A Reconfigurable Square Slot Antenna with Switchable Single Band, UWB and UWB with Band Notch Function Performances

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Abstract **─** In this paper a novel method for designing a square slot antenna with switchable single band, multi-resonance (Ultra-Wideband (UWB)) and UWB with band-notch function performances has been presented. By inserting a pair of symmetrical notches on the feed-line and a pair of gamma-shaped slots on the radiating stub, additional resonances are excited and hence much wider impedance bandwidth is produced; especially at the higher band. In order to generate a reconfigurable band-notch function, a PIN diode is utilized across the microstrip stub between the two gamma-shaped slots. Also, through implementation of two H-shaped slots on the ground plane, not only the coupling at lower and middle frequencies is adjusted, but also by embedding a PIN diode between these two H-shaped slots, an additional reconfigurable functionality is added to the antenna performances; which can switch between a single band and multi-resonance (UWB) characteristics. The designed antenna has a small size of 20×20 mm^2 while simulated and experimental results obtained for this antenna reveal that it exhibits good radiation behavior for its various switchable operation frequencies.

Index Terms **─** Band-notch function, microstrip-fed slot antenna, reconfigurable structure, ultra-wideband applications and single band performance.

I. INTRODUCTION

In UWB communication systems, which due to FCC's frequency band allocation spread from 3.1 GHz to 10.6 GHz, one of key issues is the design of compact antennas which provide wideband characteristic over the entire operating band [1]. Consequently, a number of printed microstrip slot and monopole antennas with different geometries have been experimentally characterized and automatic design methods have been developed to achieve the optimum planar shape [1]-[4].

On the other hand, the wide frequency range for UWB systems will cause interference to the existing wireless communication systems, such as the Wireless Local Area Network (WLAN) for IEEE 802.11a operating in 5.15-5.35 GHz and 5.725-5.825 GHz bands; therefore, the UWB antenna with a band-stop performance is required [2]. To overcome this problem, several novel planar antennas with band-notch characteristic have been presented recently. The most common and easiest technique is embedding a narrow slot into the radiating patch of the antenna and change the current flow directions on its metallic parts, as demonstrated in [2], [5]-[7]. All the techniques in

Submitted On: February 28, 2013
Accepted On: April 24, 2014

these references are used for rejecting a fixed band of frequencies. Another method to avoid this frequency band interference is the use of a reconfigurable structure. In order to effectively and fully utilize the UWB spectrum and to improve the performance of the UWB system, it is desirable to design the UWB antenna with reconfigurable band-notch [8]-[10]. It will help to minimize the interference between the systems and whenever there is no coexistence system and the structure of the antenna can be transformed in a way that leads to a whole coverage of UWB spectrum. In [8] and [9] in order to have selectivity on the rejection of a specific band which is between 5 GHz to 6 GHz, diodes are utilized while in [10], RF MEMS are used for the same reason.

Furthermore, future radio systems such as software defined radio and cognitive radio concepts, give rise to significant challenges for antenna design with switchable or adjustable frequency response [11]. Recently, a number of antennas with reconfigurable structures have been presented, in which wideband and narrowband functionalities are combined [12]-[13]. A Vivaldi antenna with switchable performances between a wideband mode and three narrowband modes has been presented in [12]. In [13], two reconfigurable monopole antennas by utilizing PIN diode or varactor diode have been presented, which are capable of combining wideband and narrowband functionalities.

A new compact reconfigurable microstrip-fed slot antenna with switchable single band, multi-resonance (UWB) and UWB with band-notch performances is presented and discussed in this paper. In the proposed structure, multi-resonance function is provided by etching two back to back gamma-shaped slots on the radiating stub, a pair of notches on the feed-line and a switchable band-notch characteristic is obtained by implementing a PIN diode on the microstrip line, which is placed between these two gamma-shaped slots. Also, by adding two H-shaped slots on the ground plane and embedding another PIN diode between these two H-shaped slots, electability between single band and multi-resonance performances is provided. Good return loss and radiation pattern characteristics are obtained in the frequency band of interest. Simulated and experimental results show that the proposed slot antenna could be a good candidate for UWB applications.

