RESEARCH PAPER

Reconfigurable microstrip slot antenna with DGS for UWB applications

MEHRI BORHANI KAKHKI AND PEJMAN REZAEI

In this paper, a frequency reconfigurable microstrip slot antenna for ultra-wideband applications with switchable band-notch functions is designed and manufactured. To generate a wide usable fractional bandwidth of 3 to over 13.6 GHz, square patch transforms to a fork-shaped patch, also two triangular-shaped strips have been added at above sections of rectangular slot on the ground plane. Band rejections are obtained by adding two inverted L-shaped strips in the fork-shaped patch and one L-shaped defected ground structure. Moreover, by implementation of two PIN diodes within the antenna structure, four switchable frequency responses are achieved. The designed antenna has simple structure and a small size of $20 \times 20 \times 0.8 \ mm^3$ while providing band rejection characteristics at WiMAX (Worldwide Interoperability for Microwave Access) and WLAN (Wireless Local Area Networks) systems.

I. INTRODUCTION

Planar antennas are the newest generation of antennas, boasting such attractive features as low profile, light weight, low cost, and ease of integration into arrays. These features make them ideal components of modern communications systems [1]. Also, with the commercial success of wireless handheld devices comes the important role of good manufacturing techniques. This is not only important for reducing the cost of mass production, but also for enhancing the design performance and size in a controlled fashion [2].

Ultra-wideband (UWB) technology has received an impetus and attracted academia and industrial attention in the wireless world ever since Federal Communications Commission (FCC) released a 10-dB bandwidth of 7.5 GHz (from 3.1 to 10.6 GHz) [3]. Commercial UWB systems require small low-cost antennas with omnidirectional radiation patterns and large bandwidth [4, 5]. Over the UWB working band, there are some other existing narrowband communication systems, such as 3.4–3.69 GHz band (IEEE 802.16) Worldwide Interoperability for Microwave Access (WiMAX) and 5.15–5.825 GHz band (IEEE 802.11a) Wireless Local Area Networks (WLAN), which may cause possible electromagnetic interference to the UWB applications [6]. To overcome this problem, it is desired to design UWB antennas with band rejection characteristic and reconfigurable capability. In order to create band rejection antennas, several techniques has been proposed recently such as

embedding parasitic elements [7–11], C- and S-shaped slot [12–14], square slot [15], cutting V-shaped slot [16], and combining with the notched meta-material UWB filter [17].

Recently, we are seeing lots of great trends toward design and implementation of a reconfigurable defected ground structure (DGS), which is realized by etching a certain defected pattern or slot in the ground plane. The reconfigurable DGS can be used in many applications such as antennas due to their interesting properties in terms of size miniaturization, arbitrary stopbands, and suppression of surface waves [18–21].

This paper presented a new microstrip slot antenna with switching capability for UWB applications. The designed antenna has the ability of operating in four different states. To achieve the performance of reconfiguring, two PIN diodes are used on the patch and ground plane. The needed modifications have been done on the square radiating patch and ground plane in order to achieve the UWB characteristics. The band-notched characteristics are mainly due to the change in surface current, which is determined by PIN diodes [22]. The following sections deal with the antenna geometry, design procedures, simulation, and experimental results.

II. ANTENNA DESIGN AND CONFIGURATION

The proposed antenna structure with designed parameters is shown in Fig. 1.

The antenna is printed on both sides of a low-cost FR-4 substrate with thickness of 0.8 mm, relative permittivity of 4.4, and loss tangent of 0.018. The antenna structure consists of a modified square-shaped radiating patch, a ground plane with L-shaped slot and feed line by size of $8 \times 1.5 \ mm^2$. For signal

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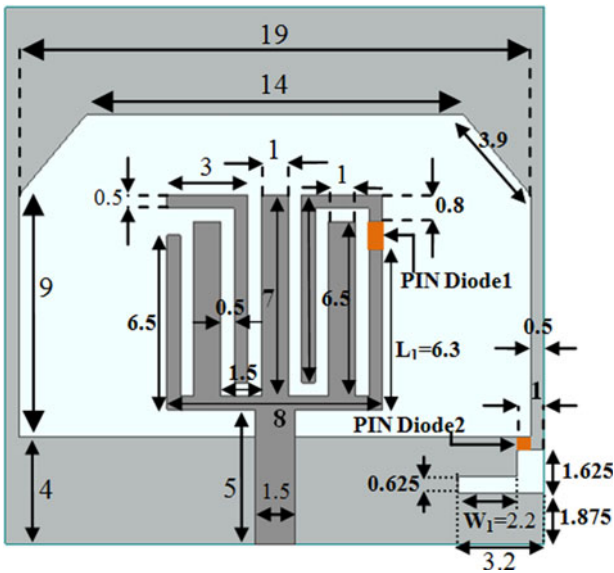M. Borhani Kakhki
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Fig. 1. Geometry of the proposed microstrip slot antenna (unit, mm).

