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CPW-Fed Small Slot Antenna with Reconfigurable Circular Polarization and Impdeance Bandwidth Characteristcis for DCS/WiMAX Applications

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Abstract—A novel printed reconfigurable square slot antenna with switchable right/left-handed circular-polarization (CP) and switchable dual-band performances for use in DCS/WiMAX applications is designed and manufactured. In the proposed antenna, in order to create a reconfigurable structure with switchable dual-band performance, a meander-line shaped radiating stub is utilized. This radiating stub can select between two operating frequency bands with respect to the number of its steps, and also right- or left-handed circular polarization at one of the operating bands (WiMAX) is determined by the growth direction of this meander-line structure. Moreover, through embedding an L-shaped slot on the ground section, circular polarization can be provided for the other operating frequency band (DCS). Having right- or left-handed circular polarization at this frequency band can be determined by the location and orientation of the L-shaped slot on the ground plane. In order to achieve a reconfigurable antenna structure with simultaneous switchable dual-band and circular polarization functions, six PIN diodes were utilized. The designed antenna has a small size of 30×30 mm. Simulated and experimental results obtained for the designed antenna reveal good radiation behavior within the DCS (1.85 GHz) and WiMAX (3.5 GHz) frequency ranges.

1. INTRODUCTION

Circular polarization is one of the common polarization schemes used in current wireless communication systems, such as radar and satellite systems, since it can provide better mobility and weather penetration than linear polarization. Microstrip patch antenna [1], spiral antenna [2], dielectric resonator antenna [3] and slot antenna [4] are some of the typical types of circularly polarized antennas. The operation principle of these circularly polarized antennas is to excite two orthogonal field components with equal amplitudes.

In recent years, many new broadband printed slot antennas have been developed to overcome the narrow impedance bandwidth and also narrow 3-dB axial-ratio (AR) bandwidth [4, 5]. Using a printed slot antenna is a possible method to prevent the increment of antenna size while improving the operational bandwidth [6]. Consequently, a number of printed slot antennas with different geometries have been reported recently to achieve CP radiation [7, 8].

In this paper, a new reconfigurable CPW-fed slot antenna with CP characteristic for DCS/WiMAX applications is presented and discussed. First of all, in order to obtain a selectable multi-band performance for the antenna under design, a meander-line radiating stub is used rather than the conventional monolith rectangular or circular shaped radiating stubs. The operating frequency band of the antenna can be selected by the number of the steps which form the meander-line structure and

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also the number of these steps can be conveniently be controlled by the PIN diode switches which are embedded between the steps. The use of meander-line radiating stub has another important advantage that is providing a CP characteristic for one of the operating spectrums which is WiMax frequency band. Moreover, the quality of having right-handed CP (RHCP) or left-handed CP (LHCP) can be determined by the growth direction of the meander-line radiating stub. This feature will be more explained at next sections. In the proposed structure, another CP characteristic for the other operating frequency band of the proposed antenna (1.8 GHz DCS) is added to the performance of the antenna by cutting two symmetrical L-shaped slots on the top section of the ground plane near its two inner corners. By embedding a PIN diode along each of these L-shaped slots a switchable RHCP or LHCP performance is achieved. This feature of the proposed antenna performance will be explained in details at next sections. The size of the designed antenna is smaller than the slot antennas with circular polarization function reported recently [1–8]. Simulated and measured results are presented to validate the usefulness of the proposed antenna structure for DCS/WiMAX applications.

2. ANTENNA DESIGN AND CONFIGURATION

The printed 50 Ω CPW-fed slot antenna shown in Figure 1 is printed on an FR4 substrate with thickness of 1.6 mm, permittivity of 4.4, and loss tangent of 0.018. The proposed antenna is connected to a 50 Ω SMA connector for signal transmission.