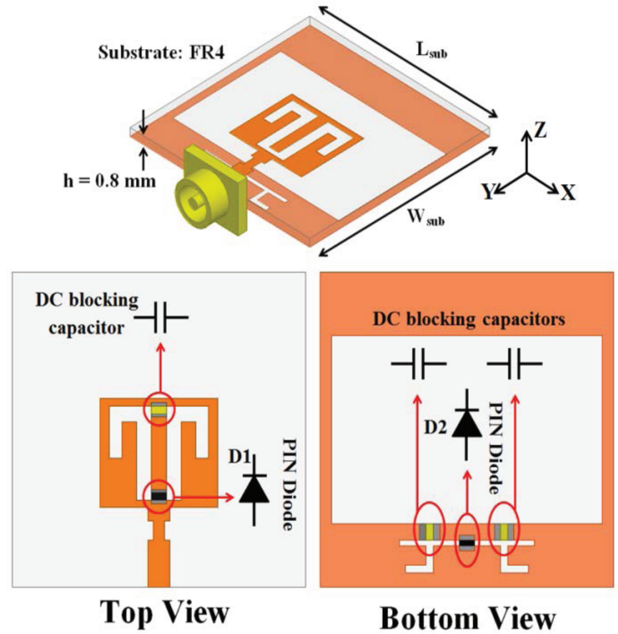

Fig. 1. Geometry of the proposed slot antenna.

II. ANTENNA DESIGN

The presented small reconfigurable slot antenna fed by a 50 Ω microstrip line is shown in Fig. 1, which is printed on a FR4 substrate of thickness of 0.8 mm, permittivity of 4.4 and loss tangent of 0.018. The basic slot antenna structure consists of a square radiating stub, a feed-line and a ground plane. The square stub is connected to a 50 Ω microstrip feed-line. On the other side of the substrate, a conducting ground plane is placed. The proposed antenna is connected to a 50 Ω SMA connector for signal transmission.

In this study, to design a novel antenna, two gamma-shaped slots with a PIN diode between their bottom sections and also two H-shaped slots with a PIN diode between them, have been added to the radiating stub and the ground plane, respectively. Moreover, two notches with variable dimensions have been also etched on the feed-line. Based on electromagnet coupling theory, these notches on the feed-line can adjust the electromagnetic coupling effects between the patch and the ground plane and improves the impedance matching in the antenna design without any cost of size or expenses, which play an important role in wideband characteristic of the antenna by adding an additional resonance to the frequency response [8].

As illustrated in Fig. 1, the gamma-shaped slots are symmetrically placed on the radiating stub, with respect to the longitudinal direction. These slots provide additional surface current paths which lead to an additional resonance and consequently wider impedance bandwidth can be produced, and as a result, the antenna frequency response covers the whole UWB bandwidth [2]. Moreover, in order to achieve a switchable band-notch function, a PIN diode is embedded on the radiating stub which role is changing the configuration of the slots on this stub. When the PIN diode (D1 in Fig. 1) is biased reversely or turned off, the gamma-shaped slots combine together and transform to a unique V-shaped like slot. The V-shaped like slot perturbs the resonant response of the antenna and acts as a half-wave resonant structure [13]. At the notched frequency, the current flows are more dominant around the V-shaped like slot and they are oppositely directed between the slot edges [8]. As a result, the desired high attenuation near the notched frequency can be produced.

The two H-shaped slots on the ground plane are modified in a way to improve the frequency response of the antenna by affecting the coupling at different switchable performances of the designed antenna. On the other hand, another reconfigurable functionality is added to the antenna performance by embedding a PIN diode between these two H-shaped slots. When the PIN diode is not biased forwardly, these two H-shaped slots unite and form a unique π-shaped slot. This transformation affects the entire characteristic of the antenna and changes it from a multi-resonance UWB antenna to a single band (narrow band) antenna, which can cover the WLAN frequency band (4-5 GHZ).

