A Novel Compact UWB Antenna with Triple Band-Notches for WiMAX/ WLAN/ ITU Bands

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Abstract — A novel compact Ultra-Wideband (UWB) antenna with triple band-notched characteristics is presented. The antenna patch consists of several circular rings and a small circle. The antenna has a compact size of 25 × 20 mm^2, which has been printed on a Rogers RO4003 substrate. Moreover, the proposed antenna has been successfully fabricated and measured, showing broadband matched impedance (2.8 up to more than 20GHz, VSWR≤ 2); almost stable gain and good omnidirectional radiation patterns.

Index Terms — Triple Band-Notches, Ultra Wideband (UWB), WiMAX, WLAN, ITU, microstrip antenna.

I. INTRODUCTION

After allocation of the frequency band of 3.1-10.6 GHz (UWB) for commercial that is used by the FCC (Federal Communication Commission) [1], Ultra Wideband systems have received phenomenal gravitation in wireless communication. The UWB technology provides promising solutions for the future communication systems because of different advantages such as small emission power, low cost for short range access and remote sensing applications, high data rate and large bandwidth. On the other hand, the frequency range for UWB systems will cause interference with existing narrow band wireless communication systems. For instance, The wireless local area network (WLAN) for IEEE 802.11a operating at 5.15-5.35 and 5.725-5.825 GHz, the Worldwide Interoperability for microwave access (WiMAX) for IEEE 802.16 operating at 3.4-3.69, 5.25-5.85 GHz, and ITU Band (8.025-8.4 GHz). Therefore, UWB antennas with band-notched characteristics to filter the potential interference are desirable. Nowadays, many UWB antennas without and with various band-notched properties have developed [2-12]. The proposed antenna can be used in UWB systems which need no filters to suppress dispensable bands. The both Ansoft High Frequency Simulation Structure (HFSS) [13] and computer Simulation Technology (CST) [14] Three-dimensional (3-D) electromagnetic EM simulators are used to optimize the presented design. The proposed antenna with three tuneable narrow notched bands, which capability of its increasing exists, is proposed. The triple-band notch was successfully implemented and the simulated results show reasonable agreement with the measured results. Rest of the paper describes the antenna design in Section II, discussions on results is presented in Section III and followed by conclusive comments and further scope in Section IV.

II. ANTENNA DESIGN

The geometry of the proposed CPW-fed antenna for UWB applications is depicted in Fig. 1; also the optimized values of parameters are listed in Table 1.

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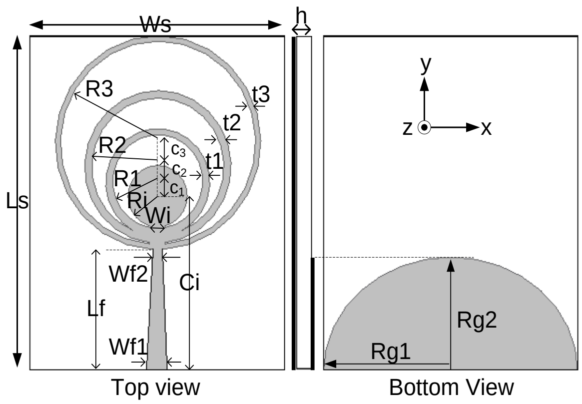

Fig. 1. Geometry of the proposed antenna.

Table 1: Optimal parameter values of the antenna and scale of the parameters (mm)

L_S	W_S	L_f	W_{f1}	W_{f2}	W_i	C_i
25	20	9	1.6	0.7	1.2	13
C_1	C_2	C_3	R_i	R_1	R_2	R_3
1.1	1.1	1.8	2.3	3.5	5.2	7.8
t_1	t_2	t_3	R_{g1}	R_{g2}	ε_r	h
0.5	0.5	0.2	9.9	8.5	3.55	0.8

The antenna is printed on a 25 × 20 mm^2 Rogers RO4003 substrate with relative permittivity 3.55, thickness 0.8mm, and loss tangent 0.0027. The antenna consists of three rings with radiuses R_1, R_2, R_3 and thicknesses of t_1, t_2, t_3 respectively, a small circle with radius R_i in front of the side, and one nearly semicircular ground on the back side. Besides, the antenna feed line is in the form of trapezium with parameters W_{f1}, W_{f2}, and L_f which is connected to a SMA connector 50Ω from Gigalane company with part number of PSF-S02 Series1. Presentation of a novel technique to obtain the controllable notches is the most advantage of the antenna. By enhancing the number of circular rings, the number of notched bands can be easily increased. Figure 2 exhibits Photograph of the fabricated antenna.

