A Planar UWB Reconfigurable Face-shaped Monopole Antenna with Dual Band Rejection for WIMAX/WLAN

Sedighe Saghayi, Pejman Rezaei, and Hamed Nimehvari Varcheh

Abstract – **In this paper, a novel ultra-wideband (UWB) frequency-band reconfigurable antenna with four switchable frequency states is presented. The proposed antenna possesses a simple structure and size of 26×26×0.8 mm^3. Notched frequency bands are obtained by embedding U-shaped slot in the radiation patch and adding the parasitic patch. A frequency reconfigurability is controlled by two switches located on the patch. To improve a bandwidth, a defected ground structure with a rectangular slot and two symmetrical incisions on the ground plane have been used. The proposed antenna covers bandwidth 3.08-11.32 GHz. Also, the antenna impedance matching has been obtained by using two symmetrical incisions in the microstrip feed.**

Keywords – **Ultra-wideband, Notched frequency bands, Reconfigurable antenna.**

I. INTRODUCTION

UWB systems are suitable for wireless communication because of their ability to provide high bit rate and low power [1]. Federal Communications Commission (FCC) specifies 3.1 GHz to 10.6 GHz band for the commercial usages of ultra-wideband (UWB) systems [2]. In UWB systems, one of the key issues is the design of a compact antenna while providing wideband characteristics over the whole operating band. Due to the relatively simple structures, omnidirectional radiation patterns and low cost, the planar microstrip antennas are a good choice [3-6].

To obtain the switchable ability of the antenna, the concept of a reconfigurable antenna was proposed a few years ago. In recent years, many studies are carried out in this field and several reconfigurable antenna designs have been reported [7-11]. Also, the switchable frequency responses are achieved by the implementation of a PIN diode within the antenna structure [12-17]. Furthermore, the existing wireless standard bands, like WIMAX and WLAN bands can cause interference with the UWB communication system. This problem led to design different UWB antennas with the ability of annoying frequency band rejection. Several types of these antennas have been proposed [18-21].

In fact, by using a frequency reconfigurable antenna can avoid undesired band interference. With this method, the ability of the frequency band rejection is variable and can be controlled. The antenna structure can be changed while the interference system does not exist. Therefore, the bandwidth antenna covers the entire frequency spectrum UWB. Also, the reconfigurable antenna can modify its radiation characteristics such as gain, radiation pattern and operating frequency [22-25].

In [22], a novel UWB antenna with dual notched bands for WIMAX and WLAN applications is presented. To realize dual notched bands characteristics, a T-shaped stub embedded in the square slot of the radiation patch and a pair of U-shaped parasitic strips beside the feed line is used. Furthermore, the dimension of the proposed antenna is 26 × 31 mm^2 and has been prototyped on Rogers 4003 substrate of 0.8 mm thickness. Also, the gain of the structure at first (3.6 GHz) and second (5.5 GHz) frequency notch is -4 dB and -8 dB, respectively. In [23], a dual band-notch UWB slot antenna by means of simple parasitic slits is designed. To create a notched band for WIMAX, one angle-shaped parasitic slit is etched out along with the tuning stub, while for WLAN, two symmetrical parasitic slits are placed inside the slot of the ground plane. Also, the dimension of the proposed antenna is 22 × 24 mm^2 and has been prototyped on FR4 substrate of 1.6 mm thickness. Also, the gain of the structure at first (3.5 GHz) and second (5.5 GHz) frequency notch is -2.9 dB and -3.5 dB, respectively. In [24], a novel design of dual band-notched monopole antenna with bandwidth enhancement for UWB applications is presented. By adding an inverted T-shaped parasitic structure inside the inverted T-shaped slot on the radiating patch, a dual band-notched function is achieved. Also, the dimension of the proposed antenna is 12 × 18 mm^2 and has been prototyped on FR4 substrate of 0.8 mm thickness. Also, the gain of the structure at first (3.8 GHz) and second (5.5 GHz) frequency notch is -17 dB. In [25], the design and analysis of a compact planar dual band-notched UWB antenna are presented. The design consists of a unique lamp post shaped radiator fed through a microstrip feedline with one U-shaped slot and a C-shaped slot etched on the radiator and a slotted ground plane. Moreover, the dimension of the proposed antenna is 30×30 mm^2 and has been prototyped on FR4 substrate of 1.6 mm thickness. Also, the gain of the structure at first (3.5 GHz) and second (5.5 GHz) frequency notch is -3 dB and -1 dB, respectively.