In this study, to design a novel reconfigurable CPW-fed square slot antenna, a meander-line shaped radiating stub, two L-shaped slots, and also six PIN diodes are introduced to the antenna structure. Based on current distribution analysis, the meander-line-shaped radiating stub and the corresponding PIN diodes, which are placed along it, has the main role in multi-band characteristics of the antenna, because by changing the bias conditions of the PIN diodes two distinguish frequency responses can be achieved, which is obtained without any extension of size or any dramatic additional cost [8–12].

As illustrated in Figure 1, the L-shaped slots which are placed on the top section of the ground plane near its inner corners are also symmetrical with respect to the longitudinal direction. The L-shaped slot perturbs the current distribution path and also acts as a circular polarization generator structure [7]. At the desired frequency, the current flows are more dominant around the slot, and they are oppositely directed between the slot edges which leads to circulation of the currents and consequently orthogonal current factors are exited on the ground plane [5–7]. As a result, the desired low axial ratio near the desired frequency can be produced. A PIN diode is protruded inside each of these L-shaped slots which can short circuit the corresponding slot and as a result the effect of that particular L-shaped slot is cancelled. This feature of the L-shaped slots and their PIN diodes are used to form selectivity

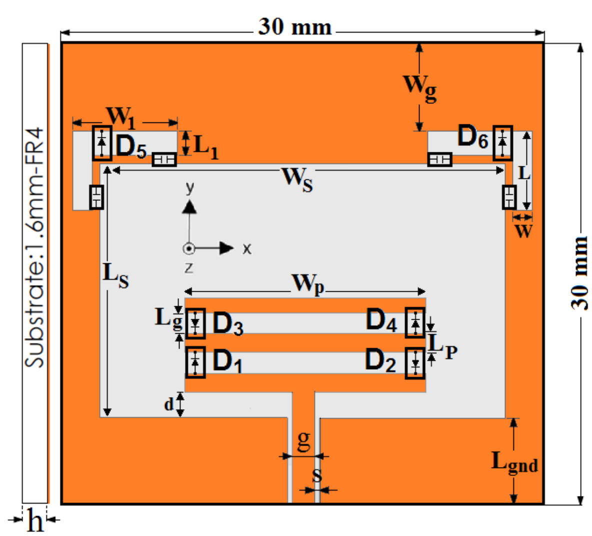


Figure 1. Geometry of the proposed slot antenna.

between having RHCP or LHCP for the antenna performance at its DCS frequency band operation. In other words, having RHCP or LHCP at DCS frequency band depends on which slot is active (its corresponding PIN diode is off) and which slot is inactive (its corresponding PIN diode is on and the slot is short circuited). By changing the bias statuses of these two PIN diodes convenient switching between RHCP or LHCP is possible.

The final dimensions and design parameters for the presented antenna are as follows: $W_{Sub} = 30\,\text{mm}$, $L_{Sub} = 30\,\text{mm}$, $L_{gnd} = 5\,\text{mm}$, $L_S = 16\,\text{mm}$, $W_S = 24\,\text{mm}$, $S = 0.135\,\text{mm}$, $g = 1\,\text{mm}$, $d = 1\,\text{mm}$, $L_P = 1\,\text{mm}$, $L_g = 1\,\text{mm}$, $W_P = 15\,\text{mm}$, $L_1 = 1\,\text{mm}$, $W_1 = 8\,\text{mm}$, $W = 1\,\text{mm}$, $L = 5\,\text{mm}$, $W_g = 6\,\text{mm}$, $h = 1.6\,\text{mm}$.

3. RESULTS AND DISCUSSION

The proposed printed CPW-fed slot antenna with its final design parameters was fabricated and tested and in this section the numerical and experimental results of its impedance bandwidth and radiation characteristics are presented and discussed. The simulated results are obtained using the Ansoft simulation software high-frequency structure simulator (HFSS) [13].