The next section is about the antenna design process and the effect of various parameters on VSWR.

III. ANTENNA PERFORMANCE AND DISCUSSION

In this section, the design procedure of the triple band-notches antenna by VSWR curves is demonstrated. Note that the simulated results are obtained using the HFSS and CST software's.

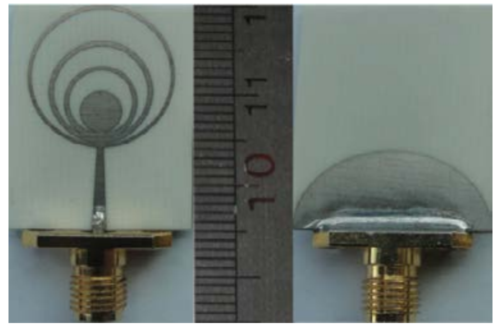

Fig. 2. Photograph of the fabricated antenna and scale of the ruler (cm).

A. Full-Band Design

The main reference or primary shape of the triple band-notches antenna was in the form of circular monopole with radius R_3+t_3 which is shown in Fig. 3.

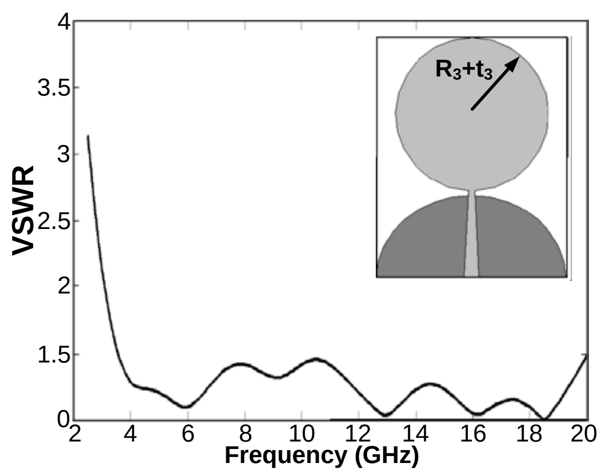

Fig. 3. Simulated VSWR of the referenced antenna.

Also, in this Figure VSWR can be seen in a way that the bandwidth for VSWR ≤ 2 is from 3.1 up to more than 20 GHz. Meanwhile, structure of the ground and feed line are similar to the proposed antenna structure.

B. Triple band-notches Design

In this section, the design procedure of the notches and the effect of varying the major parameters on lower, middle, and finally upper notched band are examined. The main idea of the proposed antenna has come from [2-3].The Proposed antenna has plenty of benefits related to these references. According to it, size of the proposed antenna has been fallen 74% and 44% related to [2], [3] respectively. It is also noticeable that bandwidth of the proposed antenna has been risen 20% and 50% related to [2], [3] in order. The last advantage of the antenna is three notches that in both of the references is a notch. At first, the effect of varying radius R_3 on VSWR for three cases is studied. Figures 4a to 4c illustrate the effect of varying radius R_3 on VSWR in the form of a notch (a), two notches (b), and three notches (c) respectively. From Figs. 4 can be concluded parameter R_3 which has an independent effect on lower notched band. On the other hand, other notches have not major effect on the first notched band and this subject makes easy design of the antenna. As previously expected, by increasing radius R_3 the notched-band frequency is decreased and vice versa. Last point in Figs. 4 is related to amount of frequency shift in a way that for Fig. 4a, in case of one notch, by varying R_3 frequency shift is more than 1GHz, while in Figs. 4b and 4c is not same. The best value to filter WiMAX band interference, 3.4 up to 3.69 GHz, is 7.8 mm.

