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RECONFIGURABLE SLOT ANTENNAS WITH CIRCULAR POLARIZATION

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Abstract—A new design for circularly-polarized (CP) slot antennas is first described. The antenna is a combination of a shorted square-ring slot and an L-shaped linear slot, and its CP operation frequency can be easily tuned under the condition that the slot area is unchanged. Based on the CP design, two reconfigurable slot antennas are then developed. One is a frequency reconfigurable antenna, whose CP operation frequency can be switched between two adjacent frequencies. The other is a polarization reconfigurable antenna, whose polarization can be switched between two orthogonal CP senses. The two reconfigurable antennas are realized using PIN diodes. Details of the designs and experimental results are shown.

1. INTRODUCTION

A ring slot antenna is a coplanar structure and as compared to a conventional microstrip antenna, it has the advantage that lumped circuit components are easily placed between the radiating patch and ground plane. The lumped component can be used to alter antenna performances. For example, when the component is a capacitor, the operation frequency of the slot antenna can be decreased with increasing the capacitance value [1]. Also, the antenna polarization can be changed if the component is a conducting strip and is placed at a proper position [2]. Therefore, a considerable number of reconfigurable antenna designs have been realized by integrating diodes with the slot antenna [3–9]. These past designs are mainly divided into two

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types. One is frequency reconfigurable designs integrating varactor diodes, where the antenna polarization is fixed as the operation frequency is tuned. The other is polarization reconfigurable designs integrating PIN diodes, where the operation frequency is constant while the polarization is switched. In addition to the two types mentioned above, a very small number of designs related to polarization reconfigurable antennas with frequency agility have also been reported. One example is described in [10], which can provide the switching between right-handed circular polarization (RHCP) and left-handed circular polarization (LHCP), but the two CP modes operate at different frequencies.

In this paper, a new CP design for the ring slot antennas is first proposed and the key parameters of affecting the CP operation frequency are investigated. The proposed structure can be employed to develop the polarization switchable and frequency tunable CP antennas. Moreover, a systematic design method for these reconfigurable antennas can be drawn from the parametric analyses. Two prototypes integrating PIN diodes are constructed and their measured results are presented and discussed.

2. ANTENNA CONFIGURATION

The proposed slot antenna, as shown in Fig. 1, is fabricated on a FR4 substrate of relative permittivity 4.4 and thickness 1.6 mm, and it is composed of a shorted square-ring slot and an L-shaped linear slot. The shorted square-ring slot has a side length of 32 mm and the shorted section of width 1 mm is located at a distance of s away from the upper right corner of the square-ring slot. As for the L-shaped slot, the length of the vertical segment is fixed to be 4 mm and the length of the horizontal segment is d. The slot antenna is excited with a microstrip line which is etched on the other side of the FR4 substrate. The microstrip feed line mainly includes a shorted stub and an impedance transformer with the dimensions of $l \times w$.

For the studied slot antenna, the dominant parameter of determining the CP operation frequency is s and the optimum axial ratio at the CP frequency can be obtained if d is properly selected. In other words, a given $(s,\ d)$ would correspond to one frequency where the antenna can generate good CP radiation. In addition, the impedance matching around the CP operation frequency is achieved with the impedance transformer.

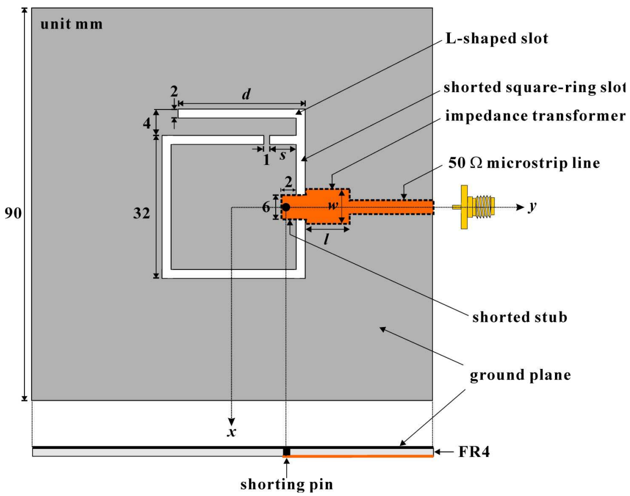


Figure 1. Geometry of the proposed circularly-polarized slot antenna.