Various antenna structures used in simulation studies are shown in Figure 2, and their return loss characteristics are compared in Figure 3. By comparison among the return loss characteristics for slot antenna with a single step meander-line radiating stub and two parasitic strips (Figure 2(a)), slot antenna with double-step meander-line radiating stub and single parasitic strip (Figure 2(b)), and slot antenna with triple-step meander-line radiating stub (Figure 2(c)), it is found that by utilizing meander-line structure as the radiating stub, the antenna can create three resonance frequencies at 1.8 GHz, 3.5 GHz, and 2.4 GHz [4]. In other words, as shown in Figure 3, in this structure, the meander-line radiating stub with PIN diodes is used in order to electronically switch between the multi-band performances at above mentioned resonance frequencies which mean that by adding the overall length of the meander-line structure the resonance frequencies tend to cover the lower frequency band and vice versa. In this case antenna in Figure 2(a) has a single resonance at 3.5 GHz (WiMAX), antenna in Figure 2(b) has its main resonance at 2.4 GHz (WLAN) and finally the antenna in Figure 2(c) can properly cover two frequency bands at 1.85 GHz (DCS) and 3.5 GHz (WiMAX) which means that the proposed antenna has a switchable frequency performance between three different cases [8, 9].

In order to understand the phenomenon behind this electronically switchable multi-band performance, the simulated current distributions on the radiating stub of the proposed antenna for various switchable bands are shown in Figure 4. As shown in Figure 4, the current distribution is concentrated on the radiating stub, and the feed-line and the resonance frequency does change by the

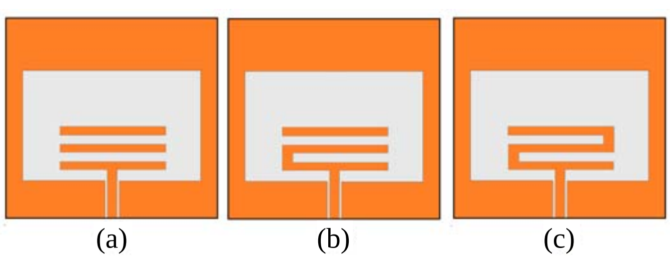


Figure 2. (a) Slot antenna with a single step meander-line radiating stub and two parasitic strips. (b) Slot antenna with double-step meander-line radiating stub and single parasitic strip. (c) Slot antenna with triple-step meander-line radiating stub.

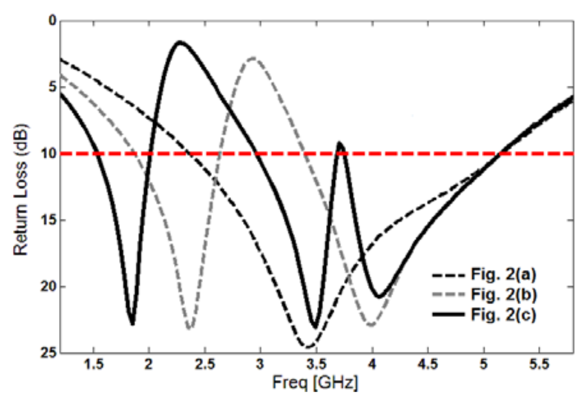


Figure 3. Simulated return loss characteristics for antennas shown in Figure 2.