In Fig. 5 the design procedure of notch on middle band in two cases (a), and (b) has been exhibited. As shown in Fig. 5, it is found that the second notch on middle band is independent from other notches; it means that by varying R2 the second notch is just shifted, while other notches on lower and upper band are constant. Amount of frequency shift for proposed antenna in case (b) is more than case (a). The desired value to filter WLAN and WiMAX bands interference, 5.15 up to 5.85 GHz, is 5.2mm.

Figure 6 exhibits VSWR for different values of R_1. The best value R_1 to filter ITU band interference, 8.025-8.4 GHz, is 3.5mm. The proposed antenna has been implemented based on the dimensions presented in Table I. The VSWR of the proposed antenna has been measured using an Agilent E8362B network analyzer in its full operational span (10 MHz-20 GHz). The simulated and measured VSWR of the fabricated antenna are depicted in Fig. 7.

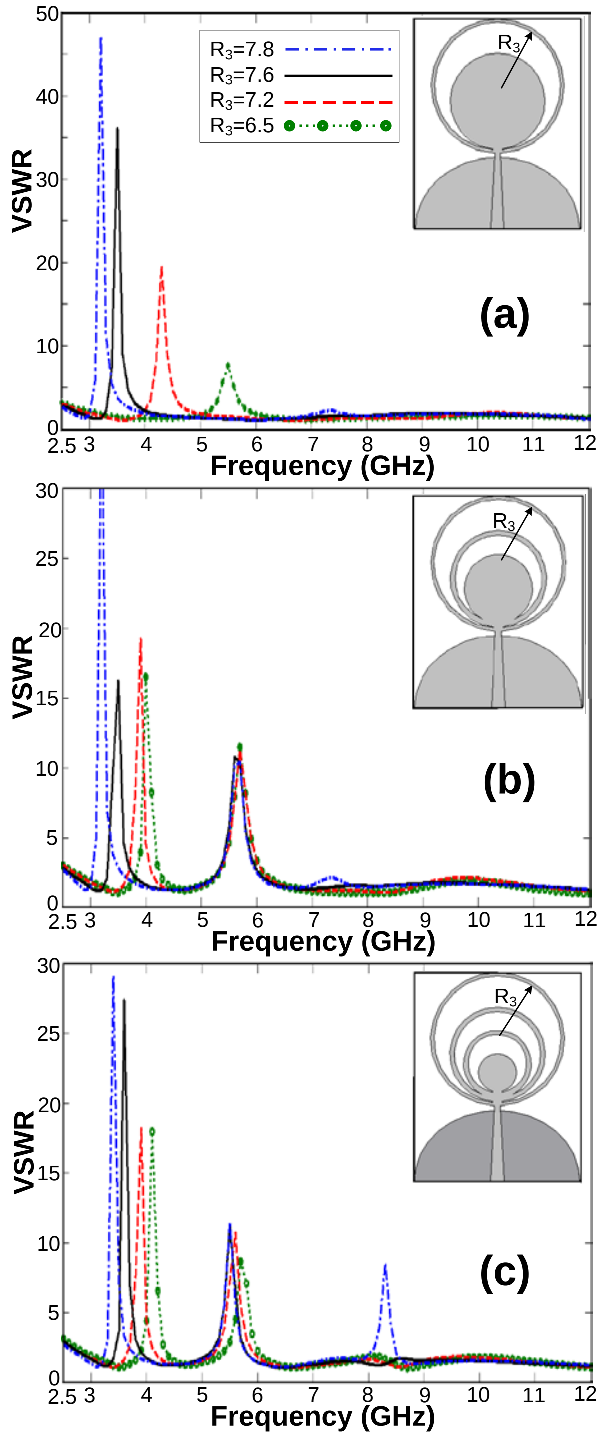

Fig. 4. The design procedure of the notch on lower band and Simulated VSWRs for different values of R_3 in three cases (a), (b) and (c).