Fig. 3. Simulated return loss characteristics for the steps of antenna design.

transmission a SMA connector (SubMiniature version A) is connected to the feed-line. To achieve the performance of frequency reconfigurable, two PIN diodes are used on the antenna structure, which are placed in the antenna patch and ground plane. The proposed antenna is capable to switch among four different states.

Figure 2 shows the various antenna structures in five steps, which are investigated during the simulation studies, and their return loss characteristics are compared in Fig. 3. To simulate the antenna and get return losses, Ansoft HFSS software is used [23].

Figure 2(a) shows an ordinary antenna, which consists of a square patch by dimension of 8×8 mm² and a DGS, which provides a bandwidth of 2.7–8.8 GHz. According to Fig. 2(b), in order to improve the impedance bandwidth of 3 to over 13.6 GHz, square patch transformed to a fork-shaped patch and two triangular-shaped strips added at above sections of rectangular slot on the ground plane. The changes were obtained through simulation procedure and we realized that their dimensions play an important role in order to obtain desired result, whereas the absence of each slot on the patch or triangular-shaped strips at above sections of rectangular slot on the ground, eliminates the resulted bandwidth. As shown in Fig. 3, by adding two inverted L-shaped strips in the fork-shaped patch, band rejection from 4.51 to 5.7 GHz obtained (Fig. 2(c)). As can be seen in Fig. 3, adding an L-shaped slot to the ground plane and forming the antenna structure in Fig. 2(d), eliminates the created band rejection. By transforming of Figs 2(d)–2(e),
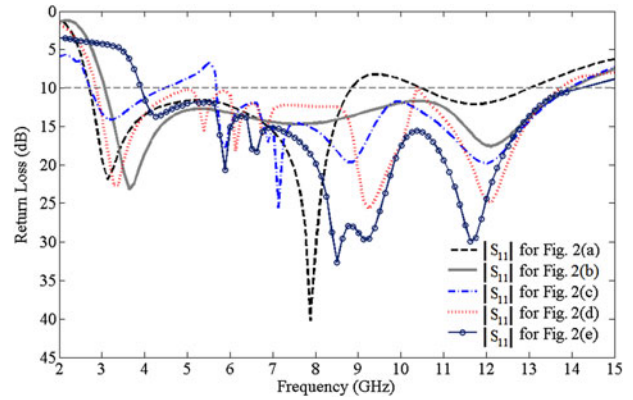
the presented antenna satisfies the frequency range of 3.8–13.5 GHz, which is UWB performance with a band rejection in the WiMAX band.

In order to illustrate the operation theory behind the band rejection characteristics of the proposed antenna, the surface current distribution is depicted for three cases in Fig. 4. It can be seen from this figure that for different states of diodes, different part of the structure has a corresponding resonating path.

To model PIN diode switch in the simulation, there are two techniques. In first technique, ideal switch models are used. This means that closed (ON) and opened (OFF) states of the switch are simulated in the presence or absence of a metal pad, respectively. In second technique, PIN diode is modeled as a capacitance/resistor in the OFF/ON state, respectively [24].

Figure 5 shows the equivalent circuits of the PIN diode. PIN diodes act as a variable resistance in radio frequency (RF) frequency. But in ON and OFF states, their circuit models are complicating. In both ON and OFF states, PIN diodes have an inductance in their structures. As can be seen in Fig. 5(a), when PIN diode is biased forwardly (ON state), the equivalent circuit of the diode consists of a small resistance and an inductance, which are series with each other. In the OFF state, when the diode is reversing biased, the equivalent circuit of the diode is composed of parallel combination of resistor and capacitor, which are series with an inductance [7].

In the designed antenna, to model PIN diode switches, both the mentioned techniques have been applied and we saw good agreement between their results.