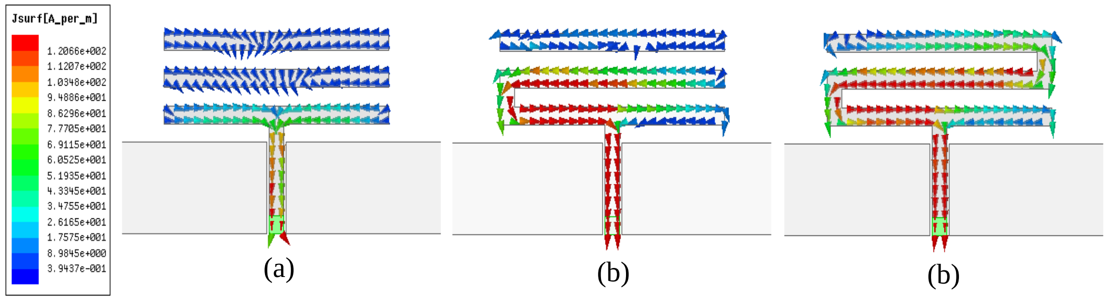


Figure 4. Simulated surface current distributions on the radiating stub for the: (a) slot antenna with a single step meander-line radiating stub and two parasitic strips at 3.5 GHz, (b) slot antenna with double-step meander-line radiating stub and single parasitic strip at 2.4 GHz, (c) slot antenna with triple-step meander-line radiating stub at 1.8 GHz.

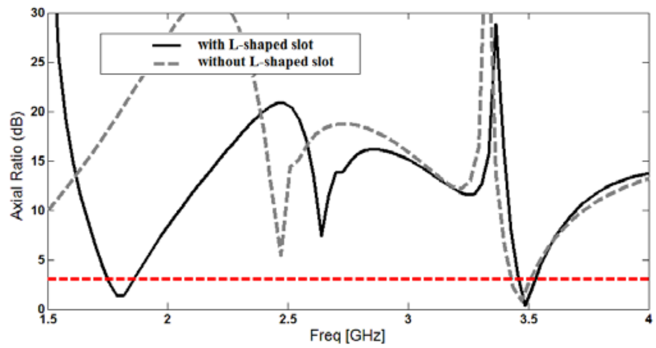
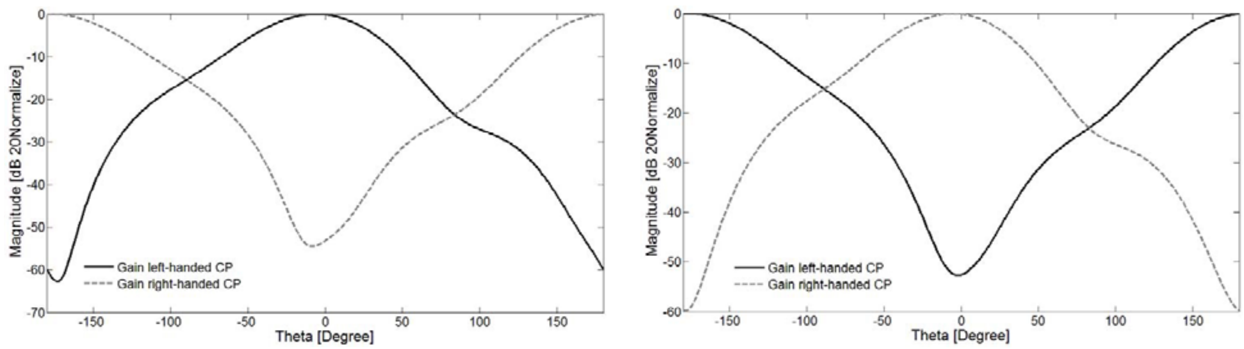


Figure 5. Simulated axial ratio for the proposed antenna with and without L-shaped slot on the ground plane.

change in overall length of the radiating stub. In fact the resonance frequency is switchable according to the length of the meander-line radiating stub which itself can be controlled by the bias statuses of the PIN diodes embedded between meander-line steps [5].

