A New Dual-Band, Dual-Polarized and Single Feed Reconfigurable Antenna

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***Abstract* —** In this paper, a new single feed reconfigurable annular-ring slot antenna for polarization and frequency diversity for WLAN and WiMAX applications is proposed. This antenna has a simple structure; it contains two concentric circular slots, and four tuning stubs on one side of the substrate, and a 50 Ω microstrip feed line and two stubs on the other side. The proposed antenna can be switched between two resonant frequencies, 2.4 GHz (WLAN) and 3.5 GHz (WiMAX). Furthermore, it can be switched between left-hand circular polarization (LHCP) and right-hand circular polarization (RHCP) at both resonant frequencies. Using seven switches (PIN diode), on both sides of the substrate. Details of the antenna design are shown and the results are also exhibited and discussed. Simulation and experimental results indicate that the proposed antenna demonstrates a good impedance bandwidth at the two resonant frequencies, and satisfactory axial ratios in the circularly polarized states.

***Index Terms* —** Annular-ring slot antenna, dual-band, dual-polarized, reconfigurable antenna.

I. INTRODUCTION

Multifunction antennas, with different radiation characteristics in a single antenna element, have become an important research area in antenna engineering field. Reconfigurable antennas with the ability of radiating more than one pattern at different frequencies and various polarizations offer several degrees of freedom to antenna designers. Therefore, these antennas are good candidate in the future wireless communication systems. Application areas that drive the development of reconfigurable antennas include multifunction wireless devices, multiple-input multiple-output (MIMO) systems, and ultra-wideband systems, anti-jamming secure communication to accommodate the ever demanding requirements of such systems [1]. Reconfigurable antennas are divided into 4 main categories, consisting antennas that exhibit reconfigurable return loss, radiation pattern, polarization, and different combinations of the previous categories.

The reconfigurable antenna with polarization agility offers an impressive enrichment in receiving the communication signal which includes an exceptional ability of multipath fading reduction. Moreover, multi-band reconfigurable antennas are desirable in modern communication systems. Hence, designing a new microstrip antenna with reconfigurable polarization and frequency is the main motivation in this paper.

The microstrip antennas with polarization diversity have been studied and their characteristics reported in [2-4]. The antenna studied in [5] uses dual-feeding for reconfigurability, while an antenna with the simple feeding network is one of the main factors in wireless communication systems.

In order to achieve polarization switching in single-fed microstrip patch antennas, one simple method is changing the electrical characteristics of the perturbation segments through PIN diodes. Several polarization reconfigurable antennas based on this method have been proposed [6]-[7].

Some reconfigurable antennas that have been introduced, present combinations of polarization and frequency diversities. Patch antennas with switchable slot (PASS) with both frequency and polarization diversities which are discussed in [5,8,9] utilize dual-fed structures. Reference [4] proposes a reconfigurable single-feed microstrip patch antenna with frequency and polarization diversities using some PIN diodes and a U-slot, incorporated into a square patch. This antenna does not provide polarization diversity in any of the resonant frequencies.

In this paper, we present a single-feed antenna that exhibits dual-band and dual-polarized reconfigurablity for different antenna configurations, suitable for WLAN and WiMAX applications. In our work, for polarization diversity at the first resonant frequency of the proposed antenna, tuning stubs on the ground plane are used. Moreover, for polarization diversity at the second resonant frequency, two open stubs perpendicular to feed line are used, too. Another advantage of the proposed antenna in this paper, is its single layer structure. The antenna is simulated, fabricated and tested. The measurement results show

Submitted On: February 15, 2014
Accepted On: May 25, 2015

good agreement with those obtained by simulations.

II. ANTENNA DESIGN

The geometry of the antenna is shown in Fig. 1. It has two concentric circular slots printed on a 1.6 mm thick FR4_epoxy substrate of relative permittivity 4.4. The microstrip feed line is placed on the opposite side of the substrate and the annular slot is placed on the other side. For the annular slots, the inner radius is R2 with slot width of S2, and the outer radius is R1 with slot width of S1. A pair of stubs is loaded with four PIN diodes in the annular-ring slot with length (Ls) and width (Ws) to have polarization diversity at the first resonant frequency.