III. PARAMETRIC STUDY OF THE PROPOSED ANTENNA

Parametric study is performed to obtain the final design values and optimize the performance of the antenna. Essential
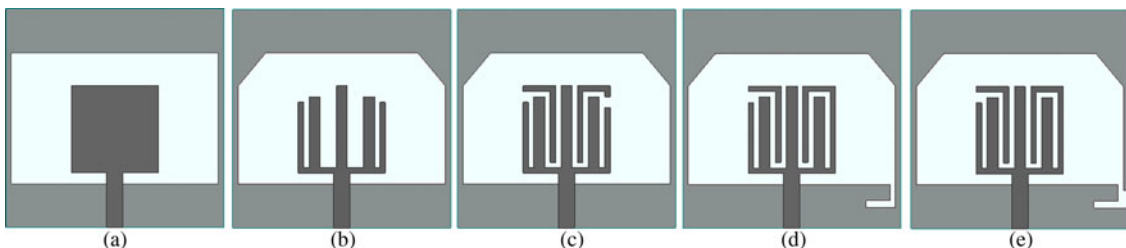

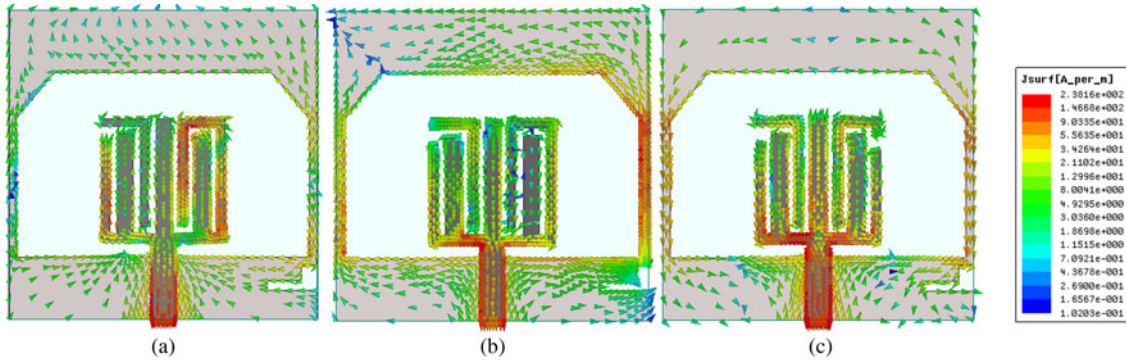**Fig. 2.** Simulated different antenna structures.

Fig. 4. Simulated surface current distributions on the proposed antenna: (a) antenna in UWB mode and (b) band-notch antenna with PIN diode 1 at 3.5 GHz. (c) Band-notch antenna with PIN diode 2 at 5.5 GHz.
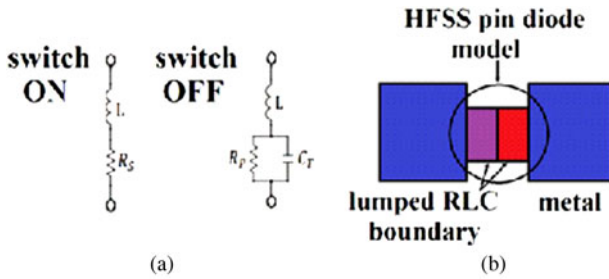

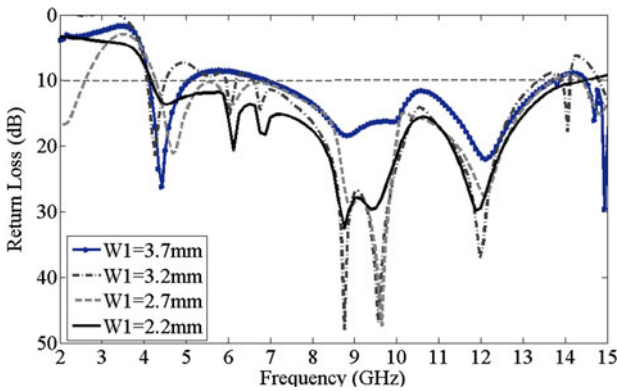**Fig. 5.** RF PIN diode: (a) equivalent circuit model and (b) HFSS model.

Fig. 7. Photograph of the slot reconfigurable antenna with bias circuit: (a) top view and (b) bottom view.

