Tunable Band-Notched UWB Antenna from WLAN to WiMAX with Open Loop Resonators using Lumped Capacitors

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Abstract **─** The proposed antenna in this paper is compact UWB monopole antenna with a rectangular patch consists of stepped cuts and triangular slot. A two open loop resonators are designed and added near microstrip feed line to achieve sufficient band rejection from 5.1 GHz to 6.5 GHz for avoiding interference with WLAN frequency bands. The proposed antenna has low profile and compact size, its size equals 3.2 x 3.2 cm^2. It has bandwidth from 3.1 GHz to 19.3 GHz with voltage standing wave ratio (VSWR) < 2, except the undesired band of 5.1–6.5 GHz. Two-lumped capacitors are inserted in order to investigate the ability of tuning the resonance frequency of the band-notched structures from 5.6 GHz to 3.5 GHz. Finally, the layout of the proposed UWB monopole antenna with the notched band is experimentally fabricated and measured to verify the simulation results. Furthermore, the return loss and far-field measurements of the fabricated antenna exhibit good match with simulation predictions.

Index Terms **─** Lumped capacitors, notched characteristic, open loop resonator, UWB monopole antenna.

I. INTRODUCTION

The congestion of the frequency spectrum and the interference of various communication systems are considered the most important problems due to the advancement of wireless systems and the sustainable demand for improving the operation bandwidth [1]. Commercially, the development of the ultra-wideband systems is evident after the allocation of frequency band 3.1–10.6 GHz by the Federal Communications Commission (FCC) for that purpose [2-8].

There are many wireless communication systems operating in the UWB frequency range (3.1-10.6) GHz such as at 5.15-5.85 GHz and 3.3-3.8 GHz for Wireless Local Area Network (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX) respectively. The previous systems cause interference with the UWB systems and degrade the overall performance. Hence, an UWB antenna with band rejection characteristic is desired [9-17].

In order to eliminate the interference, the UWB antenna should be integrated with external band-stop filters, which in turn will increase size, cost, and complexity of the system. Consequently, the demand for compact antenna with band-notched characteristics became necessary [18]. Furthermore, the theory behind creating the band-notched characteristics with UWB antennas is like using resonators in multiband antennas to increase the number of frequency bands [19]. Different methods such as etching slots with various shapes in the microstrip feed-line [20, 21], loading resonators etched on the radiator [19, 21-24] or on the ground plane [25], loading parasitic elements of different shapes behind the truncated ground plane [26], and utilizing EBG structures [27] have been addressed to obtain UWB operation with the capability of band rejection.

In this paper, a single band-notched monopole antenna for UWB operation is introduced. The UWB monopole antenna with stepped cuts and partial slotted ground plane is designed firstly, which exhibits radiating characteristics in the frequency range 3-19 GHz. Two open loop resonators are mounted on the substrate behind the microstrip feed line and the radiator to achieve the band-notched functionality at the operating band of WLAN applications. The proposed UWB antenna with stop band behavior is fabricated on low cost substrate and then measured in order to verify the simulation results. To tune the resonance frequency of band-notched structure from the operating band of WLAN to the operating band of WiMAX, two lumped capacitors are used. Commercial software HFSS 13 is employed to simulate the proposed antenna.

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II. DESIGN PROCEDURES

A. UWB antenna configuration

The designed UWB monopole antenna is fed by 50 Ω microstrip line and is printed on epoxy FR4 substrate with 4.4 relative permittivity, 0.02 loss tangent and 1.5 mm thickness ‘h’.

The antenna is designed to achieve the desired UWB performance. Subsequently, different procedures are introduced in order to achieve the desired design. First of all, monopole antennas with partial ground plane and triangle slot in the radiator patch are designed (case I and case II) to produce UWB behavior as shown in Fig. 1. However, this design has frequency band from 3 GHz to 10 GHz with VSWR lower than 2 as shown in Fig. 2. In order to extend the frequency band from 3 GHz to 13 GHz, the case III with triangle slot in the patch radiator and simple U slot in the ground plane are utilized. Also the matching bandwidth of the UWB antenna can be improved by using three steps in the radiator patch as shown in case IV. The bandwidth of case IV is extended to operate at frequency band from 3 GHz to 19 GHz as illustrated in Fig. 2. Finally, the proposed antenna (with/without triangle slot) is integrated with two open loop resonators to achieve a single notch frequency for interference mitigation with the WLAN applications (case V & VI). It can be noticed from Fig. 2 that the behaviour of case V is the same as case VI except the frequency range from 14.6 to 16.3 GHz. So, case VI is chosen as the proposed model for band-notched UWB antenna.

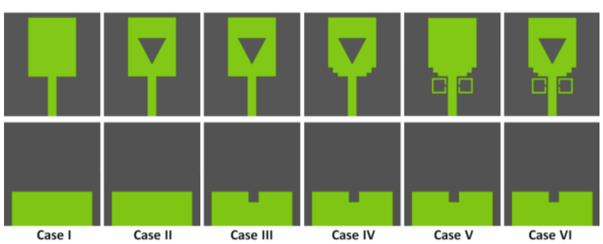


Fig. 1. Design procedures of the proposed UWB antenna.