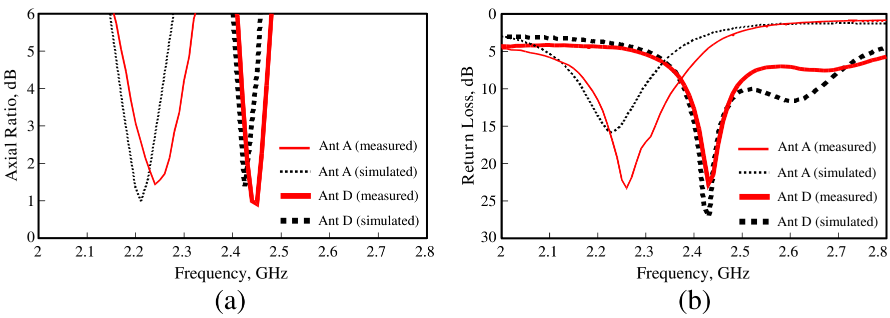


Figure 2. Measured and simulated results for Ant A and Ant D. (a) Axial ratio, (b) return loss.

3. STUDIES OF KEY PARAMETERS

For the proposed antenna structure, several CP designs with various combinations of (s, d) were carried out with the aid of HFSS, and their prototypes were also constructed. Details of the antenna dimensions and experimental results for these prototypes are summarized in Table 1. The measured axial ratio and return loss for the typical cases, Ant A and Ant D, are given in Fig. 2 along with the simulated results, and they have satisfactory agreements. Observing the results in Table 1, it is found that the CP center frequency (f_c), here defined as the frequency with minimum axial ratio, ranges between 2240 and

Table 1. Detailed dimensions and experimental results of the slot antenna prototypes with various combinations of (s, d).

Ant	s (mm)	d (mm)	l (mm)	w (mm)	f_c (MHz)	BW_{CP} (%)
A	2	31	10.5	7.5	2240	3.5
B	6	28.5	10	7.5	2300	3.2
C	10	26	6.5	7.5	2370	2.5
D	14	22	4	7.5	2450	1.8

2450 MHz, corresponding to a frequency variation of about 10%, when s is increased from 2 to 14 mm and d is decreased from 31 to 22 mm. Note that these dimension variations would not cause the substantial increase in the slot area. Moreover, the CP operation bandwidth (BW_{CP}), determined by 3 dB axial ratio, is reduced with the increasing of f_c. On the other hand, the typical results in Fig. 2 demonstrate that a return loss of less than 10 dB can be obtained within the CP operation bandwidth. It has to be mentioned that, in the feed line, only l needs to be adjusted for achieving the impedance matching at different CP operation frequencies. The radiation patterns of each prototype are measured and they are similar to each other (shown in next section).

4. RECONFIGURABLE DESIGNS AND EXPERIMENTAL RESULTS

According to the above studies, two possible reconfigurable antenna designs can be drawn and they are exhibited in Figs. 3(a) and 3(b), respectively. In Fig. 3(a), the value of s is s_1 when D_1 is ON, and it is s_2 when D_1 is OFF and D_2 is ON. Moreover, the values of d are d_1 and d_2 as the states of D_3 are OFF and ON, respectively. Consequently, two sets of (s, d), (s_1, d_1) and (s_2, d_2), can be obtained by controlling the states of the PIN diodes, and the CP operation frequency of the antenna can be switched between two different frequencies, forming a frequency reconfigurable antenna.

As for Fig. 3(b), another L-shaped slot is introduced and connected to the lower right corner of the square-ring slot. When D_4 is OFF and D_6 is ON, only the upper L-shaped slot is active. On the contrary, the lower L-shaped slot is electrically connected to the shorted square-ring slot when D_4 is ON and D_6 is OFF. It can be expected that the polarization of the antenna is switched between RHCP and LHCP as long as the state of each PIN diode