Fig. 6. Simulated return loss characteristics of the single-band-notch (WiMAX) antenna with different values of W_1.
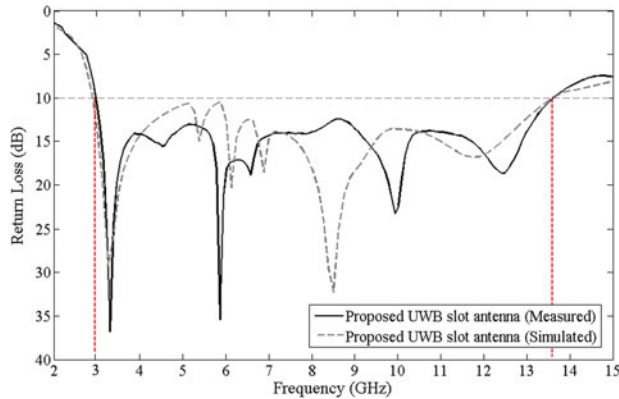
Fig. 8. Measured and simulated return-loss results in UWB antenna.

parameter in order to cause a band notch at WiMAX of the proposed structure is W_1. Figure 6 shows the simulated results of the proposed antenna with the effects of W_1 on adjusting band-notch performance in WiMAX. The results indicate that with decrease of W_1 from 3.7 to 2.2 mm, the notched frequencies can cover the WiMAX band, but there is undesirable notched frequency between 4 and 14.5 GHz when W_1 decreases from 3.7 to 2.7 mm with the step of 0.5 mm. However, for W_1 as 2.2 mm there is no undesirable notched frequency in mentioned range. Hence, the value of W_1 is optimized as 2.2 mm.

IV. RESULT AND DISCUSSION

The photograph of the manufactured antenna is presented in Fig. 7. Simulated and measured return loss characteristics of
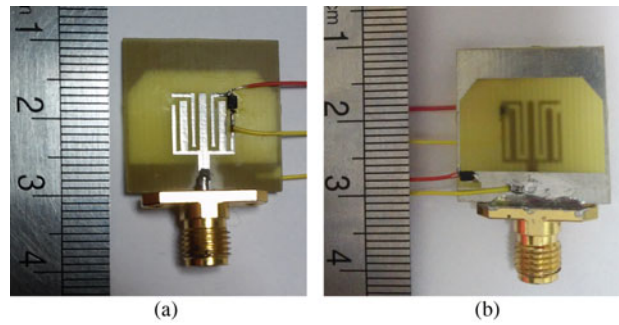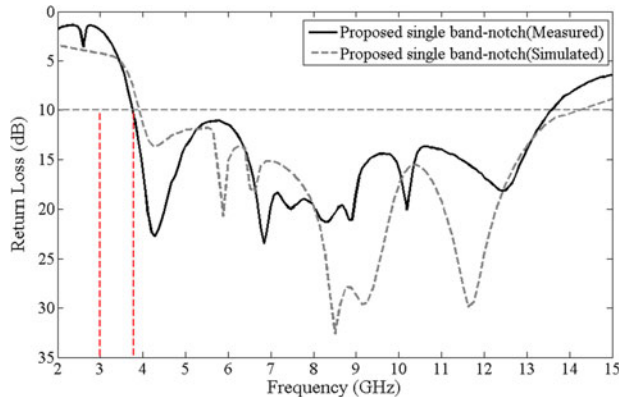

Fig. 9. Measured and simulated return-loss results in single-band-notch (WiMAX) antenna.
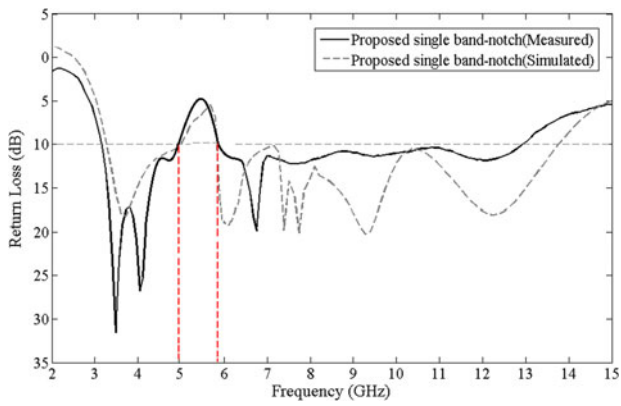
Fig. 10. Measured and simulated return-loss results in single-band-notch (WLAN) antenna.
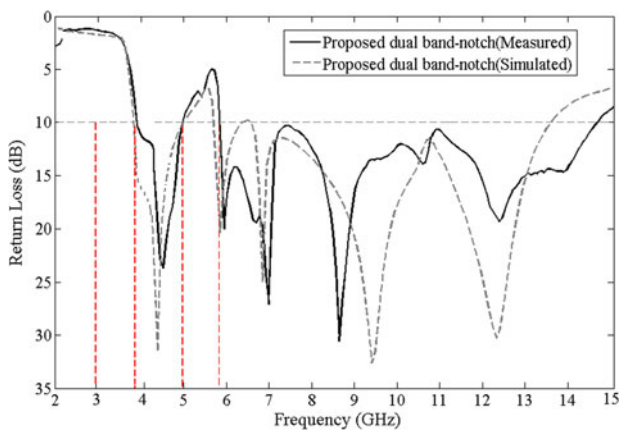

