A Compact Planar Ultra Wideband Antenna with Triple-Notched Bands Using Capacitive Coupled and Parallel LC Elements

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Abstract **—** Overlapping of frequency bands such as Worldwide Interoperability for Microwave Access (WiMAX), Wireless Local Area Network (WLAN) and International Telecommunication Union (ITU) bands with Ultra Wide Band (UWB) cause serious interference problems. As an attempt to reduce the effect of this coexistence, a triple band-notched monopole antenna is presented. A modified semi ellipse element with two I-shaped slots is used as the ground plane. A U-shaped slot, a pair of inverted L-shaped strips, and a modified G-slot structure which act as parallel LC circuit and capacitive-coupled elements, are embedded in feed line and radiation patch to create the triple band notch characteristics. The notched bands position can be controlled by tuning the dimensions of the foregoing filtering elements. The proposed antenna has been fabricated and measured. According to the measured results, the antenna operates over the frequency band of 2.5-16.5 GHz with three notched bands at the 5-6.2 GHz (WLAN), 3.1-4 GHz (WiMAX), and 7.15-8.1 GHz (X-band).

Index Terms **—** Capacitive-coupled elements, parallel LC circuits, triple band-notched antenna, Ultrawideband (UWB) antenna.

I. INTRODUCTION

Among the printed UWB antenna designs, the planar monopole antennas have gained great popularity due to their attractive characteristics such as wide impedance bandwidth (BW), simple structure and omni-directional radiation patterns [1]–[5], along with multitasking capabilities such as multiband and multi notched applications. However, due to the existence of many narrow frequency bands such as HIPERLAN/2 WLAN operating in the 5.15-5.825 GHz band, wireless local-area network (IEEE 802.11a), WiMAX IEEE 802.16 operating in the 3.3-3.7 GHz [3], and X-band in the 7.25-7.75 GHz over the UWB frequency range and the consequent interference problem, the need for techniques to filter the foregoing bands from UWB has been emerged. Band notched antennas, a new category of antenna structures, have been proved as a promising solution to the interfering problem. Many researches have been carried out and different techniques have been proposed to reach the filtering property. Embedding various geometrical shaped slots on the radiation patch [1], inverted L-, G-, and Γ-shaped strips, modified G-slot structures, rectangular subs and parasitic elements, are some of these techniques to suppress the dispensable bands [1], [4], [6].

This paper aims to design a novel antenna with triple band notched capability with increasing the bandwidth. By using the modifying ground plane and radiation patch, the bandwidth of antenna is increased. First, two symmetrical I-shaped slots are inserted on the ground plane with bandwidth enhancement purpose. Then, to achieve the filtering characteristics and improve the antenna bandwidth, U-shaped slot, two symmetrical inverted L-shaped strips, and a modified G-slot structure are added to the antenna structure. The mentioned elements act as parallel circuit and capacitive-coupled elements. The notched frequency bands are generated in the 5-6.2 GHz (WLAN), 3.1-4 GHz (WiMAX), and 7.15-8.1 GHz (X-band) over the 2.5-16.5 GHz (152%) operating frequency band. These may be controlled by changing the dimensions of the filtering structures. The rest of the paper will be as follows: Section II discusses the antenna design process. The simulated and measured results and discussion on them are presented in Section III.

II. ANTENNA DESIGN AND CONIFURATION

Figure 1 shows the geometrical configurations of the proposed antenna, which consists of a semi-ellipse shaped ground plane with two symmetrical I-shaped slots. The antenna is implemented on cheap FR4-epoxy substrate with a compact size of 19×22×1 mm^3 and permittivity of 4.4. To achieve 50-ohm characteristic impedance, the length (L_f) and width (W_f) of the μ-strip feed line are fixed at 5.7 mm and 1.95 mm respectively. To analyze the antenna precisely, the antenna design is explained in Fig. 2 in five steps. These structures have been analyzed using Ansoft High Frequency Structure Simulator (HFSS). Figure 3 shows the S_{11} and VSWR curves for Antenna 1-5. It can be observed from Fig. 3

