Reconfigurable dual-slit perturbed patch antenna for circular polarization diversity

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Abstract: This paper reports a reconfigurable patch antenna using a novel dual-slit perturbation for circular polarization diversity. The proposed antenna consists of the dual-slit with in- and out-slit at a diagonal corner and three identical single-slits at the residual corners for generating right- and left-handed circular polarization. By controlling two pin diodes mounted in the dual-slit, the size of the slit can be switched and circular polarization diversity can be achieved. The measured results of the implemented antenna which employed the dual-slit show a good agreement with the simulation results and demonstrate an excellent controllability of alternating circular polarization senses at the resonant frequencies.

Keywords: reconfigurable microstrip antenna, circular polarization, dual-slit perturbation, polarization diversity

Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

Because circularly polarized (CP) antennas provide advantages of insensitive orientation mismatch losses and suppressed multi-path fading interferences [1], CP antennas have been considered for wireless communication systems [2] and wireless power transfer applications [3]. In addition, reconfigurable antennas with diversity functions make the system capability double owing to reuses and controls of the frequency and polarization [4]. For these reasons, the simplest way to obtain reconfigurable linear and circular polarization diversity was introduced in [5]. Recently, the perturbations have been improved to pursue enhanced radiation performances using slots on patch [6], ground slots [7] and one corner cut [8].

In this work, a new dual-slit perturbation of a reconfigurable patch antenna is proposed for circular polarization diversity. Compared with that of the single slit in three corners, the dual-slit enabling small and large slits is dealt with to achieve right-/left-handed circular polarization (RHCP and LHCP), respectively. For alternating circular polarization senses, two PIN diodes are installed between in-slit and out-slit of the dual-slit. By controls of the diode states, the circular polarization can be alternated because the dominantly operating size of the dual-slit can be controlled. Details of the proposed antenna, reconfigurable mechanism, simulation and measurement are described in following sections.

2 Antenna design and analysis

Fig. 1 shows the proposed antenna which employed the dual-slit and the operation principle. The square ring is designed with the size of \( L \) and the inner slot size of \( w \).

The 50 \( \Omega \) line to feed the square ring patch radiator and a quarter-wave impedance transformer to match the antenna impedance are used. In the square ring patch, three single slits with the slit gap of \( g \), and the lengths of \( d_2 \) and the bent width of \( s_2 \) are etched with the distance of \( p \). The dual-slit which consists of the small in-slit and the large out-slit with \( d_1 \), \( s_1 \), \( d_3 \) and \( s_3 \), respectively is being located at one diagonal corner and two PIN diodes are mounted between the in-slit and out-slit. The isolated area between out-slit and in-slit is used for the bias pad for applying bias voltages of 0 V or 0.7 V and the square ring patch is also used for the bias pad for reference voltage of 0 V.

To investigate the configuration of the dual-slit, the full-wave EM simulation is carried out, and the simulated results are illustrated in Fig. 2. The states of the diodes was replaced for on and off states equal to an ideally short and open condition in the simulation. By applying the different bias voltages,
the dominant size of the dual-slit can determine as expected from the operation mechanism and the geometry of the dual-slit. For applying forward voltage of 0.7 V, the isolated area and the square ring patch are connected each other, thus, the out-slit is inactivated and the in-slit with \( d_1 \) and \( s_1 \) is activated. It is noted that the in-slit can operate as a perturbation for generating RHCP as shown in Fig. 2(a) because \( d_1 \) and \( s_1 \) are electrically smaller than \( d_2 \) and \( s_2 \). In opposite case for applying 0 V, the separated out-slit is connected and changed to the closed loop circle, therefore, the out-slit with \( d_3 \) and \( s_3 \) is activated and the in-slit is invisible. The out-slit which has larger size than the size of the single slot with \( d_2 \) and \( s_2 \), accordingly, can also

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**Fig. 1.** Geometry of the proposed square ring patch antenna perturbed by a novel reconfigurable dual-slit and the operation mechanism of the dual-slit.

**Fig. 2.** Simulated electric current distributions on square patch at their resonant frequencies. (a) on-state with ideal short for RHCP and (b) off-state with ideal open for LHCP.
operate as a perturbation for generating LHCP as shown in Fig. 2(b). It is shown that the states of diodes provide the independently operating and excellently controllable perturbation and produce both RHCP and LHCP senses in the square ring patch radiator, respectively.