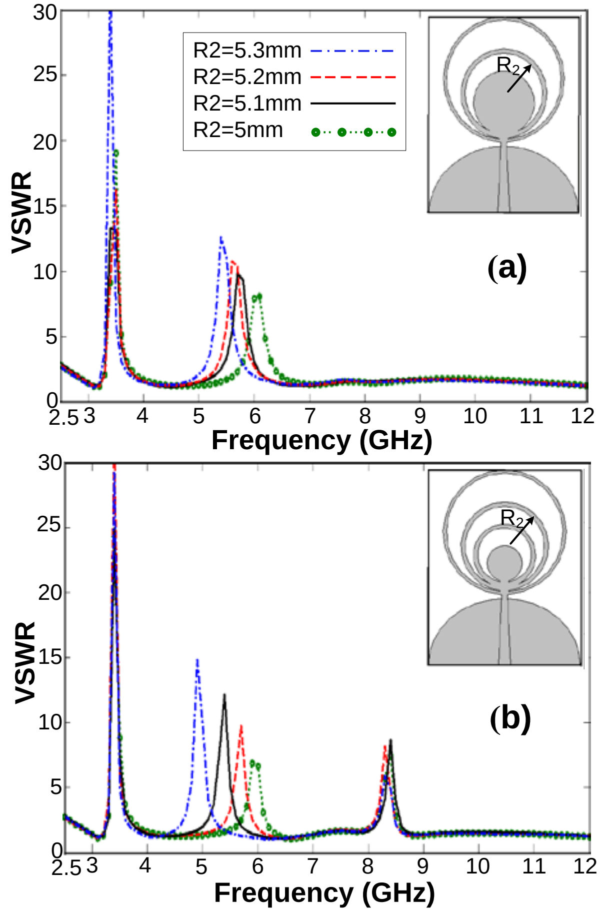

Fig. 5. The design procedure of notch on middle band and Simulated VSWRs for different values of R_2 in two cases (a), and (b).

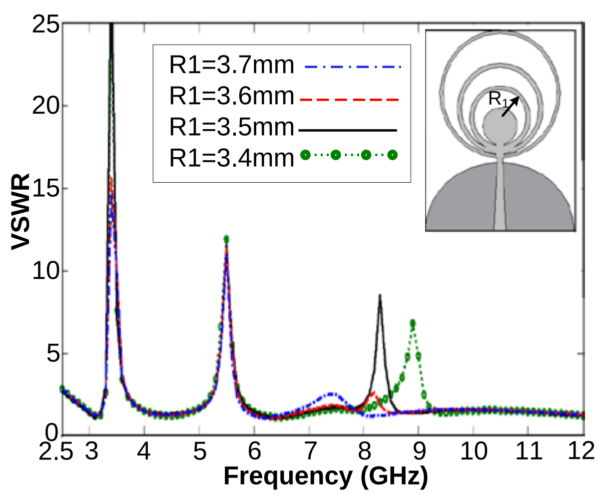

Fig. 6. Simulated VSWR for different values of R_1.

Moreover, Fig. 7 to compare the VSWR results between the proposed antenna and referenced circular monopole antenna has been presented. This point should be again repeated which each circular ring corresponds to a notch. It can be observed that the antenna has a wideband performance of 3.05 to more than 20GHz for VSWR≤ 1.7. Besides, the impedance bandwidth consists of three notched bands of 3.26-3.76, 5.14-5.87, and 8-8.5 GHz. It is apparent that the presented antenna can be used for higher frequencies above the FCC band. This behavior almost was predicted from HFSS based on the finite element method (FEM). Good agreement between simulated and measured results is observed and a bit difference between them is attributed to factors such as inappropriate quality of the microwave substrate effects, fabrication imperfections, and SMA connector.

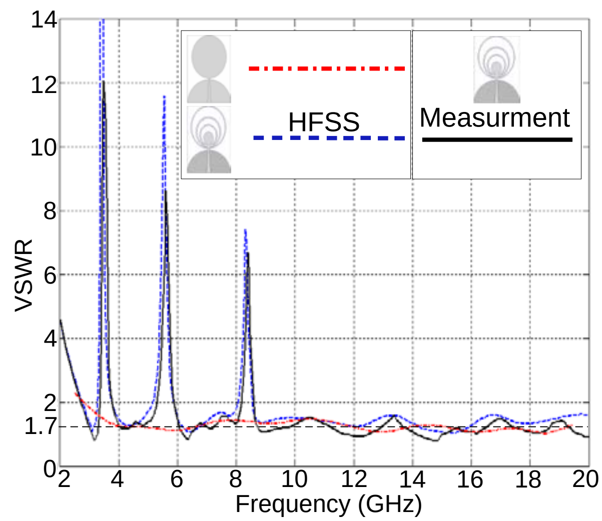

Fig. 7. Measured and simulated VSWRs of the proposed antenna.