In this paper, a face-like frequency-band reconfigurable UWB antenna has been introduced with four switchable frequency states and possesses a simple configuration. Also, the physical design of the structure is different from other structures. Moreover, the dimension of the proposed antenna is 26 × 26 mm^2 and has been prototyped on FR4 substrate of 0.8 mm thickness. Also, the gain of the structure at first (3.5 GHz) and second (5.5 GHz) frequency notch is -4 dB and -6.5 dB, respectively. The performance of a notched frequency band is achieved by embedding a printed U-shaped slot in the radiation patch and adding the parasitic patch. Also, the

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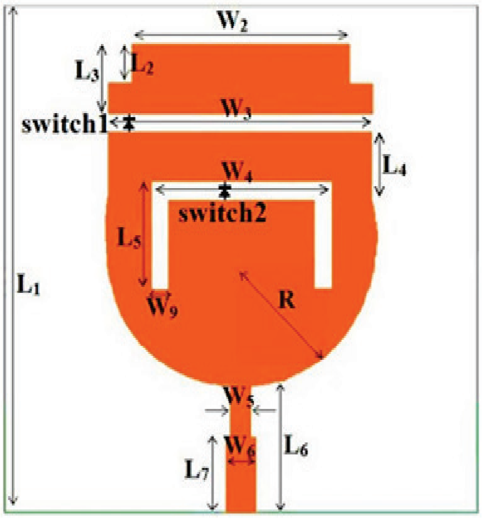
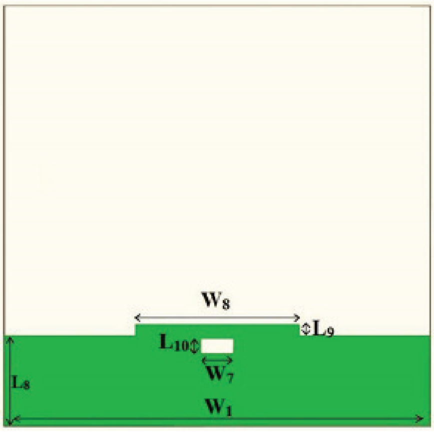
frequency reconfigurability is controlled by two switches placed on the patch. The features such as compact size, wide bandwidth and great radiation properties are additional advantages of the proposed antenna. However, the main advantage of the proposed antenna is the ability to reject frequency bands for WIMAX and WLAN.

II. Antenna Configuration and Design

The antenna is implemented on a substrate with a dielectric constant of 4.4 with a loss tangent of 0.02 and a thickness of 0.8 mm. The basic antenna structure consists of the circular patch, the microstrip feed-line and the defective ground plane.



(a)



(b)

Fig. 1. Geometry of the proposed antenna (a) Top view, (b) Bottom view

The proposed antenna is fed by a 50-ohm microstrip feed-line. This antenna possesses a compact size of 26×26×0.8 mm^3. A parasitic element is located above the patch radiation and a U-shaped slot on the patch radiation. To achieve the frequency reconfigurability, two PIN diode switches are used on the radiation patch and the parasitic element. These pin diodes in the mode forward bias are equivalent low resistance and at the mode reverse bias are equivalent low-loss capacitor. The PIN diodes placed on the antenna are suitable for a short circuit on the surface slot. The induced current distribution around the slot can be changed by controlling these diodes. Also, the frequency reconfigurability could be performed by switching these diodes. The geometry of the proposed antenna, top and bottom view, is shown in Fig. 1 (a), (b) respectively.