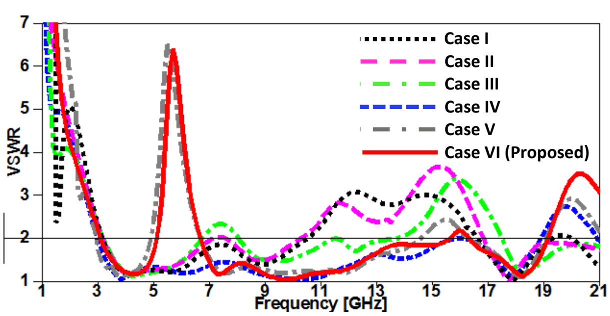


Fig. 2. VSWR of the UWB antenna at different cases.

The total length of the utilized resonator to be resonating at the WLAN frequency band should be half the guided wavelength of the rejection frequency [28, 29] as the following equations:

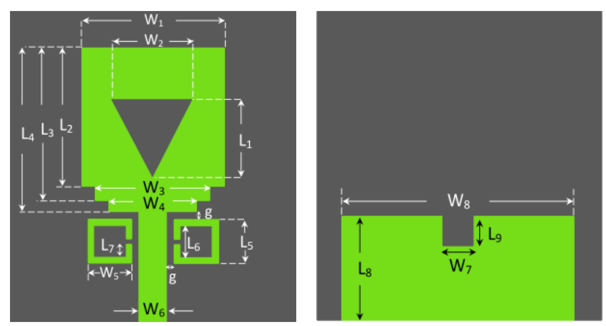
$$L_{total} \approx \frac{\lambda_g}{2} = \frac{c}{2\, f_{notch}\sqrt{\varepsilon_{eff}}}, \tag{1}$$

$$\varepsilon_{eff} \approx \frac{\varepsilon_r + 1}{2}. \tag{2}$$

The VSWR which is shown in Fig. 2 for case VI illustrates the UWB behavior of the proposed antenna with band-notch from 5 GHz to 6.5 GHz.

B. Parametric study of band-notched UWB antenna

The layout of the proposed UWB antenna is demonstrated in Fig. 3. The optimized dimensions of antenna are tabulated in Table 1. The antenna is composed of monopole antenna with three steps stepped cut, triangle slot in the radiating patch and two open loop resonators near the microstrip feed line. Also, the ground plane has simple slot as shown in Fig. 3. To understand the effects of the resonator gap (g), width (W_5) and length (L_7) on the impedance matching characteristics, parametric studies are carried out.



(a) (b)

Fig. 3. 2-D layout of WLAN band-notched UWB antenna: (a) top and (b) bottom view.

Table 1: Design parameters of the proposed band-notched UWB antenna

Parameter	L_1	L_2	L_3	L_4	L_5	L_6
Value (mm)	7.5	14.5	16	17	4.5	3.4
Parameter	L_7	L_8	L_9	W_1	W_2	W_3
Value (mm)	1.4	10	3	15	8.66	12
Parameter	W_4	W_5	W_6	W_7	W_8	g
Value (mm)	9	4.5	2.76	3	25	0.5

Figure 4 shows the VSWR at different gaps (g) of the band-notched resonator. It is clear that the gap (g) affects the position of the band-notched frequency. The position of the center frequency is shifted from 3.5 GHz to 5.6 GHz when the gap (g) is changed from 0.1 mm to 0.7 mm and we chose the gap (g) of 0.5 mm to achieve the desired band-notched characteristics. Figure 5 and

Fig. 6 illustrate the VSWR at different width (W_5) and length (L_7). It is obvious that the open loop resonator consists of parallel inductance (the overall length of the resonator) and capacitor (the gap between the resonator arms), so when the length and the width of the resonator are increased, the inductance of the resonator is increased. Consequently, the center frequency of the notched band is shifted down as shown in Fig. 5 and Fig. 6.

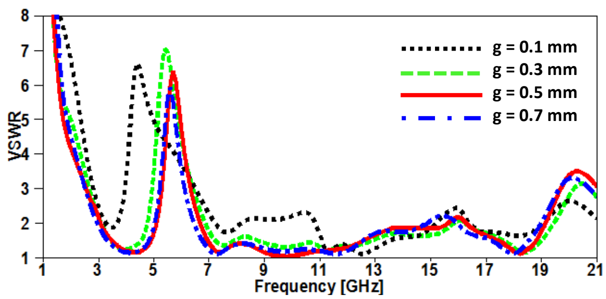


Fig. 4. Simulated VSWR at different gaps (g).