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that, the antenna 1 has poor VSWR in the frequency range of 10-15 GHz frequency. Therefore to improve the impedance matching in the frequency range of 10-15 GHz, two I-shaped slots in the ground plane is embedded. Then, by using of modifying radiation patch, triple band notch antenna created and the impedance matching at the upper edge frequency is improved. As shown in Fig. 2, the addition of the I-shaped slots on the ground plane leads to the excitation of new resonances and bandwidth enhancement. As it is depicted in Fig. 2, U-shaped slot, two symmetrical inverted L-shaped strips, and a modified G-slot structure are embedded in Antenna 3; Antennas 4 and Antenna 5 which realize the notched bands in WLAN, WiMAX and X-band respectively. According to the results, the proposed triple band notch antenna structure covers the frequency band from 2.5 to 16.5 GHz with VSWR<2 (S_{11}< -10 dB) and the band notch frequencies covering the 5-6.2 GHz, 3.1-4 GHz, and 7.15-8.1 GHz.

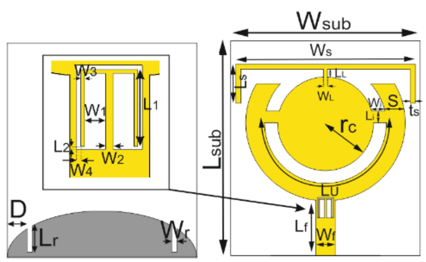

Fig. 1. Configuration of the proposed triple band-notched antenna: W_{sub}=19, L_{sub}=22, W_f=1.95, L_f=5.7, W_i=1.35, L_i=1.2, W_L=0.4, L_L=0.8, W_s=18, L_u=19, t_s=0.5, L_s=4, W_1=0.5, W_2=0.2, W_3=0.1, S=1.95, W_4=0.1, L_1=1.93, L_2=0.07, W_r=0.5, L_r=2.7, D=2, r_c=4.8; (all dimensions are expressed in mm).

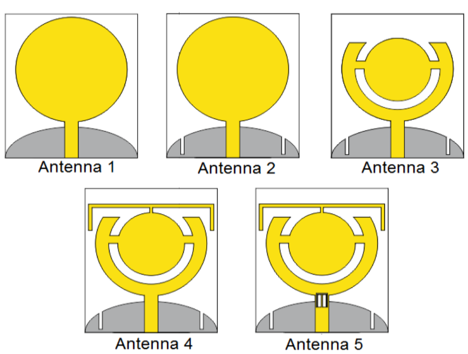

Fig. 2. The antenna design process.

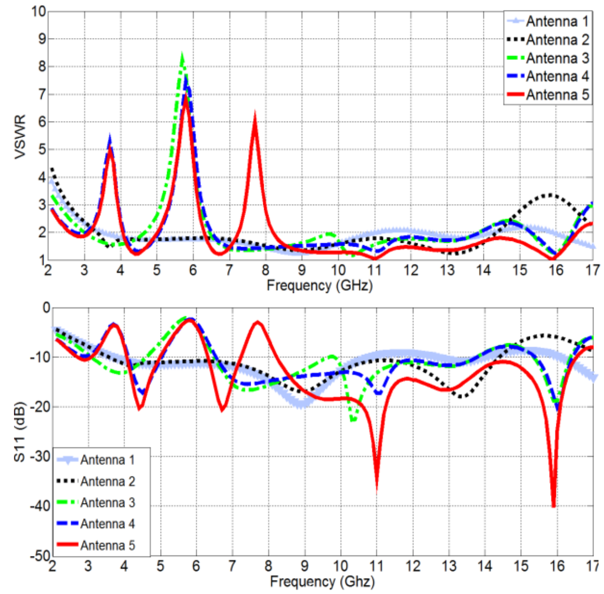

Fig. 3. S_{11} and VSWR curves for Antenna 1-5.

III. RESULTS AND DISCUSSION

A. Full band antenna

In this section, the bandwidth enhancement process to reach the full band antenna is studied in detail. As it was mentioned earlier, the basic structure of the proposed UWB antenna is composed of a circular radiation patch and a semi-ellipse shaped ground plane with a pair of I-shaped slots. As the insertion of the I-shaped slots helps the bandwidth enhancement, it is expected that antenna performance be a function of the I-shaped slots dimensions, named as L_r and W_r. Figure 4 shows simulated VSWR curves for different values of L_r and W_r. It is seen that even in the case that there is no slot on the ground plane, the UWB frequency band is covered. By inserting the slots and tuning their dimensions, upper edge frequency has been noticeably tended toward higher frequency bands, leading to bandwidth improvement. The lower edge frequency is remained almost constant and seems to be insensitive to this change. The widest bandwidth is obtained when L_r=2.7 mm and W_r=0.5 mm. To have a deeper insight of the antenna bandwidth enhancement process, surface current distribution is shown in Fig. 5. It is seen that at 13.2 GHz, where the new resonance is appeared, the current is concentrated around the two I-shaped slots, leading to performance improvement.