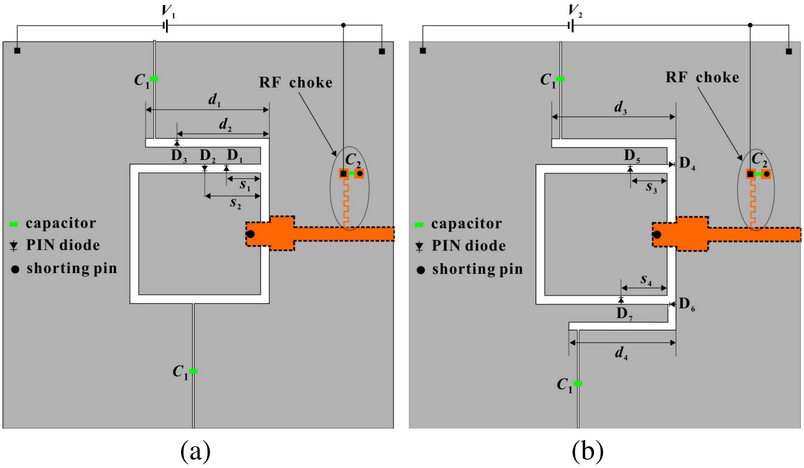


Figure 3. Two reconfigurable antenna designs and related DC bias circuits. (a) Frequency reconfigurable design, (b) polarization reconfigurable design.

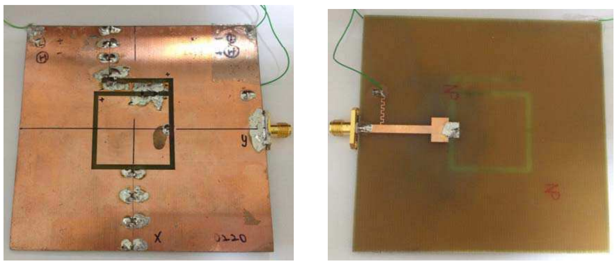
Table 2. Operating principles and experimental results of the two reconfigurable prototypes.

Prototype	DC Bias	Diode State	Pol.	f_c (MHz)	BW_{CP} (%)	Gain dBic
A	$V_1 = 1\,\text{V}$	D_1 ON D_2, D_3 OFF	RHCP	2250	3.6	1.5
	$V_1 = -1\,\text{V}$	D_1 OFF D_2, D_3 ON	RHCP	2350	1.8	1.9
B	$V_2 = 1\,\text{V}$	D_4, D_7 OFF D_5, D_6 ON	RHCP	2200	2.1	2.2
	$V_2 = -1\,\text{V}$	D_4, D_7 ON D_5, D_6 OFF	LHCP	2210	2	2

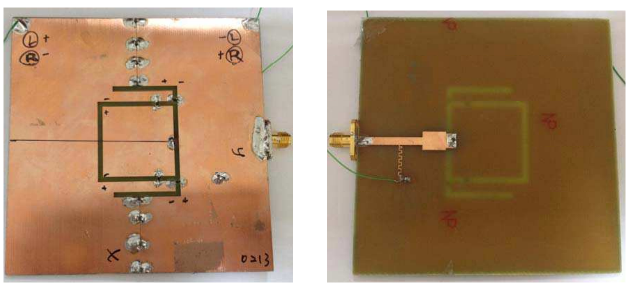
is properly controlled, forming a polarization reconfigurable antenna. Furthermore, the operating frequencies of the two CP modes are respectively determined by (s_3, d_3) and (s_4, d_4), suggesting that the two CP modes can be designed at the same frequency or different frequencies.

Two reconfigurable antenna prototypes, Prototype A and B, using the designs of Figs. 3(a) and 3(b) were implemented, respectively. In

Prototype A, the antenna polarization is fixed and the CP operation frequency is tuned. In Prototype B, the CP operation frequency is constant but the polarization is switched. The photographs of the finished prototypes are exhibited in Fig. 4. Prototype A has the dimensions of $s_1 = 6\,\text{mm}$, $d_1 = 29\,\text{mm}$, $s_2 = 10\,\text{mm}$, $d_2 = 24\,\text{mm}$,

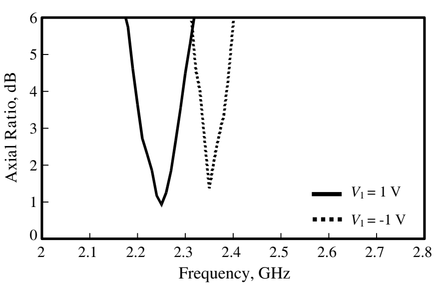


(a)

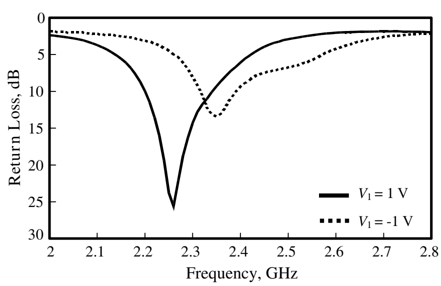


(b)

Figure 4. Photographs of the constructed prototypes. (a) Prototype A, (b) Prototype B.