C. Time-Domain Analysis

In this portion, more is used from CST software to analyse the antenna in time domain. In UWB systems, the information is transmitted using short pulses. Hence, it is important to study the temporal behavior of the transmitted pulse. The communication system for UWB pulse transmission must limit distortion, spreading and disturbance as much as possible. Group delay is an important parameter in UWB communication, which represents the degree of distortion of pulse signal. The key in UWB antenna design is to obtain a good linearity of the phase of the radiated field because the antenna should be able to transmit the electrical pulse with minimal distortion. The group delay is usually used to evaluate the phase response of the transfer function because it is defined as the rate of change of the total phase shift with respect to angular frequency. Ideally, when the phase response is strictly linear, the group delay is constant.

$$\text{group delay} = -\frac{d\theta(w)}{dw} \tag{1}$$

As depicted from Fig. 8, the group delay variation is less than 1ns over the frequency band without notched bands which ensure us pulse transmitted or received by the antenna will not distort seriously and will retain its shape.

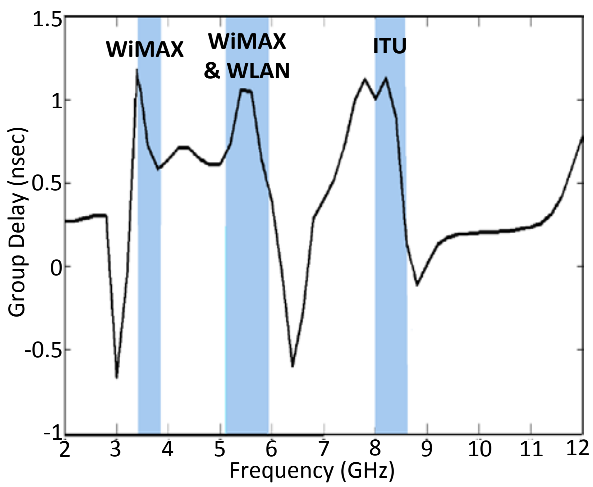

Fig. 8. Simulated group delay versus frequency for the proposed antenna.

As expected before, the groups delay variation at notches from 3.4-3.69GHz, 5.15-5.85GHz, and 8.025-8.4 GHz for WiMAX, WLAN, and ITU bands with respect to other frequencies is much. In spite of it, therefore, the proposed antenna is suitable for modern UWB communication systems. Transient response of the antenna is studied by modeling the antenna by its transfer function. The transmission coefficient S_{21} was simulated in the frequency domain for the face-to-face orientation. Figure 9 shows the magnitude of measured S_{21} for the face-to-face and side by side orientations. As it is apparent, S_{21} plot is almost flat with variation less than 15dB in the operating band. The reason of three tangible resonances in S_{21} plot is due to three notches WiMAX, WLAN, and ITU bands.

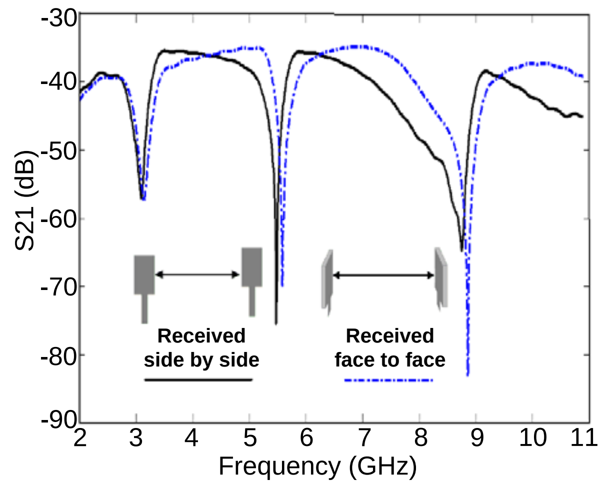

Fig. 9. Simulated S_{21} with a pair of identical antennas for face to face and side by side orientations.