The microstrip feed line is broken into two segments, with PIN diode inserted between two paths with transformer in antenna feed line and two matching stubs with the length (Lsf) and width (Wsf), leads to have an appropriate impedance matching for all states. Two open stubs which are connected by two PIN diodes allow polarization diversity at the second resonant frequency.

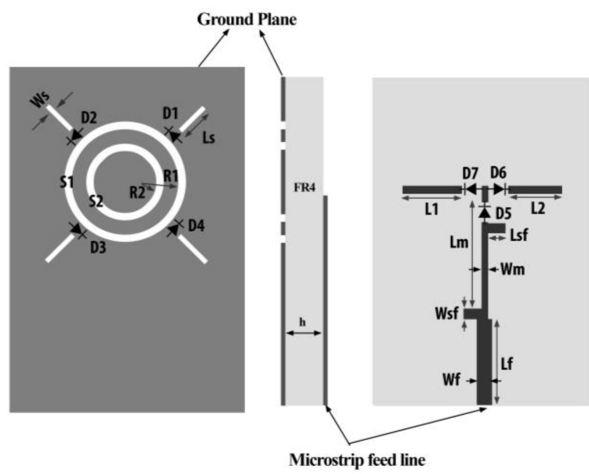


Fig. 1. Geometry of the proposed antenna.

A. Frequency diversity

By changing the circumference of the annular-ring slots, the proper operating frequency can be obtained. Hence, in order to allow one resonant frequency to operate, either inner or outer slot should be excited. To have frequency diversity, the PIN diode (D5) is inserted in the feed line. When the PIN diode is biased (on-state), inner ring slot is excited for generating the second resonant frequency.

On the other hand, when the PIN diode is in "off-state", the outer ring slot is excited and generates the first resonant frequency. The outer radius (R1) is selected proportional to 2.4 GHz for the WLAN application, and the inner radius (R2) is selected proportional to 3.5 GHz for the WiMAX application. Hence, the proposed antenna can operate with frequency diversity using only one PIN diode.

Figure 2 illustrates the surface current distribution on the proposed antenna structure at frequencies 2.4 GHz and 3.5 GHz. The surface current distributions are obtained, through HFSS. It is obvious that either inner or outer slot is excited. It shows they operate independently.

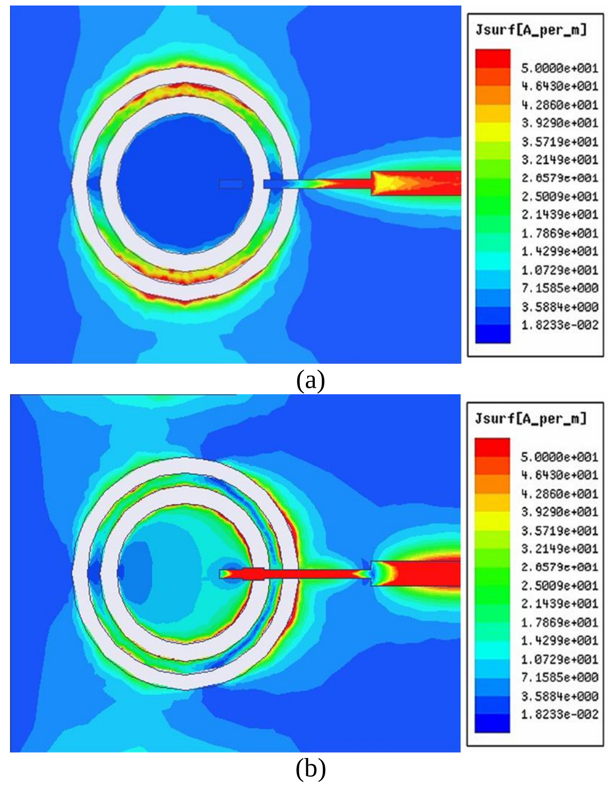


Fig. 2. Surface current distribution on the proposed antenna structure at: (a) 2.4 GHz, and (b) 3.5 GHz.