Fig. 11. Measured and simulated return-loss results in dual-band-notch (WiMAX and WLAN) antenna.

Fig. 13. Measured and simulated (*H*-plane) and (*E*-plane) radiation patterns of the antenna at: (a) 4.6, (b) 7.5, and (c) 10 GHz (not normalized).

presented antenna in four states are plotted and compared in Figs 8–11.

As can be seen in Fig. 8, the proposed antenna allows the frequency reconfigurability by activating two PIN diodes. When both diodes are ON, the presented antenna covers all the 3–13.5 GHz.

When D1 is ON and D2 is OFF, it is observed that the fabricated antenna satisfies the frequency range of 3.8–13.5 GHz,
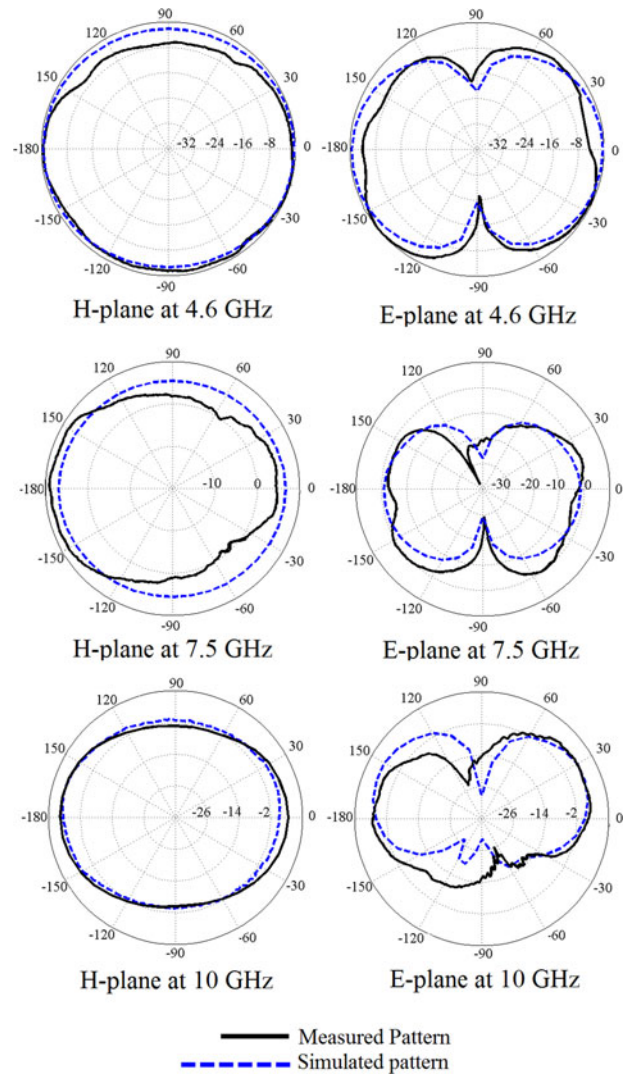
which is UWB performance with a band rejection in WiMAX (Fig. 9).