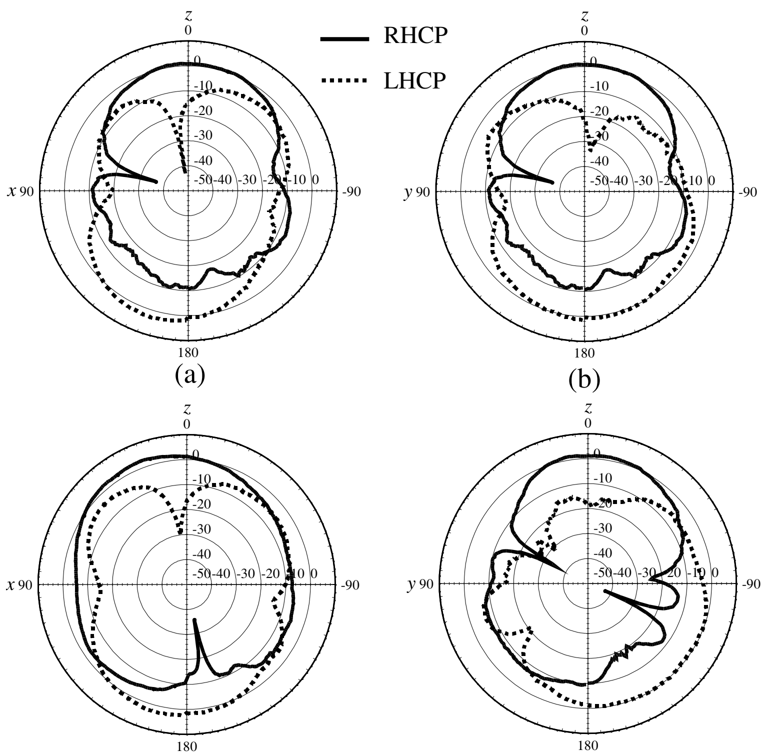
(a)



(b)

Figure 5. Measured results of Prototype A operating at different. modes. (a) Axial ratio, (b) return loss.

$l = 7$ mm, and $w = 9$ mm. Prototype B has the dimensions of $s_3 = s_4 = 6$ mm, $d_3 = d_4 = 26$ mm, $l = 9$ mm, and $w = 7.5$ mm. Other dimensions of the two prototypes are the same as those shown in Fig. 1. For each prototype, the states of the diodes (SMP1320-079, Skyworks Solutions Inc.) are controlled through their respective DC biases. To do so, a pair of slits are cut in the ground plane, and the coupling capacitors (C_1) are employed so that RF signal can pass through the slits. In addition, for preventing the RF signal from entering the dc-bias network, a RF choke, which is composed of a meandered thin line and a grounded capacitor (C_2), is required. The values of C_1 and C_2 are both 2.2 nF. The arrangement of the diodes and related circuit layouts are shown in Fig. 3. Table 2 gives the operating principles of the two prototypes. The measured results of Prototype A operating at



(a) (b) (c) (d)

Figure 6. Radiation patterns of Prototype A operating at different CP frequencies. (a) x-z plane at 2250 MHz, (b) y-z plane at 2250 MHz, (c) x-z plane at 2350 MHz, (d) y-z plane at 2350 MHz.