B. Polarization diversity

Generally, the annular-ring slot antenna operates in the fundamental TM11 mode. Circular polarization operation is excited by loading a pair of stubs in the annular-ring slot. The fundamental TM_{11} mode can be splitted into two near degenerate resonant modes. Therefore, circular polarization (CP) operation can be obtained and optimized by varying the tuning stub dimensions. The two near resonant modes have almost equal amplitudes and 90° phase difference in CP operation. When a pair of tuning stubs is located at 135° and -45°, the LHCP operation can be obtained. On the other hand, when a pair of tuning stubs is placed at -135° and 45°, the RHCP operation can be obtained. Based on this structure, the proposed antenna can switch by four PIN diodes (D1, D2, D3, and D4) between LHCP and RHCP states at 2.4 GHz for WLAN application.

As it was explained, to radiate circular polarization, two orthogonal modes should be excited with the same amplitude and a 90° phase difference. Generally, two orthogonal modes of the circular microstrip antenna can be excited in series with the microstrip feed line through the coupling of the ring slots. The magnitudes of the two orthogonal modes are related to the amplitudes of the vertical and horizontal directed currents under the ring slot. It means that by altering the current distributions in the microstrip feed line, the CP radiation of the ring slot coupled microstrip antenna can be achieved. Hence, polarization diversity can be attained by adjusting the stub length.

In order to have polarization diversity between LHCP and RHCP states at the second resonant frequency, two stubs perpendicular to feed line are used. When either of them is excited, LHCP or RHCP mode is achieved. Inserting two PIN diodes (D6 and D7) to excite one stub every time are utilized. Therefore, the antenna can also switch between LHCP and RHCP states at 3.5 GHz for the WiMAX application, too. Different diodes combinations and their associated operation status are summarized in Table 1.

Table 1: Different diodes combinations and their associated operation status

	D5	D1 and D3	D2 and D4	D6	D7	Freq.	Polarization
Ant. 1	Off	Off	On	Off	Off	F_L	LHCP
Ant. 2	Off	On	Off	Off	Off	F_L	RHCP
Ant. 3	On	On	On	On	Off	F_H	LHCP
Ant. 4	On	On	On	Off	On	F_H	RHCP

C. Matching approach

The proposed feed line consists of double-stub shunt tuning circuits to achieve input impedance matching for LHCP and RHCP polarizations at both resonant frequencies. Generally, stub spacing near 0 or λ/2 lead to very frequency sensitive matching networks. In practice, stub spacing are usually chosen λ/8 or 3λ/8 [10]. The spacing used in this paper is about 14 mm that is, on average, λ/8 for both frequencies. Symmetrical stubs are used to achieve the best responses.

III. RESULTS

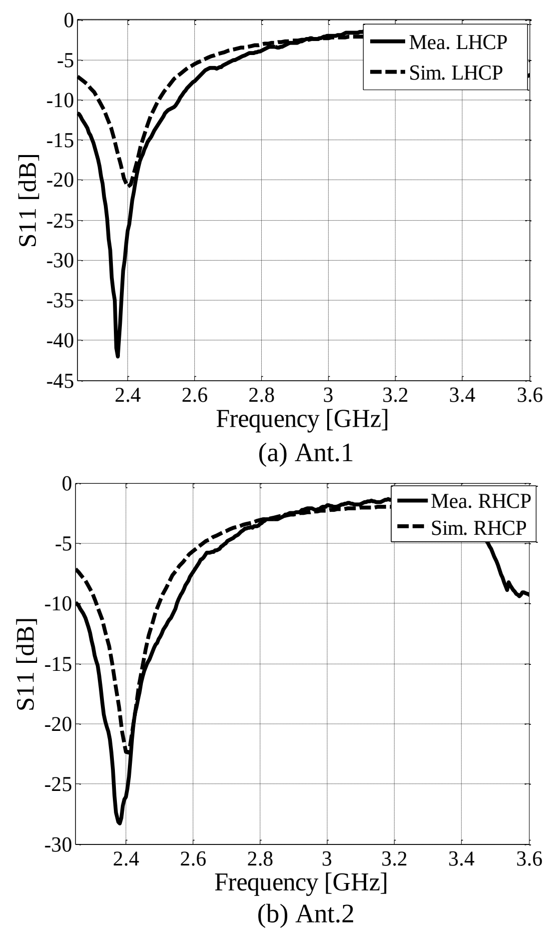
The S-parameters, axial ratio and pattern shape of the proposed antenna have been simulated and tested. It is worth mentioning that the size of the gaps for all states is proportional to the PIN diode models MA4P274-1141T [11].