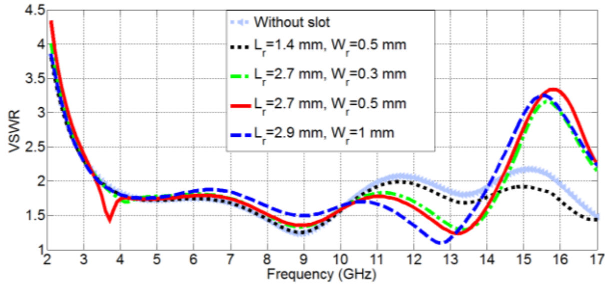

Fig. 4. Simulated VSWR curves of proposed antenna for different values of L_r and W_r.

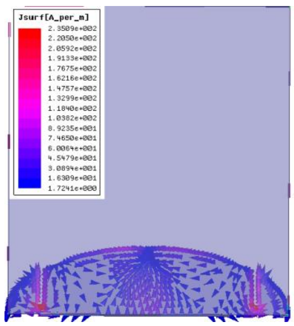

Fig. 5. Simulated current distribution on the ground plane at 13.2 GHz.

B. UWB monopole antenna with three band notched frequency characteristics

To obtain the band-notched functions, the concept of the parallel LC circuit is applied. In this technique, the desired impedance mismatch near the notch frequency may be achieved by increasing the input impedance [2]. In this antenna, the first notched band at 3.6 GHz, the second notched band centered at 5.7 GHz and the third notched-band functions at 7.15-8.1 GHz are realized using a pair of symmetrical inverted L-shaped strips at the top of the circular patch, a U-shaped slot inside the patch and a modified G-slot structure respectively as shown in Fig. 1. The modified G-slot acts as a parallel LC circuit. Hence, just by adjusting the capacitor and inductor values the desired notched frequency bandwidth can be achieved. Figure 6 shows the simulated current distribution at the centre of the three notch bands. As shown in Fig. 6 (a), where U-shaped slot is embedded in the antenna structure, the surface currents are more dominant around the slot and they are oppositely directed between the interior and exterior edges. Therefore, at the vicinity of the desired notch frequency the resultant radiation fields override, and high attenuation is produced. Figure 6 (b) shows the current distribution at 3.6 GHz, where by the addition of two inverted-L shaped elements, the first notched band is obtained. According to the results, the current flows in opposite directions at two edges of the inverted L-shaped strips leading to filtering mechanism [6]. Results in Fig. 6 (c) show that the surface current distribution at 7.6 GHz is disturbed around G-shaped slot and as a consequence, the frequency range of 7.15-8.1 GHz is blocked.

To investigate the parameters variation effects on the antenna performance, a parametric study is carried out. The position of the notched 5 to 6.2 GHz depends on the length of L_u. Figure 7 studies the VSWR curves for different values of L_u. When length of L_u is increased, the notched band moves toward lower frequencies and when L_u is fixed at 19 mm, the complete blockage is reached. The dependency of the position of the notched band from 3.1 to 4 GHz to L_s is shown in Fig. 8. It is clearly seen that when length of L_s is increased, centre of the notched band tends to the lower frequencies. The third notched band from 7.15 to 8.1 GHz depends on the values of L_1 and W_1. Figure 9 shows the VSWR curves for different values of L_1 and W_1. The results show that when L_1=1.95 mm and W_1=0.5 mm, the best performance is obtained.