Phase of S_{21} the face to face and side by side orientations has been plotted, also and is shown in the Fig. 10. As previously expected, the plot shows a linear variation of phase in the total operating band except notched bands.

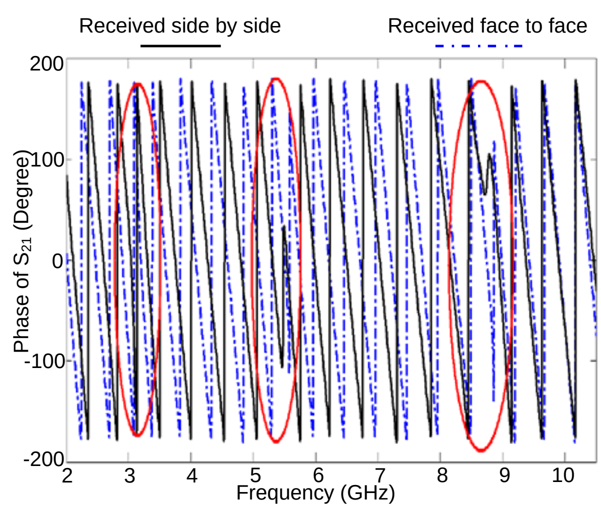

Fig. 10. Simulated Phase of S_{21} for face to face and side by side orientations.

The transfer function is transformed to time domain by performing the inverse Fourier transform. Fourth derivative of a Gaussian function is selected as the transmitted pulse.

Therefore the output waveform at the receiving antenna terminal can be expressed by convoluting the input signal and the transfer function. The input and received wave forms for the face-to-face and side-by-side orientations of the antenna are shown in Fig. 11.

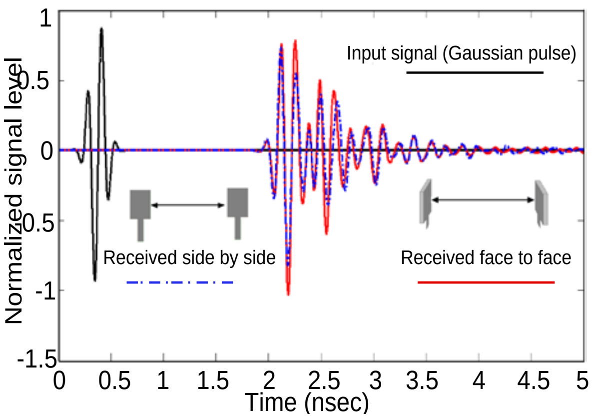

Fig. 11. Simulated transmitted and received pulses by the simulator CST.

It can be seen that the shape of the pulse is preserved in all the cases. Only due to being three notches, there is a bit distortion on received pulses which it was predictable. Using the reference and received signals, it becomes possible to quantify the level of similarity between signals. In telecommunication systems, the correlation between the transmitted (TX) and received (RX) signals is evaluated using the fidelity factor (1)

$$F = max_{\tau} \left| \frac{\int_{-\infty}^{+\infty} S(t) r(t-\tau) dt}{\sqrt{\int_{-\infty}^{+\infty} S(t)^2 \cdot \int_{-\infty}^{+\infty} r(t)^2 \, dt}} \right| \quad (2)$$

Where S(t) and r(t) are the TX and RX signals, respectively. For impulse radio in UWB communications, it is necessary to have a high degree of correlation between the TX and RX signals to avoid losing the modulated information. However for most other telecommunication systems, the fidelity parameter is not that relevant. In order to evaluate the pulse transmission characteristics of the proposed UWB antenna with triple band-notches, two configurations (side-by-side and face-to-face orientations) were chosen. The transmitting and receiving antennas were placed in a d=0.5 m distance from each other. As shown in Fig. 11, although the received pulses in each of two orientations are broadened, a relatively good similarity exists between the RX and TX pulses. Using (1), the fidelity factor for the face-to-face and side-by-side configurations were obtained equal to 0.72 and 0.7, respectively. Values the fidelity factor show that the antenna imposes negligible effects on the transmitted pulses. The pulse transmission results are obtained using CST.