For avoiding DC short circuit in the PIN diodes biasing circuits, three 100 pF DC blocking capacitors were utilized, as shown in Fig. 1. The effect of the PIN diodes on the frequency response of the antenna has been considered at simulation studies, through simulating them as corresponding low capacitor and low resistance at their reverse and forward bias statuses, respectively. The antenna design parameters are shown in Fig. 2 and their final values are presented in Table 1.

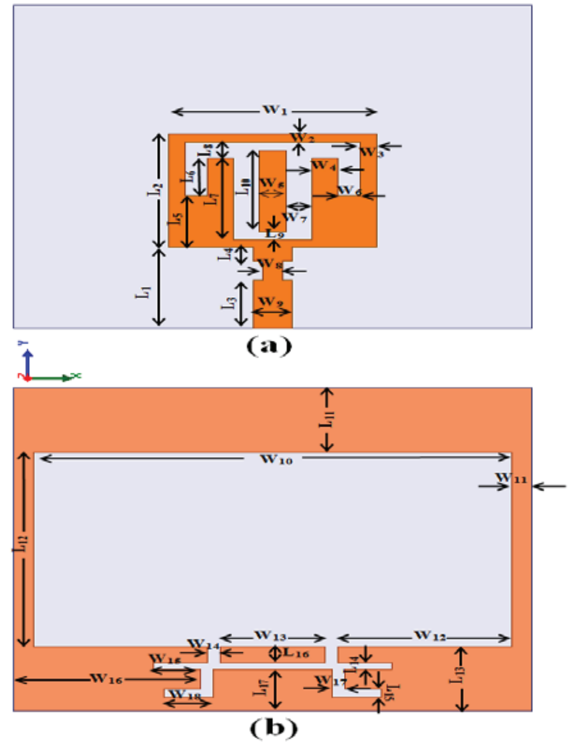

Fig. 2. The proposed antenna design parameters: (a) top view and (b) bottom view.

Table 1: The final dimensions of the designed antenna

Param.	mm	Param.	mm	Param.	mm
W_{sub}	20	W_{11}	0.75	L_6	2.3
L_{sub}	20	W_{12}	6.75	L_7	5
h	0.8	W_{13}	4	L_8	1
W_1	8	W_{14}	0.5	L_9	0.5
W_2	0.5	W_{15}	1.8	L_{10}	5
W_3	0.6	W_{16}	7.2	L_{11}	4
W_4	1	W_{17}	0.5	L_{12}	12
W_5	1	W_{18}	1.9	L_{13}	4
W_6	0.9	L_1	5	L_{14}	0.4
W_7	1	L_2	7	L_{15}	0.5
W_8	0.8	L_3	3	L_{16}	1
W_9	1.5	L_4	0.8	L_{17}	2.6
W_{10}	18.5	L_5	3.2		

III. RESULTS AND DISCUSSIONS

In this section, the proposed slot antenna with various design parameters was constructed and the numerical and experimental results of the input impedance and the radiation characteristics are presented and discussed. The simulated results are obained using the Ansoft simulation software High Frequency Structure Simulator (HFSS) [14].

The configurations of various antenna structures which are compared to the proposed antenna structure in the simulation study, are shown in Fig. 3. Return loss characteristics for ordinary slot antenna (Fig. 3 (a)), slot antenna with gamma-shaped slots inside the radiating stub (Fig. 3 (b)) and the proposed slot antenna structure (Fig. 1) with different states of PIN diodes biasing, are compared in Fig. 4.

As shown in Fig. 4, it is observed that the upper frequency bandwidth is firstly affected by the presence of the gamma-shaped slots in the radiating stub and then it is affected by cutting two notches on the feed-line. It is found that by inserting the gamma-shaped slots in the radiating stub, the antenna can create an additional resonance at 9.25 GHz and also it is found that by inserting two notches with modified dimensions on the feed-line, the antenna is capable of exhibiting another additional resonance at frequency of 10.2 GHz. This is mainly due to the fact that the surface current path on the feed-line and the radiating stub is changed and determined by the notches on the feed-line and the gamma-shaped slots, respectively [8]. Moreover, as illustrated in Fig. 4, the gamma-shaped slots with a PIN diode (D1) between their bottom sections are used in order to electrically switch between the frequency band-notch performance and the new excitation function.