For the on-state diode, the equivalent circuit that can be extracted from its data sheet is represented by a resistor (R = 3 Ω), while for the off state diode, the equivalent circuit is represented by a capacitor (C = 0.35 PF). The ground plane should be separated into four parts by using thin slits to supply the DC voltage. The DC voltage is supplied directly through the divided ground plane. The details of the design parameters are summarized in Table 2.

Table 2: Details of design parameters (mm)

R_1	R_2	S_1	S_2	Ls_f
12.45	7.7	2	2.8	3.45
Ws_f	W_s	L_s	L_m	W_m
2	0.5	10	23	1.1
L_f	L_1	L_2	W_f	h
17.11	13.45	13.45	3.059	1.6

The S-parameters of the proposed antenna for all states described in Table 1, has been measured. Figure 2 shows the S-parameters of the antenna for the first resonant frequency mode. In this figure the simulation and measurement results of the two states Ant.1 (Fig. 3 (a)) and Ant. 2 (Fig. 3 (b)), are shown.



(a) Ant.1

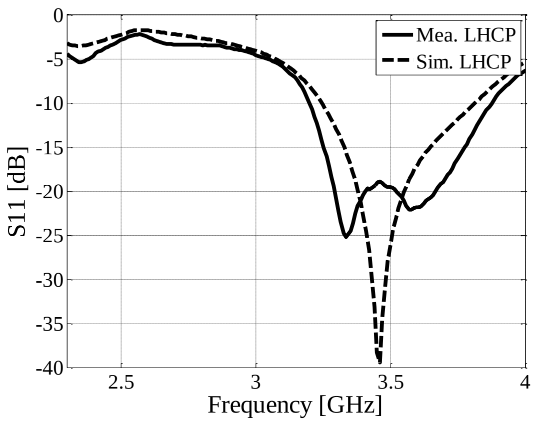
(b) Ant.2

Fig. 3. Simulated and measured S11 of the proposed antenna at 2.4 GHz (WLAN application): (a) LHCP mode (Ant.1), and (b) RHCP mode (Ant.2).

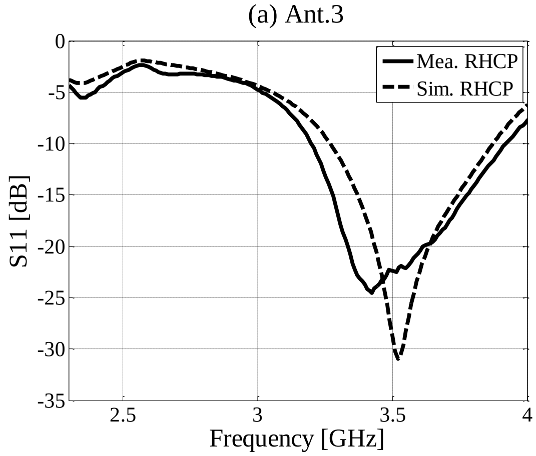
Figure 4 shows the S-parameters of the antenna for the second resonant frequency mode. The results of this figure are on the case when two diodes on the microstrip feed line is “on-state”.