D. Radiation Characteristics

The y-z plane and the x-z plane are selected to show the antenna radiation patterns referred to as E-plane and H-plane, respectively. Figure 12 illustrates the antenna normalized radiation pattern at E-plane and H-plane at 4.2, 7, and 9 GHz.

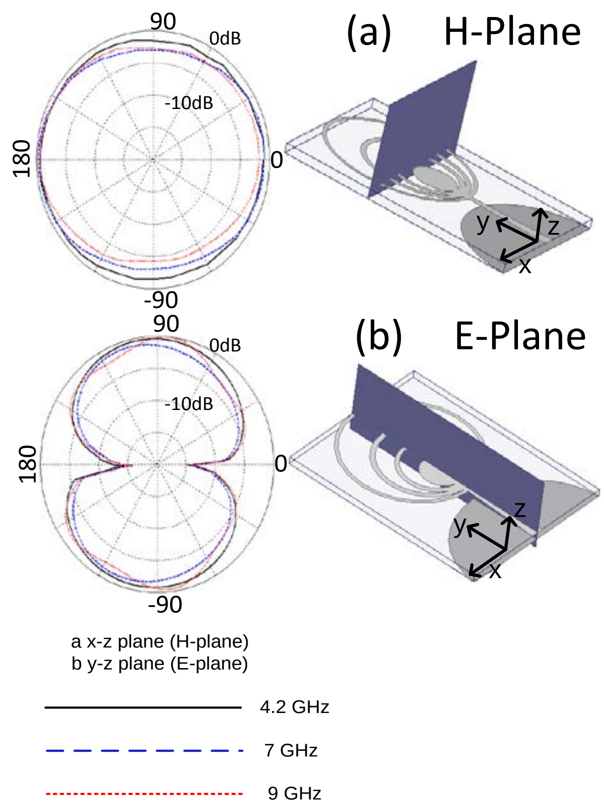

Fig. 12. Measured normalized radiation pattern of the antenna.

It can be seen that the antenna has a nearly omni-directional radiation pattern in the H-plane and a dipole-like radiation pattern in the E-plane in the very wide frequency band. Figure 13 exhibits the measured gain of the antenna. It is quite clear that the antenna gain decreases down to -4 dBi at three WLAN, WiMAX, and ITU bands indicating the effect of the notched bands clearly.

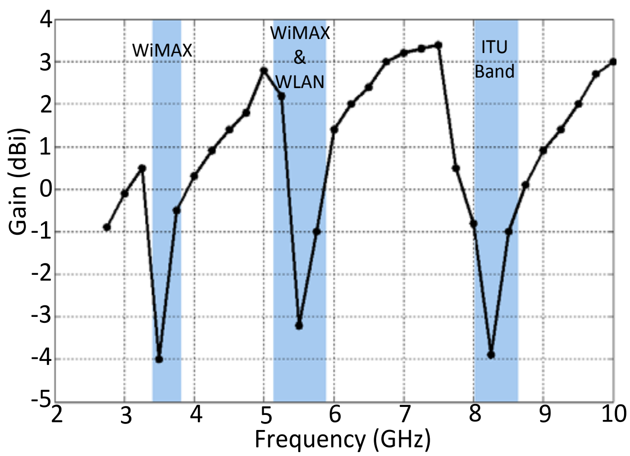

Fig. 13. Measured gain versus frequency for the proposed antenna.

IV. CONCLUSION

A novel compact UWB printed monopole antenna with triple notched bands has been proposed. Three band-notching structures, including three circular rings, are exploited to obtain the aimed for rejection bands. By enhancing the number of circular rings, the number of notched bands can be increased easily. In addition, by changing the thickness of rings, the bandwidth of notched bands can be tuned. Moreover, sufficient bandwidth and good monopole-like radiation patterns are observed.

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