By using two switches, the antenna operates in four different frequency modes; mode A, B, C and mode D. When the switch 2 is on and the switch 1 is off, the antenna operates in mode A. In this mode, the antenna covers the UWB frequency range. In mode B, both switches are off and the antenna rejects WLAN frequency band. Moreover, the antenna operates in mode C and eliminates WIMAX frequency band while switches 1 and 2 are on. Also, the antenna operates in mode D and removes WLAN and WIMAX frequency bands whenever the switch 1 is on and the switch 2 is off. Therefore, different modes of the proposed antenna are presented in Table 1.

TABLE 1
Different Modes of the Proposed Antenna

Modes	SW1	SW2	Bandwidth
A	OFF	ON	UWB frequency
B	OFF	OFF	WLAN band rejection
C	ON	ON	WIMAX band rejection
D	ON	OFF	WIMAX and WLAN bands rejection

The proposed antenna is analysed using HFSS software [26]. A parametric study is done on the key parameters of the antenna to achieve the optimum values. The final values of the proposed antenna design are specified in Table 2.

TABLE 2
Final Dimensions of the Proposed Antenna

Parameter	Dimension(mm)	Parameter	Dimension(mm)
L_1	26	L_{10}	1
W_1	26	W_2	12
L_2	2	W_3	14.4
L_3	3.5	W_4	8
L_4	3.4	W_5	1
L_5	5.5	W_6	1.5
L_6	6.5	W_7	2
L_7	3.7	W_8	10
L_8	5.5	W_9	1
L_9	0.6	R	7.5

The equivalent circuit of the dual band-notched UWB antenna is shown in Fig. 2. The equivalent circuit starts from the feed port of the antenna and quarter-wavelength at the resonance frequencies. The resonant frequencies are 3.5 GHz (L1, C1) and 5.5 GHz (L2, C2). According to the formulas:

$$Z = R + j\,(\omega L - 1/\omega C), \quad (1)$$

$$\omega_0 = 2\pi f_0 = 1/\sqrt{LC}. \quad (2)$$

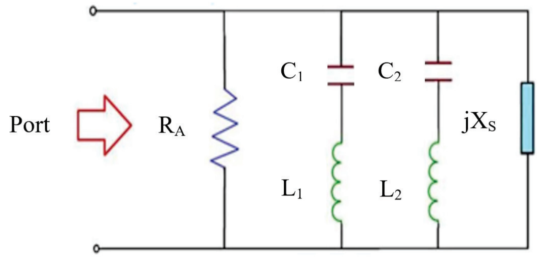


Fig. 2. Equivalent circuit of the proposed antenna around the notch band

Therefore, the radiation resistance, R_A, is shorted at 3.5 or 5.5 GHz. As a result, the antenna impedance is mismatched at 3.5 and 5.5 GHz. In fact, the band rejection characteristics of the proposed antenna are achieved. The input impedance of a single slot parallel to the radiating edge can be given as:

$$Z_S = R_{slot} + jX_s \qquad (3)$$

In Eq. (3), R_{Slot} (real part) is the radiation resistance and X_S (imaginary part) is the input reactance. In this study, only the capacitive reactance, X_S, is considered and the value of R_S is very small and can be neglected. In this paper, the U-shaped slot is taken as a capacitive reactance on the patch for wideband characteristics.

III. Results and Discussions

In this section, results of the return loss and radiation pattern of the fabricated UWB reconfigurable monopole antenna are presented. The planar UWB reconfigurable face-shaped monopole antenna with dual-band rejection for WIMAX/WLAN is shown in Fig. 3.