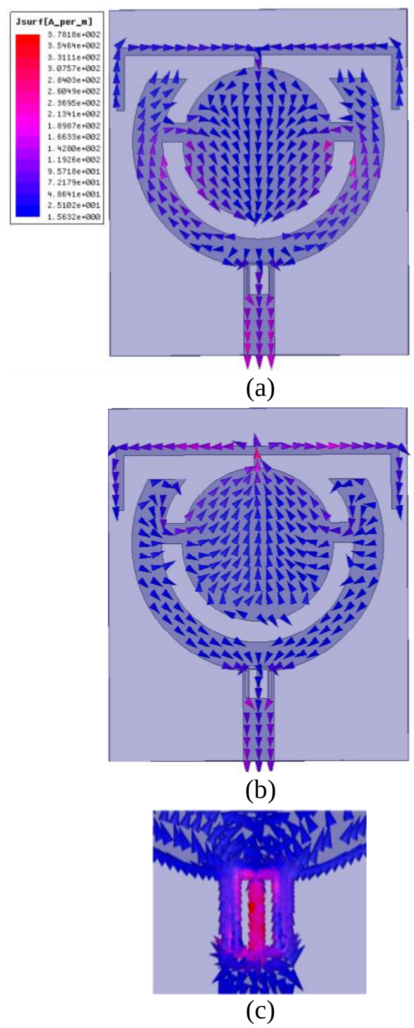

Fig. 6. Simulated current distribution on the radiation patch at: (a) 5.7 GHz, (b) 3.6 GHz, and (c) 7.6 GHz.

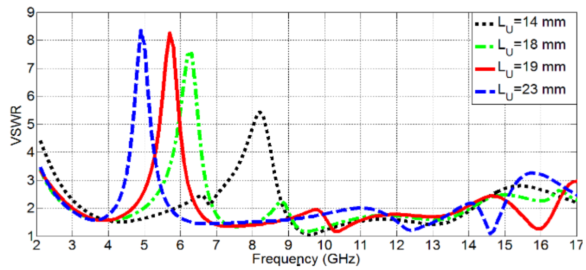

Fig. 7. Simulated VSWR curves for different values of Lu.

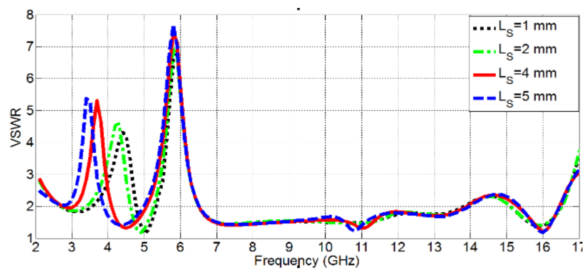

Fig. 8. Simulated VSWR curves for different values of Ls.

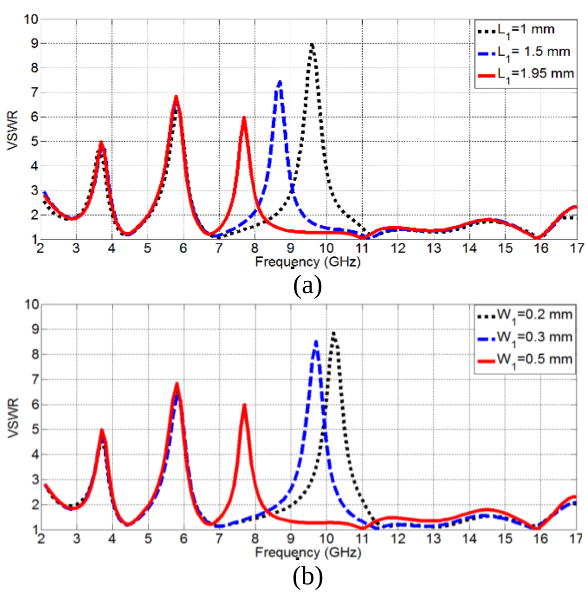

Fig. 9. Simulated VSWR curves for different values of: (a) L1 and (b) W1.

C. Measured results

The antenna with the given parameter values in Fig. 1, has been fabricated and is shown in Fig. 10. The fabricated prototype has been measured to validate the results from simulation. Agilent 8722ES network analyser has been used. The simulated and measured VSWR results of the proposed triple band-notched antenna are illustrated in Fig. 10. VSWR is a function of the reflection coefficient, which describes the power reflected from the antenna. If the VSWR is under 2, the antenna match is very good. As VSWR increases, more power is reflected to the radio and the antenna has poor impedance matching. Figure 10 shows that the proposed antenna has the acceptance VSWR curves over the frequency bands and has poor impedance matching at the notch frequency bands at 3.6, 5.7, and 7.6 GHz. Measured radiation patterns of antenna at 4.2 GHz, 6.3 GHz, and 12 GHz sample frequencies are plotted in Fig. 11. As shown in Fig. 11, omnidirectional radiation patterns with low cross polarization levels are obtained which are suitable for UWB applications. Gain of the antenna has been measured and is shown in Fig. 12. The simulated and measured gain from 2.5 to 16.5 GHz indicates acceptable and flat gain with variation less than 3 dB except for three notched bands. The group delay for the proposed antenna with 10 cm separation between two similar antennas as receiver and transmitter, was simulated in Fig. 13. Group delay variation less than 0.3 ns over the entire band except for notched bands ensure a good performance for the proposed antenna.