3 Implementation and measurement

To verify the theoretical investigation of the dual-slit perturbation, the single-feed square ring patch antenna with the \( L \) of 25 mm and the \( w \) of 6.5 mm in Fig. 1 is implemented on a 1.6 mm-thick FR4 substrate with \( \varepsilon_r = 4.4 \). All dimensions are optimized for the circularly polarized radiation of the square ring patch resonator, thus, are equal to the \( g \) of 0.5 mm, \( d_1 \) of 8.15 mm, \( d_2 \) of 9.5 mm, \( d_3 \) of 10.55 mm, \( s_1 \) of 3.2 mm, \( s_2 \) of 5.0 mm, \( s_3 \) of 5.6 mm, and \( p \) of 2 mm. Two diodes of BAR64-02V supported with the equivalent resistance of 2.1 \( \Omega \) at on-state and the equivalent capacitance of 0.23 pF at off-state and a DC block capacitor of 47 pF are used. The transformer and 50 \( \Omega \) feed line is to the length of 18 mm and the width of 0.5 mm and the length of 5 mm and the width of 3 mm, respectively.

The photograph of the implemented antenna and reflection coefficients of the proposed antenna are shown in Fig. 3. As discussed from the analysis and simulation in previous sections, the case for the diodes turned on by applying 0.7 V, the implemented antenna shows the RHCP sense and the 10-dB bandwidth of 72 MHz from 2.360 GHz to 2.432 GHz. When the diodes are turned off by 0 V, the implemented antenna shows the LHCP sense and the 10-dB bandwidth of 78 MHz from 2.400 GHz to 2.478 GHz.

![Photograph of the implemented antenna and reflection coefficients of the proposed antenna at on-state for RHCP and off-state for LHCP.](image)

Fig. 3. (a) Photograph of the implemented antenna and (b) reflection coefficients of the proposed antenna at on-state for RHCP and off-state for LHCP.

Fig. 4 shows the simulated and measured axial ratios (ARs) and antenna gains at both on and off states of the diodes for RHCP and LHCP senses, respectively. In RHCP, the 3-dB AR bandwidth is observed to be 20 MHz from 2.361 GHz to 2.381 GHz. The minimum AR and RHCP gain obtained 0.98 dB and −0.29 dBi at 2.37 GHz, respectively. In LHCP, the 3-dB AR
bandwidth is observed to be 23 MHz from 2.417 GHz to 2.440 GHz. The minimum AR and LHCP gain obtained 0.59 dB and 0.45 dBic at 2.43 GHz, respectively. It is noted that the observed small shift is due to a mismatch in the FR4 dielectric constant and loss tangent, i.e.,
\[ \varepsilon_r = 4.4 \text{ and } \tan \delta = 0.02 \text{ in the simulation and } \varepsilon_r = 4.3 \text{ and about } \tan \delta = 0.025 \text{ in the actual measurement.} \]
The simulation and measurement results are well agreed with in both cases, in spite of the substrate mismatch. The antenna CP gain is feebly decreased because of the electrically small radiator compared with that of a conventional square patch. The measured results of the implemented antenna are summarized at Table I.

| diode state | polarization sense | –10 dB imp. BW | resonant freq. | minimum AR | 3 dB AR BW | Antenna CP gain |
|-------------|-------------------|----------------|---------------|------------|------------|----------------|
| on-state (0.7 V bias) | RHCP | 3.01% (72 MHz) | 2.37 GHz | 0.98 dB | 0.84% (20 MHz) | –0.29 dBic |
| off-state (0 V bias) | LHCP | 3.20% (78 MHz) | 2.43 GHz | 0.59 dB | 0.95% (23 MHz) | 0.45 dBic |

The measured radiation patterns are shown in Fig. 5. For both cases, the radiation patterns are measured at the resonant frequencies of 2.37 GHz and 2.43 GHz with minimum AR values, respectively. Measured results show that broadside radiation patterns, that is, the z-direction with good CP characteristics are obtained at the resonant frequencies and the symmetrical patterns are achieved between yz-plane and zx-plane and between RHCP and LHCP modes. The almost identical radiation patterns in yz-plane (\( \phi = 90^\circ \)) and zx-plane (\( \phi = 0^\circ \)) are due to the radiator geometry, that is, the square ring patch with the internal perturbing element and small distortions from the bias network.

It is shown that the implemented antenna has an excellent circular polarization controllability by only applying bias voltages at the isolated area.
between the out-slit and in-slit. In addition, the radiation pattern distortions are almost ignorable.

4 Conclusion

A novel dual-slit perturbation method for the reconfigurable circularly polarized square ring patch antenna is described and carefully discussed. By means of controlling the size of the dual-slit, that is, in-slit for on-state and the out-slit for off-state, the reconfigurable patch antenna with circular polarization diversity is successfully designed and demonstrated. In addition, the implemented antenna needs no complex matching and bias network due to almost unchanged antenna impedance from the geometry of the dual-slit. The proposed dual-slit perturbed patch antenna provides a good CP controllability for polarization diversity without degenerating radiation performances in both RHCP and LHCP.

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Fig. 5. Measured radiation pattern of the proposed antenna. (a) RHCP mode with on-state at 2.37 GHz and (b) LHCP mode with off-state at 2.43 GHz.