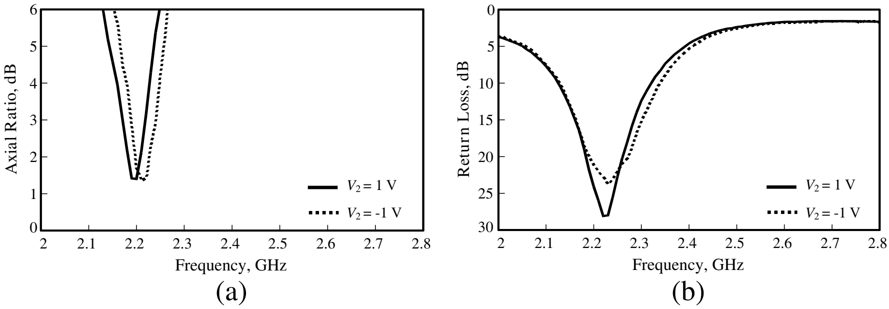


Figure 7. Measured results of Prototype B operating at different modes. (a) Axial ratio, (b) return loss.

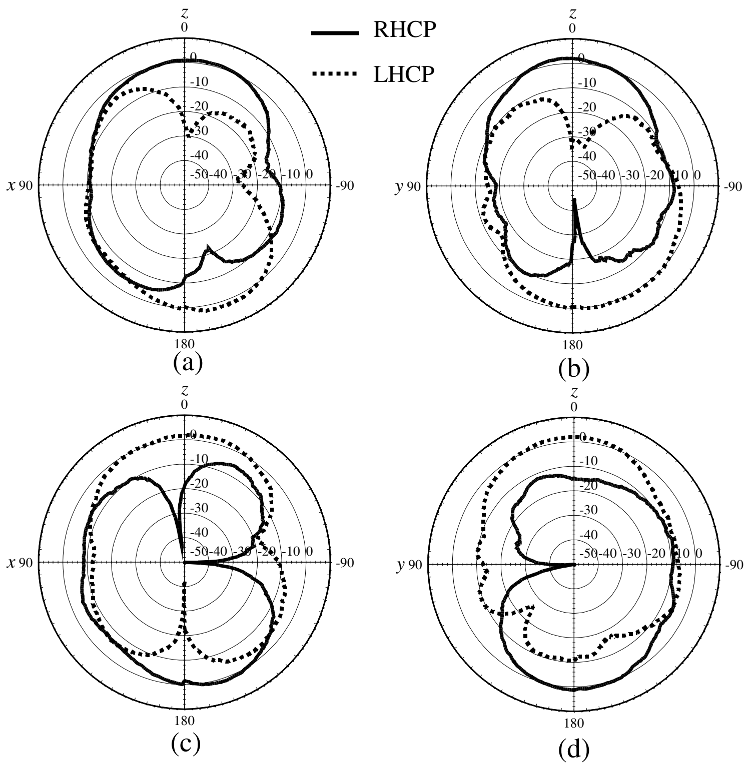


Figure 8. Radiation patterns of Prototype B at 2200 MHz for different polarizations. (a) x-z plane for RHCP mode, (b) y-z plane for RHCP mode, (c) x-z plane for LHCP mode, (d) y-z plane for LHCP mode.

different modes are presented in Fig. 5, and they clearly indicate that the two modes have different CP operation frequencies, respectively centered at 2250 and 2350 MHz. In addition, a return loss of less than 10 dB is obtained within their respective CP operation bandwidths. The radiation patterns measured at 2250 and 2350 MHz are plotted in Fig. 6. Both are bi-directional patterns with good right-handed circular polarization on the $+z$ axis. As for Prototype B, the variations of axial ratio and return loss against frequency are shown in Fig. 7, and the radiation patterns are given in Fig. 8. From these measured results, it can be seen that the two modes have almost the same CP operation frequency but their polarization senses are orthogonal. It has to be noted that Ant B and Prototype B are designed with the same s but Prototype B has an obviously lower CP operation frequency. The reason is that the shorted square-ring slot of Prototype B has a capacitive loading which is contributed by the PIN diodes at the OFF state. The loading effect also occurs in Prototype A.

5. CONCLUSIONS

A design for circularly-polarized slot antennas has been presented. The design is suitable for developing reconfigurable antennas. Two example designs, including frequency reconfigurable antenna and polarization reconfigurable antenna, are provided, and their experimental results demonstrate that each operating mode can generate good circular polarization radiation. The designs studied in the paper could be potentially useful for improving isolation between two adjacent channels and doubling system available bandwidth; however, the antenna circular polarization bandwidth may be not enough to meet the requirements of some wireless communications. The problem would be solved by increasing the width of the shorted square-ring slot.

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