 8(b). As in the figures, the proposed antenna is operated at 2.4 GHz and 2.45 GHz. The E_θ of x-z plane at LHCP and RHCP are shaped like the number of "8". The E_ϕ of x-z plane is shaped like omni-directional radiation. Comparatively, in 3D simulation pattern, it is confirmed in Figure 8 that the radiation in Z direction is demonstrated the same as in 2D measuring. The proposed antenna has thus good performance. Basically, we are only interested in the field patterns at the operation frequency 2.4 GHz with good and smooth antenna gains on both LHCP and RHCP states.

Because the rectangular microstrip line $l_2 \times w_1$ is connected to the microstrip transmission line l_1, the impedance matching has to be $50\,\Omega$ for our proposed antenna. The impedance and polarization axial ratio can be modified by adjusting the length l_2 and width w_1 for the rectangular microstrip line. The calculation results by Ansoft HFSS are demonstrated in Figures 9(a), 9(b), 9(c) and 9(d). As in the figures, when the length of the rectangular microstrip line l_2 is

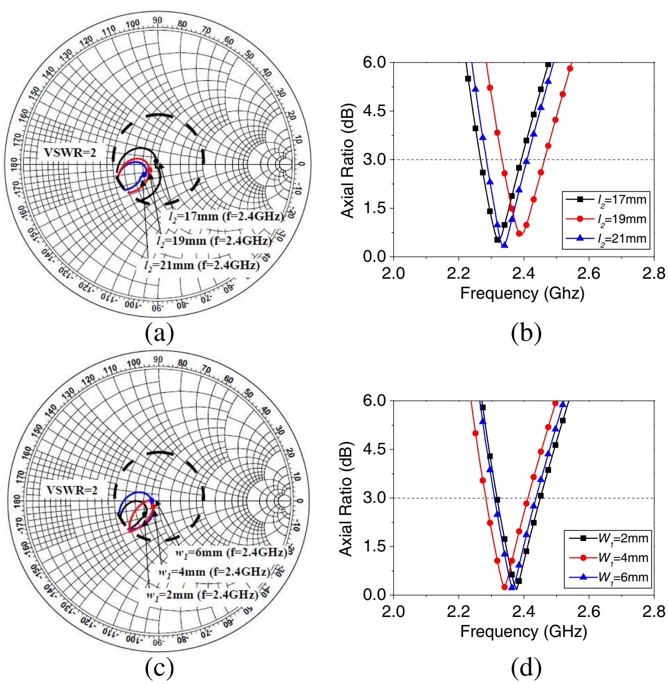


Figure 9. Effects of smith chart and axial ratio by adjustment (a) and (b) of l_2, (c) and (d) of w_1 on the proposed antenna.

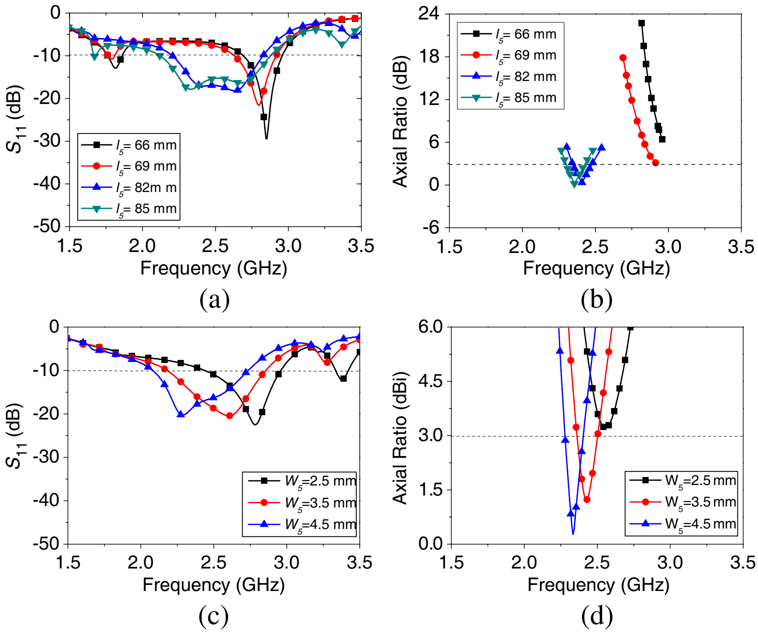


Figure 10. Effects of return loss and axial ratio by adjustment (a) and (b) of l_5, (c) and (d) of w_5 on the proposed antenna.

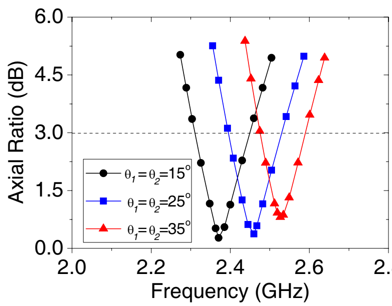


Figure 11. Variations of axial ratio for adjustments of θ_1 and θ_2.

adjusted from 17 mm to 21 mm, two degenerate resonant frequencies can be obtained. Changing the width w_1 can have a similar effect on the impedance matching at $50\,\Omega$ as well as axial ratio at 3 dB down. If the length of the annular microstrip line component l_5 was changed from 66 mm to 85 mm, the resonant mode would be changed and the axial changed as well. On the other hand, if the width of the annular microstrip line component w_5 was changed from 2.5 mm to 4.5 mm, the polarization axial ratio would be modified. The calculations are presented in Figures 10(a), 10(b), 10(c) and 10(d). If the degrees of θ_1 and θ_2 were increased from 15° to 35°, the axial ratio of the operation frequency would be modified. The calculation results are demonstrated in Figure 11.

4. CONCLUSION

This study presents an annular slot antenna design and implication with the functional microstrip circuit module by using a single probe feed to reconfigure the circular polarized states. Design parameters affect the characteristic of CP radiation significantly. The polarization states can be reconfigured by the modes of PIN diodes. Meanwhile, the antenna resonant modes can be modified by changing the length of the annular microstrip line component. Proper adjustments of the design parameters affect the resonance modes of the proposed antenna. Circular polarization and polarization axial ratio can be modified by tuning the functional module, for instance, changing the size of the annular microstrip line component and altering the degrees of included angles of the notch. The calculated and measured results confirm that our proposed antenna has good performance and that the module can be functioned as what we manage with.

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