When the antenna works in Ant.3 state, the results are shown in Fig. 4 (a), and when it works in Ant.4 state, they are shown in Fig. 4 (b).

The measured impedance matching bandwidths are 12.7% and 14.28% of the first resonant frequency for RHCP and LHCP modes, and they are 21.31% and 19.32% of the second resonant frequency for RHCP and LHCP modes, respectively.



(a) Ant.3



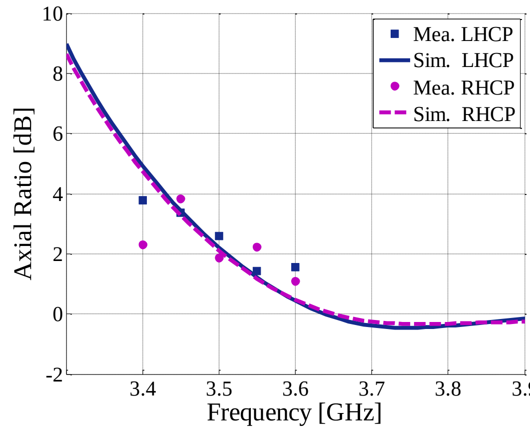
(b) Ant.4

Fig. 4. Simulated and measured S11 of the proposed antenna at 3.5 GHz (WiMAX application): (a) LHCP mode (Ant.3), and (b) RHCP mode (Ant.4).

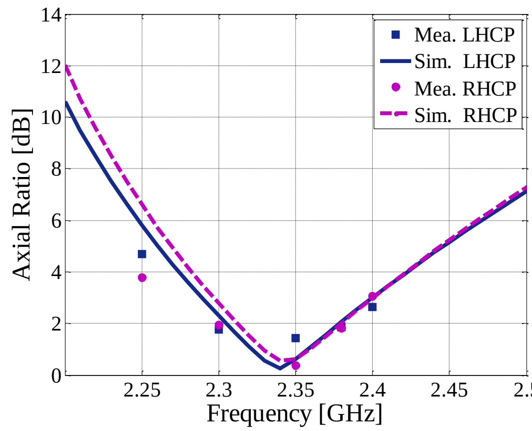
Figure 5 shows the simulated and measured axial ratio of the proposed antenna in all states. The simulated 3 dB axial ratio bandwidth is 4.7% for the first resonant frequency and 18.37% for the second one.

The simulated radiation patterns for both resonant frequencies are depicted in Fig. 6 and Fig. 7. Evidently, the antenna yields satisfactory results for the co-polarization and cross-polarization main beams.

The radiation patterns in the CP states were simulated at frequencies where the minimum axial ratio occurs. Results show that broadside radiation patterns with good LHCP and RHCP characteristics are obtained at the resonant frequency.