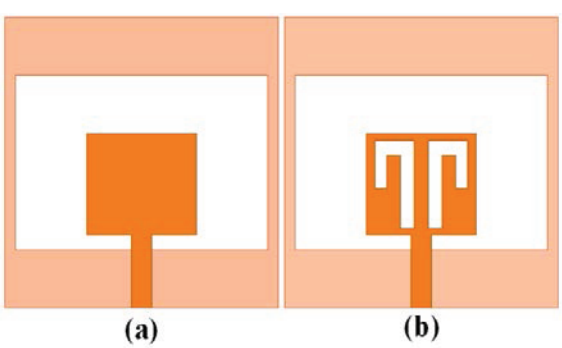

Fig. 3. (a) Basic structure (ordinary slot antenna) and (b) antenna with gamma-shaped slots on the radiating stub.

Another important result which is obtained from the simulation study, is that the notched frequency bandwidth is sensitive to the dimensions of the gamma-shaped slots [2]. To give a better insight about the band-notch behavior of the designed antenna, a smith chart demonstration of its input impedance at the band-notch performance is presented in Fig. 5.

Furthermore, it is shown in Fig. 4, that when the PIN diode between the H-shaped slots on the ground plane is off or biased reversely, the frequency response of the antenna has a fundamental change and the proposed structure turns from a wideband antenna into a single band antenna [13].

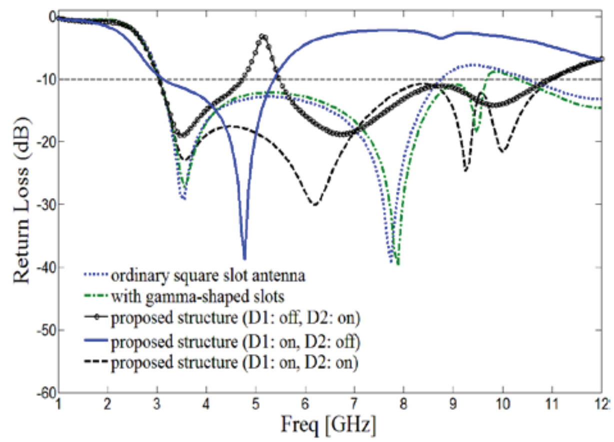

Fig. 4. Simulated return loss characteristics for antennas shown in Fig. 2 and the proposed antenna structure with various PIN diodes biasing statuses (Fig. 1).

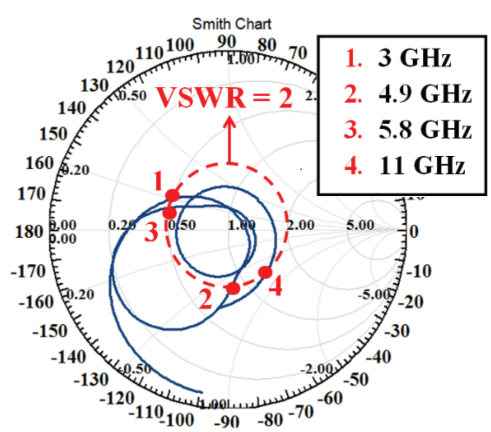

Fig. 5. Smith chart demonstration of band-notch performance of the proposed antenna.