As shown in Fig. 10, by tuning diode 2 to ON and diode 1 to OFF, the band rejection of WLAN at 5–5.7 GHz is observed.
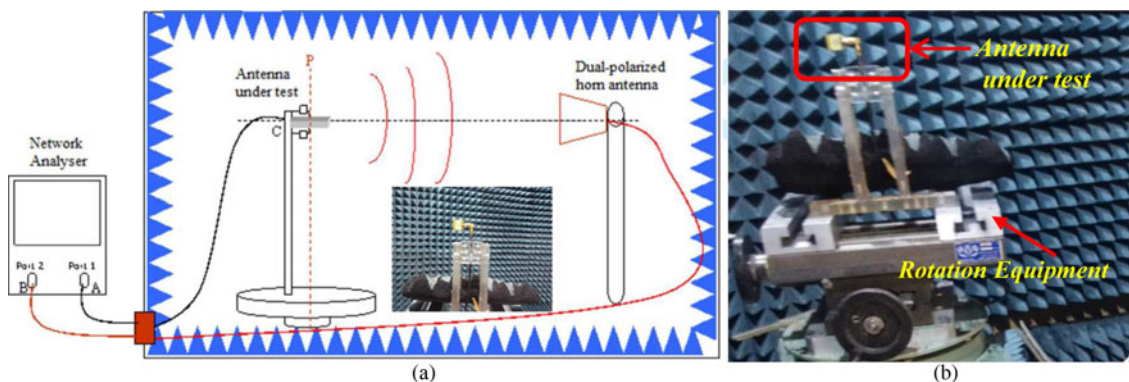

Fig. 12. (a) Schematic diagram and (b) photograph of measurement setup of the antenna for radiation patterns.
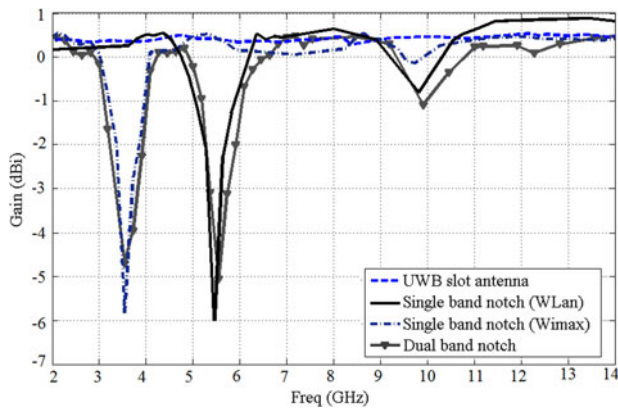
Fig. 14. Measured antenna gain of the proposed antenna.

Finally and in the fourth state, by switching both PIN diodes OFF, dual-band rejection of WiMAX and WLAN at 3–4.2 and 5–5.78 GHz are achieved, respectively (Fig. 11).

As can be seen from the proposed results, there is good agreement between the measurement and simulation results, which confirms the accurate performance of the designed antenna. However, there is some discrepancy between the simulated results and measured data, which can be due to a number of reasons such as the implementation of the PIN diodes and their biasing circuits, the effects of the SMA connector and inaccuracies in the fabrication process [25]. Schematic diagram and photograph of measurement setup of the antenna for the radiation pattern characteristics are shown in Fig. 12.

Figure 13 indicates the measured and simulated *E*- and *H-plane* radiation patterns for the manufactured antenna at three different spot frequencies 4.6, 7.5, and 10 GHz, respectively. As can be seen in Fig. 13, the *H*-plane pattern is nearly omnidirectional, which is desired for most related applications and the *E*-plane pattern depicts a dipole-like pattern in both measured and simulated results.

At higher frequencies, the radiation pattern deteriorates because of unequal phase distribution and significant magnitude of higher order modes and also variation of the equivalent radiating area with frequency over UWB [26]. Omnidirectional characteristics and radiation bandwidth can be improved if the ground plane length is approximately the same size as that of the radiating structure width and also by using a thin substrate or a substrate with low dielectric constant [3, 26].

Figure 14 shows that gain of the single- and dual-band-notch antennas from 2 to 14 GHz is between 0 and −6 dB.

In most passive circuits, dielectric constant and loss tangent of the FR-4 substrate increase as frequency increases. As a result, at the upper frequencies, it causes increasing in directivity and decreasing in gain. As can be seen in Fig. 14, there is a sharp decreasing trend in 10 GHz, which is due to the effects of the substrate losses with frequency.

V. CONCLUSION

In this paper, a new compact reconfigurable UWB slot antenna with four different switchable states has been presented. Band-notched functions are provided by etched slots on the patch and an L-shaped DGS. Simulation and measurement results show that the proposed antenna is able to cover the range of frequencies 3–13.5 GHz and a switchable frequency band rejection in the single- and dual-band WLAN and WiMAX. Frequency single- and dual-band-notched function is a solution to overcome the interference problem. The fabricated antenna has simple configuration and small size and it is suitable in a variety of wireless systems.

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