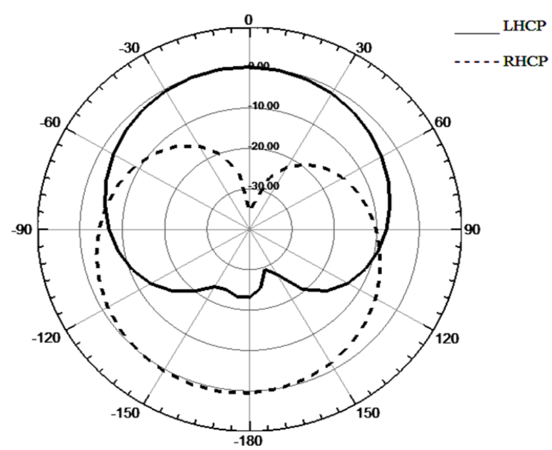


(a) Ant.1 and Ant.2

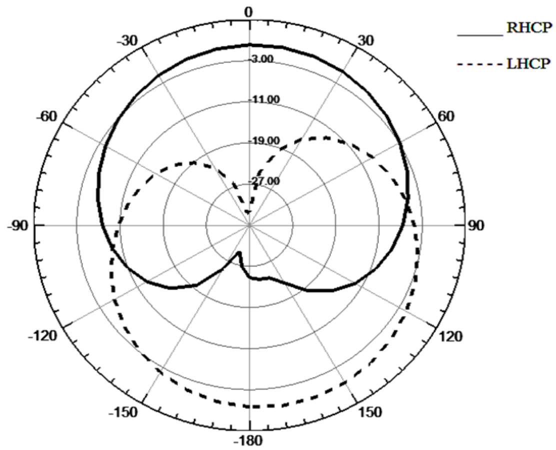


(b) Ant.3 and Ant.4

Fig. 5. Simulated and measured axial ratio of the proposed antenna for circular polarization for: (a) WLAN application (Ant.1 and Ant.2), and (b) WiMAX application (Ant.3 and Ant.4).

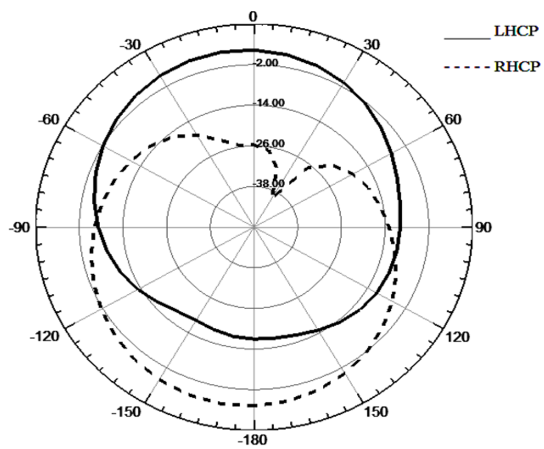


(a) Ant.1

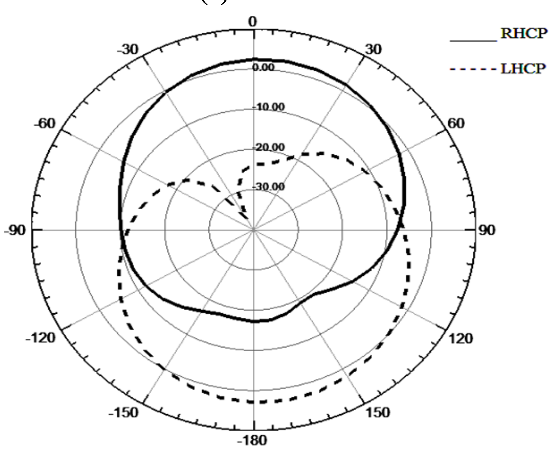


(b) Ant.2

Fig. 6. Simulated radiation patterns of the proposed antenna for circular polarization at 2.4 GHz: (a) LHCP mode (Ant.1), and (b) RHCP mode (Ant.2).



(a) Ant.3



(b) Ant.4

Fig. 7. Simulated radiation patterns of the proposed antenna for circular polarization at 3.5 GHz: (a) LHCP mode (Ant.3), and (b) RHCP mode (Ant.4).

IV. CONCLUSION

Design of a new dual-band dual-polarized and single feed reconfigurable annular-ring slot antenna for WLAN and WiMAX applications has been presented in this paper. The proposed antenna can be switched between two resonant frequencies 2.4 GHz (WLAN) and 3.5 GHz (WiMAX). Also, it can be switched between left-hand circular polarization (LHCP) and right-hand circular polarization (RHCP) at both resonant frequencies with a single feed. The antenna polarization is switched by four stubs at the ground plane for the first resonant frequency, and two open stubs at the feed line for the second one. The frequency diversity of the proposed antenna can be switched by only one PIN diode. Good impedance matching performance for all states is observed using two open stubs. A prototype has been fabricated and tested. The simulated and measured results agree very well as confirming the validity of our used models.

ACKNOWLEDGMENT

The authors wish to thank ITRC (Iran Telecommunication Research Center) for supporting this work under the contract number 15706.

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