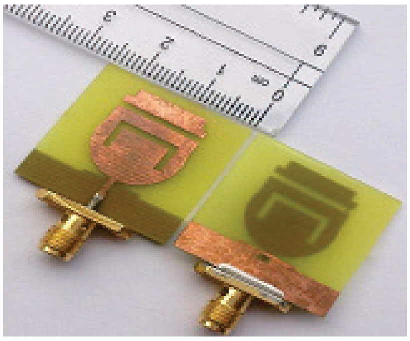
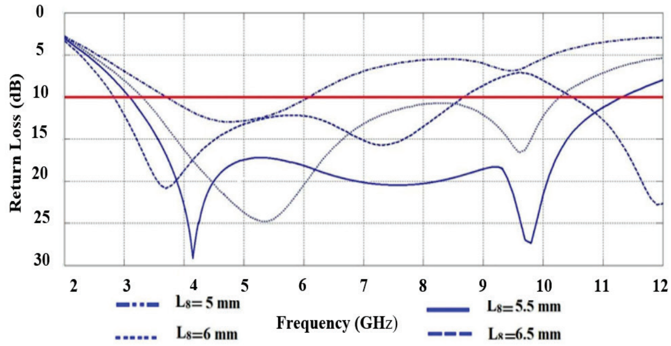


Fig. 3. Photograph of fabricated antenna

A. Mode A: UWB Antenna

In the first step, when the switch 2 is on, the antenna covers the UWB frequency band and a parametric study is done to access UWB structure. The parameter L_8 (in the ground plane), possesses a significant effect on the bandwidth of the antenna. The return loss of the proposed antenna is changed with different values of parameter L_8 which is shown in Fig. 4(a) and the optimum value of L_8=5.5 mm is shown in Fig. 4(b).



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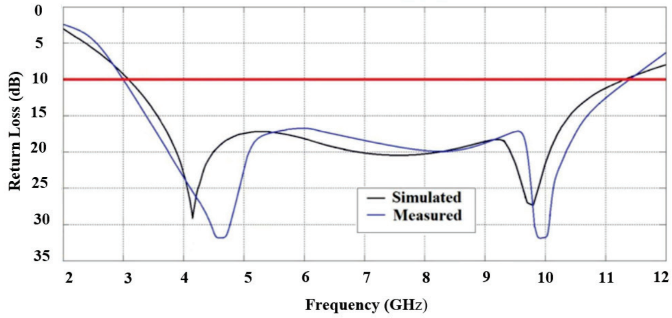
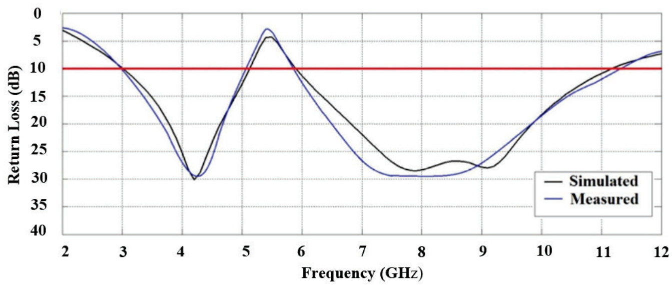


(b)

Fig. 4. (a) Simulated return loss of the monopole antenna for different value of L_8 (b) Measured and simulated return loss of the monopole antenna for UWB band

B. Mode B: UWB Antenna with WLAN Band Rejection

As the second step, the UWB antenna is designed with rejection WLAN band when switches are off. Fig. 5(a) shows the simulation and measurement of antenna return loss in mode B. The proposed antenna resonates at 5.1-5.8 GHz. To achieve the UWB antenna with the ability to reject WLAN frequency band, a U-shaped slot is inserted in the main patch. The length of parameter L5 is a significant factor in rejecting the WLAN frequency band. In Fig. 5(b), by changing the length of the slot, the WLAN frequency band is rejected. Finally, the optimum length of L5 =5.5mm is achieved.