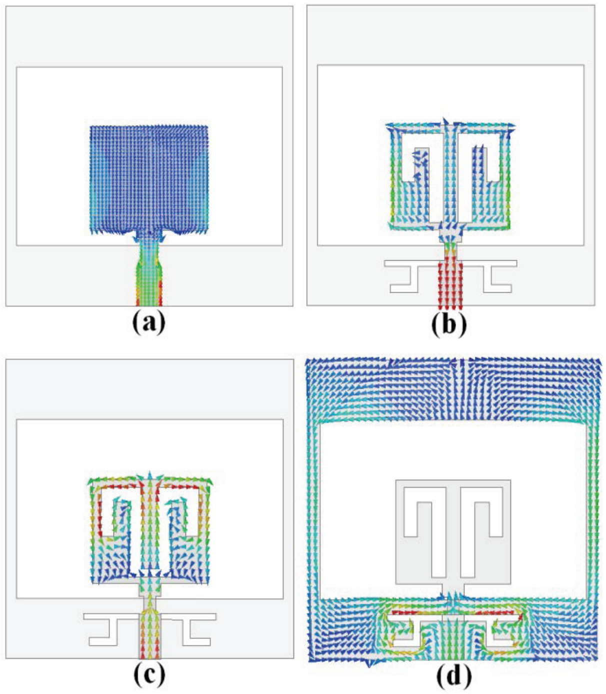

Fig. 6. Simulated surface current distributions: (a) on the radiating stub for ordinary square slot antenna with notches on the feed-line at additional resonance frequency (10.2 GHz), (b) on the radiating stub for the proposed antenna at additional resonance frequency (9.45 GHz), (c) on the radiating stub for the proposed antenna at central notched frequency (5.5 GHz) and (d) on the ground plane for the proposed antenna at single band performance central frequency (4.8 GHz).

The simulated current distribution on the ordinary square slot antenna with notches on the feed-line is shown in Fig. 6 (a). As it can be seen in this figure, the current distribution at 10.2 GHz (additional resonance frequency) is concentrated around the notches on the feed-line and therefore, the antenna impedance changes at this frequency due to the dimensions of the notches and leads to an additional resonance. Also, in order to understand the phenomenon behind switching electronically between multi-resonance (UWB), UWB with band-notch function and single band performances of the proposed antenna, the simulated surface current distributions on the radiating stub and the ground plane of the proposed antenna for on and off statuses of pin diodes, are presented in Figs. 6 (b), (c) and (d), respectively.

It can be observed in Fig. 6 (b) that when both PIN diodes are biased forwardly, at 9.45 GHz the current is concentrated near the interior and exterior edges of the gamma-shaped slots on the radiating stub. It is found that by using this structure, an additional resonance is generated at 9.45 GHz [2]. Figure 6 (c) presents the simulated current distributions on the radiating stub at the notched frequency (5.5 GHz) when the PIN diode on the radiating stub is off (D1: off) and the PIN diode on the ground plane is on (D2: on). As it can be observed in this figure, at the notched frequency the current flows are more dominant around the interior and exterior edges of the V-shaped like slot on the radiating stub and they are oppositely directed, and as a result, the desired high attenuation near the notched frequency can be produced [2].

Finally, the current distribution on the ground plane for the single band performance of the antenna at 4.8 GHz is shown in Fig. 6 (d). It is found that when the PIN Diode on the radiating stub is on (D1: on) and the PIN diode on the ground plane is off (D2: off), the current flows are concentrated and dominant around the π-shaped slot on the ground plane and this slot acts as a half wavelength resonator [8].

In order to obtain modified and final values for different design parameters of the presented antenna, a parametric study was also performed in which one parameter was changed at a time, while others were kept fixed. Figure 7 shows the effect of notches with various dimensions in the ground plane on return loss characteristic of the proposed antenna for the cases, which are listed in Table 2. As it can be seen in Fig. 7, the notches on the feed-line have an important role in wideband characteristic of the antenna.