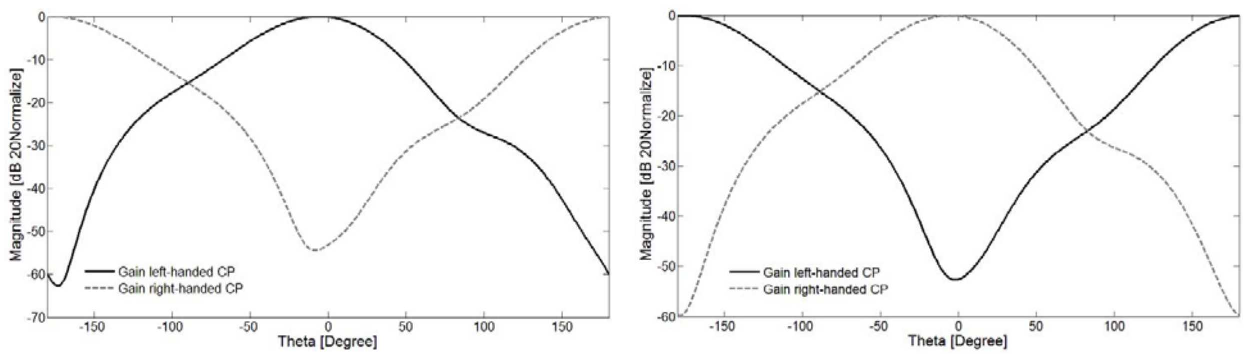
Figure 5 shows the simulated axial ratio for two antenna structures, one with the L-shaped slots on the ground plane and the other without them. In the following the CP performance of each of these structures are explained in details. According to Figure 5, the CPW-fed slot antenna with triple-step meander-line radiating stub and without the L-shaped slots on the ground plane (Figure 2(c)) has a circular polarization characteristic at WiMAX frequency band (3.45 GHz). The quality of having left- or right-handed CP at 3.45 GHz is controllable by the growth direction of the meander-line radiating stub. As can be seen in Figure 1, four PIN diodes are placed on the radiating stub and used to control the growth direction of the meander-line radiating stub. For Figure 2(c), D_1 and D_4 are biased forwardly, and D_2 and D_3 are off which creates a left-handed CP at 3.45 GHz, but if D_2 and D_3 were biased forwardly and D_1 and D_4 turned off, a right-handed CP was created. The right- and left-handed gains versus theta are shown in Figure 6 for the proposed antenna structure without the slots on the ground plane and different bias conditions of the PIN diodes on the meander-line radiating stub at 3.45 GHz. As can be seen in this figure, by changing the bias conditions of the PIN diodes, the left- and right-handed gains change magnitude reversely, which leads to a switch in the circulation direction.

In order to add another CP quality at another resonance frequency to the performance of the antenna, two L-shaped slots are etched on the top section of the ground plane near its inner corners which results to an additional CP characteristic in DCS frequency band (1.83 GHz), as shown in Figure 5. As shown in Figure 1, a PIN-diode is embedded in each slot. Only one of the slots is used at a time, and the effect of the other is almost omitted by bypassing it through the PIN diode which is embedded inside it. By changing the biasing statuses of these two PIN diodes switchable right- or left-handed CP can be achieved at 1.83 GHz. The right- and left-handed gains versus theta are shown in Figure 7 for



(a) (b)

Figure 6. Right- and left-handed gain magnitudes versus Theta at 3.45 GHz: (a) D_1 and D_4 are on and D_2 and D_3 are off, (b) D_2 and D_3 are on and D_1 and D_4 are off.



(a) (b)

Figure 7. Right- and left-handed gain magnitudes versus Theta at 1.8 GHz: (a) D_6 is on and D_5 is off, (b) D_5 is on and D_6 is off.

the proposed antenna structure with the slots on the ground plane and different bias conditions of the PIN diodes embedded inside these slots at 1.8 GHz. As can be seen in this figure, by changing the bias conditions of the PIN diodes, the left- and right-handed gains change magnitude reversely which leads to a switch in the circulation direction.