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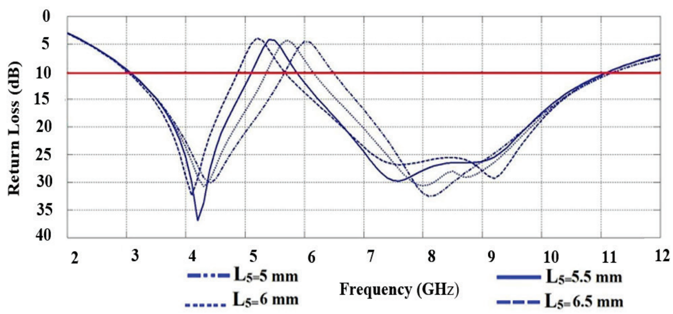
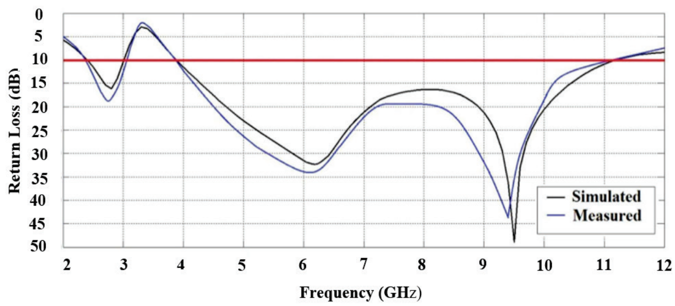


(b)

Fig. 5. (a) Measured and simulated return loss of the proposed antenna for WLAN band rejection, (b) Simulated return loss of the antenna for WLAN band rejection with different values of L_5

C. Mode C: UWB Antenna with WIMAX Band Rejection

In the third step, the UWB antenna removes WIMAX frequency band. The parasitic patch is added to the main patch and two switches are placed on the U-shaped slot to reject and control WIMAX frequency band. Fig. 6(a) shows the return loss of the proposed antenna in terms of parameter W_3 which is located in the parasitic patch. Therefore, the optimum length of parameter W_3=14.4mm is achieved and WIMAX frequency band rejection is done which is shown in Fig. 6(b).



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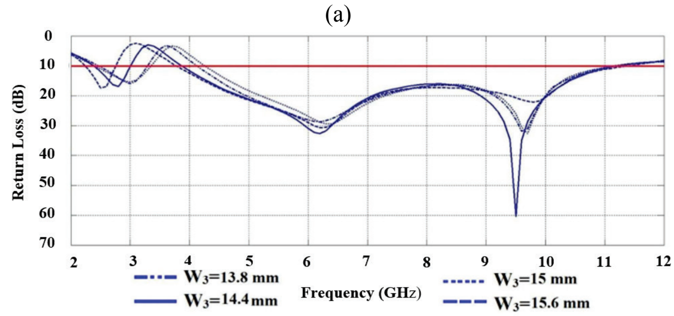

(b)

Fig. 6. (a) Simulated return loss of the proposed antenna for WIMAX band rejection with different values of W_3, (b) Measured and simulated return loss of the antenna for WIMAX band rejection

D. Mode D: UWB Antenna with WIMAX, WLAN Bands Rejection

In the fourth step design, the UWB antenna with the dual band-notched characteristics which is centered at 3.4 and 5.5 GHz is presented. Fig. 7 shows the return loss of the dual band-notched antenna.

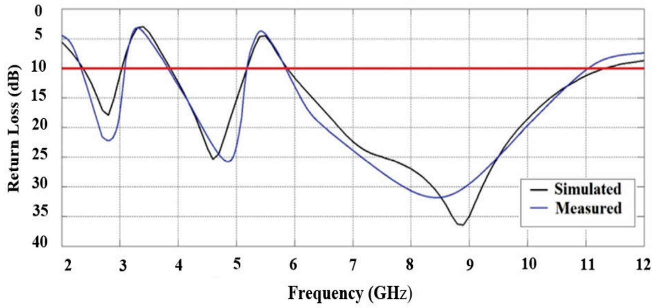

Fig. 7. Measured and simulated return loss of the dual band-notched monopole antenna

IV. Radiation Pattern

The measured radiation patterns including the co-polarization and cross-polarization in the E-plane (y-z plane) and H-plane (x-z plane) are shown in Fig. 8 (a)-(b). The radiation patterns in the x-z plane are almost omnidirectional and uniformed in all frequency band. Radiation over a wide range of the frequency band is the main purpose of the presented antenna. The simulated and measured peak gain of the dual band-notched antenna are shown in Fig. 9. The peak gain of the proposed antenna is decreased sharply at the notched bands of 3.5 and 5.5 GHz. Moreover, the comparisons for the several different dual-notched-band UWB antennas are depicted in Table 3.