Table 2: Three cases of proposed antenna with different values of notches on the feed-line

Case	L_3	L_4	W_8
1	3	0.8	0.8
2	2	0.8	0.4
3	1	2.25	0.8

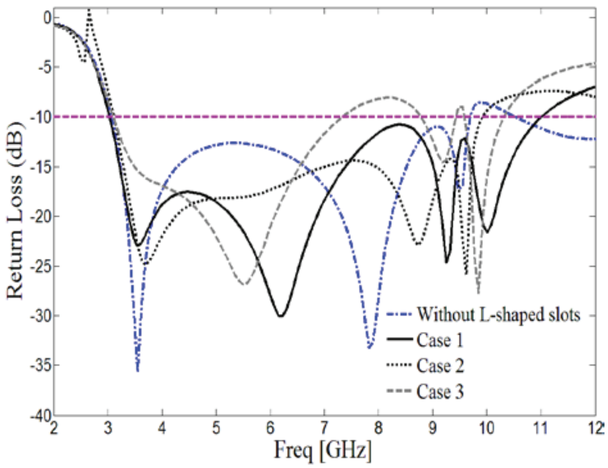

Fig. 7. The effect of a pair of notches in the feed-line on return loss for cases in Table 1.

The proposed antenna with final design parameters was built and tested. External DC wires were used in order to bias the PIN diodes. Figure 8 shows the fabricated antenna and its measured and simulated return loss characteristics are presented in Fig. 9. The measured results reveal that the fabricated antenna can satisfy the requirements for ultra-wide band performance and covers the frequency band of 2.7 GHz to over 10.65 GHz, with a band-notch function around 4.8-5.83 GHz, as it was predicted from the simulation studies. However, as shown in Fig. 9, there exists a discrepancy between the measured results and the simulated data. This discrepancy is mostly due to a number of parameters, such as the fabricated antenna dimensions accuracy as well as the thickness and dielectric constant of the substrate on which the antenna is fabricated, the wide range of simulation frequencies and also the effect of PIN diodes and their biasing circuits. In order to confirm the accuracy of 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 other components solder accuracy and FR4 substrate quality needs to be taken into consideration.

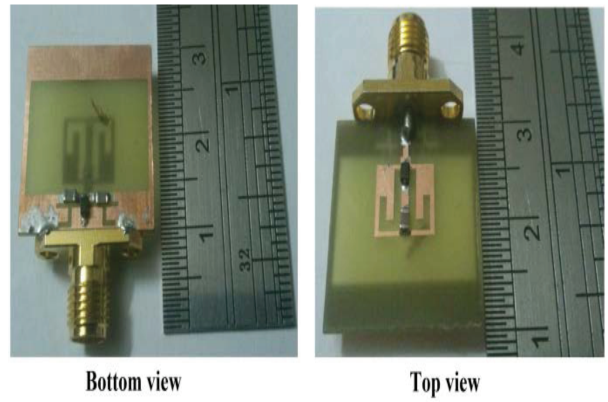

Fig. 8. The fabricated antenna.

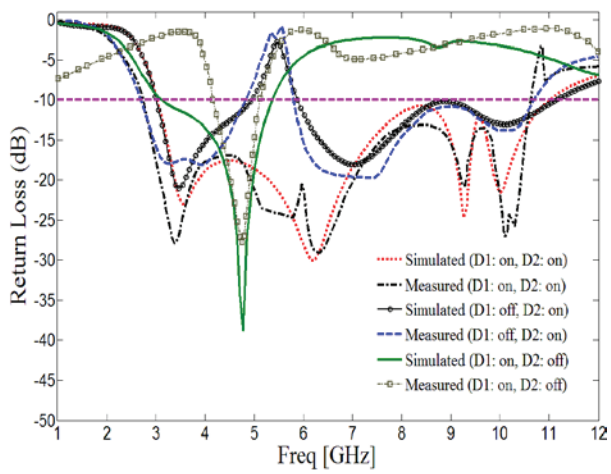

Fig. 9. Simulated and measured return loss characteristics for different performances of the proposed antenna.

The measured radiation patterns, including the co-polarization and cross-polarization in the E-plane (*y-z* plane) and H-plane (*x-z* plane) for different performances of the fabricated antenna, are shown in Fig. 10. The main purpose of presenting the radiation patterns is to demonstrate that the antenna actually radiates over a wide frequency band. It can be seen that the radiation patterns in *x-z* plane are nearly omnidirectional for different performances of the antenna at various operating frequencies.