In order to explain the CP characteristic which is produced by the slots on the ground plane, the current distribution on the antenna at 1.8 GHz and for different values of phase is presented in Figure 8. As observed in this figure, the surface current direction at the top section of the ground plane does change circularly as the phase changes. This is mainly due to the fact that by adding the L-shaped slot, additional surface current path is created, and the current flows at the edges of the slots are orthogonal [13, 14]. At the 0 phase, the figure indicates that the dominant radiating currents around the L-shaped slot on the ground plane are along x direction. For the 90 phase, the dominant surface current is rotated 90 degrees spatially and is distributed along the $-y$ direction. In other words, after one quarter-period, the vector current rotates in the right-hand direction by 90 degrees in the $-y$ direction, which satisfies the requirements of the spatial and temporal quadrature for circular polarization [15]. Note that the current distribution in 180 and 270 are equal in magnitude and opposite in phase comparing with 0 and 90 degrees statuses. As a result the antenna is capable of producing a right-hand polarization characteristic.

To avoid short-circuits in DC biasing circuits of the PIN diodes placed inside the L-shaped slots on the ground plane, four DC-blocking capacitors are embedded across the L-shaped slots, as shown in Figure 1 [8]. In the introduced design, BAR-64 PIN diodes with extremely low capacitance were used. For biasing PIN diodes a 0.7 volts supply is applied to metal strips. The PIN diodes exhibit an ohmic

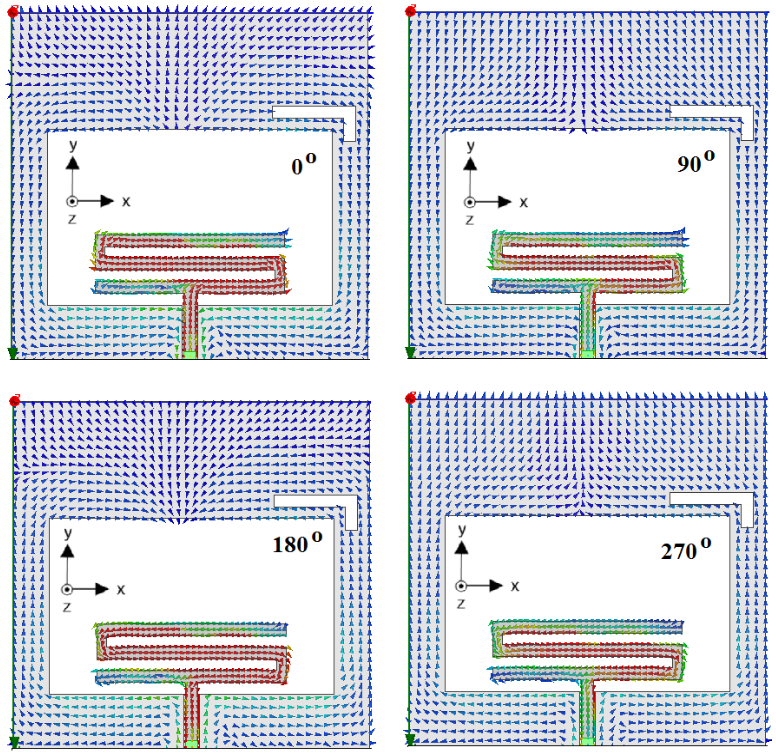


Figure 8. Distribution of the surface current on the proposed antenna at 1.85 GHz in 0, 90, 180 and 270 phases.

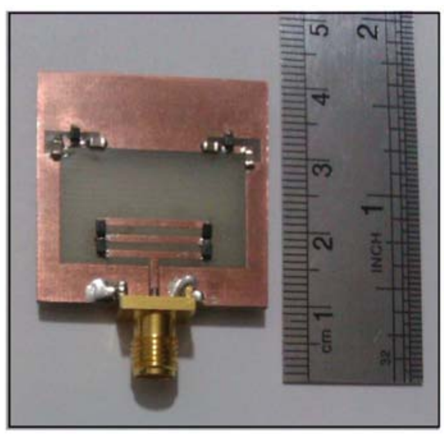


Figure 9. Photograph of the realized printed slot antenna.

resistance of 2.1 Ω and capacitance of 0.17 pF in the on and off states, respectively [15].