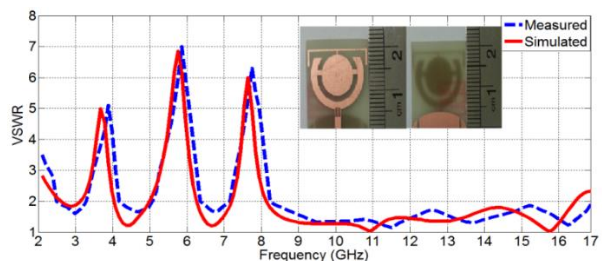

Fig. 10. Simulated and measured VSWR of the proposed antenna.

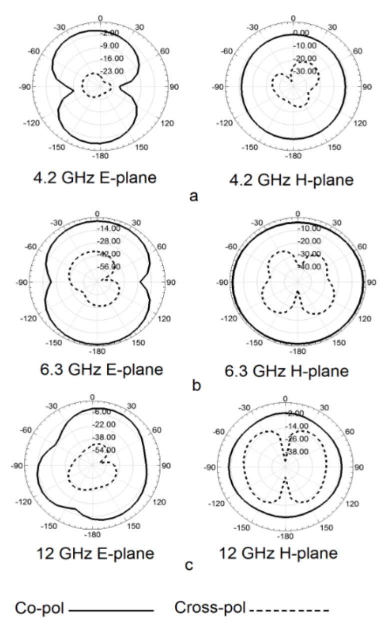

Fig. 11. Measured E-plane and H-plane radiation pattern for: (a) 4.2 GHz, (b) 6.3 GHz, and (c) 12 GHz.

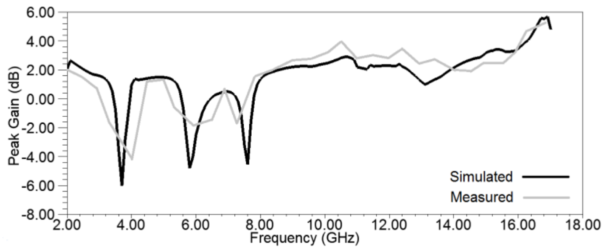

Fig. 12. Simulated and measured peak gain of the proposed triple band notch monopole antenna.

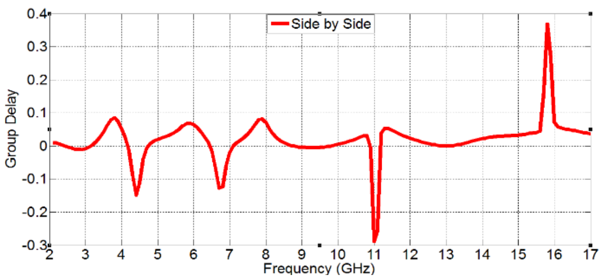

Fig. 13. Simulated group delay for side by side orientation.

IV. CONCLUSION

A printed UWB monopole antenna with triple band notched characteristics has been presented. The novelty of the proposed antenna is the antenna shape, size, and bandwidth. By using the modifying ground plane and modifying radiation patch, impedance matching is increased and the three notched frequency bands are achieved. The proposed antenna has a very small size of 19×22×1 mm^3 and operates over the frequency range of 2.5-16.5 (152%) GHz with triple band notched characteristics at 5-6.2 GHz (WLAN), 3.1-4 GHz (WIMAX) and 7.15-8.1 GHz (X-BAND). A parallel LC circuit is used to produce impedance mismatching at the desired frequencies.

The simulated and measured results are in good agreement with each other. The results certify this antenna as a promising candidate for UWB systems that is able to cancel the interference of three bands. The presented antenna is equipped with salient features such as wide bandwidth, multi-notch functions and a constant gain that highlight the potential of the studied antenna for multi task systems.

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