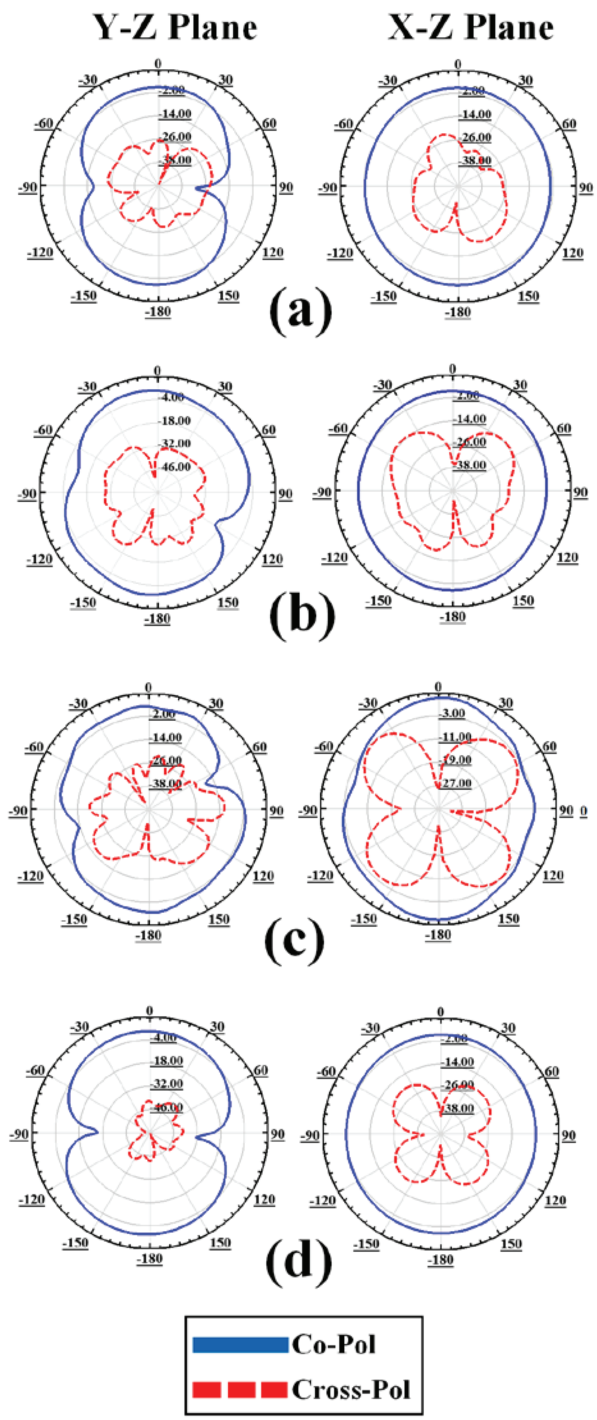

Fig. 10. Measured radiation patterns of the proposed antenna: (a) 5 GHz (D1: on, D2: off), (b) 5.5 GHz (D1: on, D2: on), (c) 10 GHz (D1: on, D2: on) and (d) 6 GHz (D1: off, D2: on).

V. CONCLUSION

In this letter, a novel compact reconfigurable printed slot antenna with switchable UWB (multi-resonance), UWB with band-notch function and single band performances has been proposed for UWB applications. By inserting a pair of notches in the feed-line of the ordinary slot antenna, wider impedance bandwidth can be obtained; especially at the higher band. Another additional resonance excitation at higher band is added to the antenna performance by etching two gamma-shaped slots on the radiating stub and a switchable single band-notch function is provided by embedding a PIN diode between these slots. By cutting two H-shaped slots on the ground plane and embedding a PIN diode across these slots, the antenna is capable of another switchable function between UWB and single band performances. By changing the biasing statuses of the PIN diodes, the antenna exhibits different desired functionalities. The fabricated antenna satisfies the return loss < 10 dB requirement from 2.7 GHz to 10.65 GHz, with a band rejection performance in the frequency band of 4.8 GHz to 5.83 GHz. The proposed antenna has a simple configuration and is easy to fabricate.

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