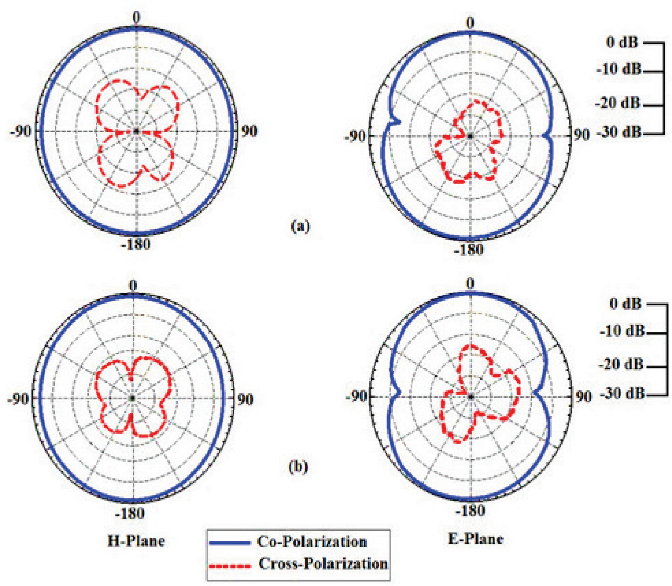

Fig. 8. Measured radiation patterns of the fabricated antenna: (a) 4.5 GHz and (b) 7.5 GHz

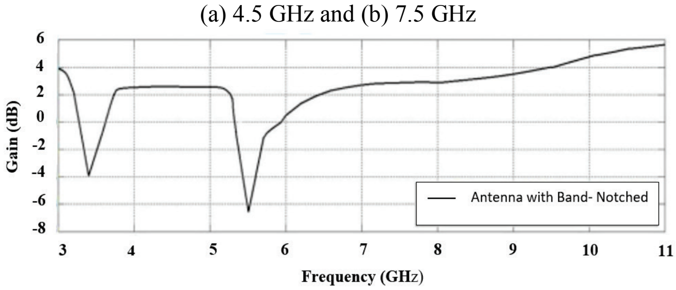

Fig. 9. Measured peak gain of the proposed antenna

TABLE 3
COMPARISON WITH OTHER REPORTED DUAL-BAND REJECTION UWB ANTENNA

Ref.	Antenna	Size (mm^3)	Substrate	Gain (dB) at notch frequency (GHz)	
				1st notch	2nd notch
[22]	Monopole	26×31×0.8	Rogers 4003	-4 @ 3.6	-8 @ 5.5
[23]	Slot	22×24×1.6	FR4	-2.9 @ 3.5	-3.5 @ 5.5
[24]	Monopole	12×18×0.8	FR4	-17 @ 3.8	-17 @ 5.5
[25]	Monopole	30×30×1.6	FR4	-3 @ 3.5	-1 @ 5.5
This work	Face-shaped Monopole	26×26×0.8	FR4	-4 @ 3.5	-6.5 @ 5.5

V. CONCLUSION

In this paper, a Face-like reconfigurable antenna with a printed slot and dual band notch performances and very simple configuration has been introduced for UWB applications. This antenna can cover the frequency band of 3.08-11.32 GHz for S11 ≤ −10dB. The performance of the notched frequency band of the proposed antenna can be controlled by two switches on the slot and adding the parasitic patch. Characteristics such as compact size, wide operating bandwidth and good radiation properties are other intriguing features of the proposed antenna. The main advantage of this antenna is the ability to reject frequency bands. Also, the proposed antenna decreases interface wireless communication with the UWB frequency band.

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