The proposed slot antenna with final modified design parameters, as shown in Figure 9, was built and tested. Figure 10 and Figure 11 show the measured and simulated return loss and axial ratio characteristics of the proposed antenna, respectively. As shown in Figure 10 and Figure 11, the fabricated antenna has the frequency bands of 1.65–1.97 GHz and 3.05–5.12 GHz with circular polarization characteristics at 1.75–1.85 GHz and 3.46–3.54 GHz. However, as shown in Figures 10 and 11, there exists a discrepancy between the measured data and simulated results. This discrepancy is mostly due to a number of parameters such as the fabricated antenna characteristics as well as the thickness and dielectric constant of the substrate on which the antenna is fabricated, the wide range

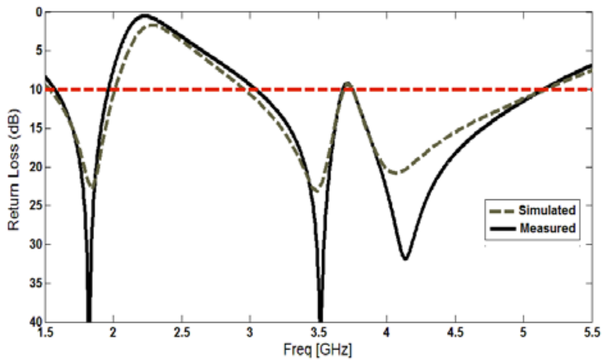


Figure 10. Measured and simulated return loss characteristics for the proposed antenna.

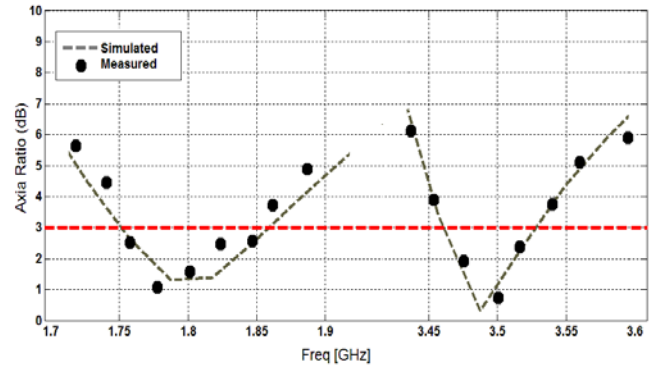


Figure 11. Measured and simulated axial ration characteristics for the proposed antenna.

of simulation frequencies and also the effect of PIN diodes and their biasing circuits [16]. In order to confirm the accurate return loss characteristics for the designed antenna, it is recommended that the manufacturing and measurement processes need to be performed more carefully. Besides, SMA and PIN diodes soldering accuracy and FR4 substrate quality need to be taken into consideration.

4. CONCLUSION

In this paper, a novel compact reconfigurable printed slot antenna (RPSA) with switchable circular polarization and frequency band selection performances has been proposed for use in DCS/WiMAX applications. By inserting meander-line strip in the radiating stub and two L-shaped slots in the ground plane of the ordinary CPW-fed slot antenna, a multi-band frequency performance can be produced. In the proposed structure, single circular polarization characteristics are provided by inserting meander-line structure in the radiating stub, and a dual circular polarization characteristic is achieved by cutting L-shaped slots in the ground plane. In the presented structure, reconfigurable performance is obtained by implementing six PIN diodes inside the L-shaped slots and the meander-line. By controlling the biasing statuses of these elements, reconfigurable multi-band and circular polarization functions are generated. The fabricated antenna supports the frequency bands of 1.65–1.97 GHz and 3.05–5.12 GHz with circular polarization characteristics at 1.75–1.85 GHz and 3.46–3.54 GHz. The proposed antenna has a simple configuration and is easy to fabricate. Experimental results show that the proposed antenna can be a good candidate for DCS/WiMAX applications.

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