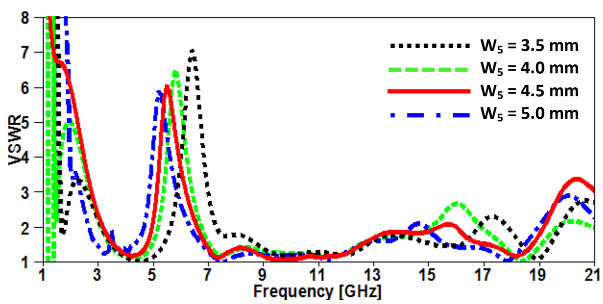


Fig. 5. Simulated VSWR at different widths of the open loop resonator.

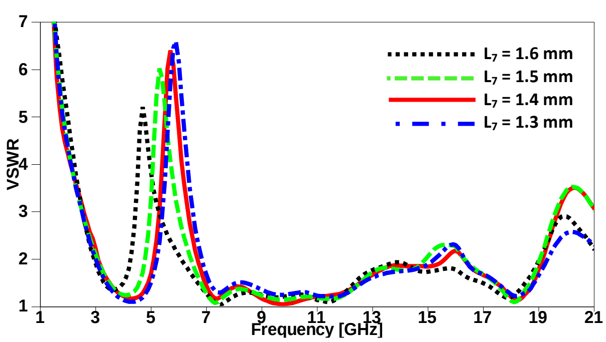
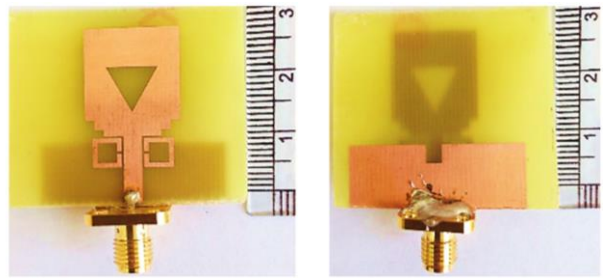


Fig. 6. Simulated VSWR at different lengths of the open loop resonator.

C. Results and discussions

A photograph of the fabricated UWB antenna is shown in Fig. 7. The antenna was tested for its VSWR characteristics using Agilent N9918A vector network analyzer (VNA), whereas the radiation pattern and gain were measured in an anechoic chamber. Figure 8 shows a comparison between the simulated and measured VSWR results of the band-notched UWB monopole antenna, where the practical results coincide with the simulation results over the whole bandwidth. It can be noticed that the two curves are all below 2 from 3.2 to 19.3 GHz except a rejection in the band from 5.1 to 6.5 GHz, which makes the presented antenna suitable for UWB applications without interfering WLAN applications.



(a) (b)

Fig. 7. Photographs of fabricated UWB antenna: (a) front view and (b) back view.

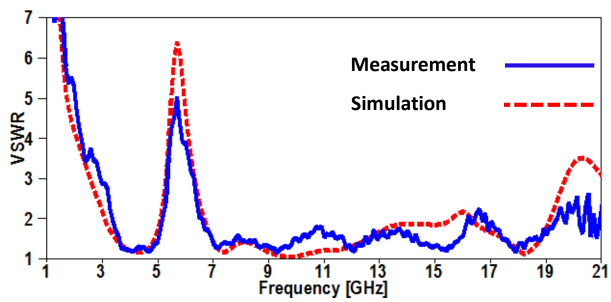


Fig. 8. The simulated and measured VSWR of the optimized structure against frequency.

III. PROPOSED TUNABLE UWB ANTENNA DESIGN

As discussed in the previous section, the center frequency of the notch can be controlled by changing both the inductance and the capacitance of the open loop resonator. By studying the electric field distribution at 5.6 GHz on the open loop resonator, it can be observed that the electric filed is concentrated around the open loop gap as shown in Fig. 9. By inserting lumped capacitor in the gap of the open loop resonator as shown in Fig. 10 (a), the center frequency of the notch can be tuned and controlled. In order to study the effect of the values of lumped capacitor on the proposed antenna response, a parametric study is carried out as illustrated in Fig. 11. It can be noticed from Fig. 11 that the central frequency of the notch is shifted from 5.6 GHz (without capacitor) to 2.9 GHz when lumped capacitors of 0.4 pF are used.

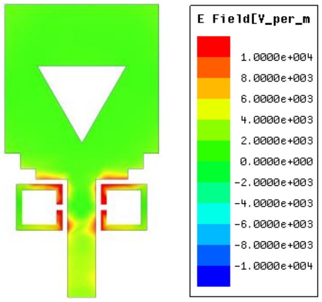
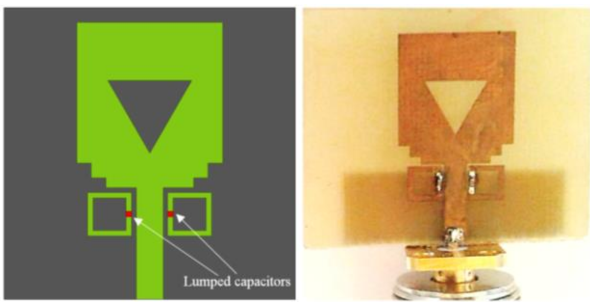


Fig. 9. Simulated electric filed distribution of antenna at 5.6 GHz.



(a) (b)

Fig. 10. The geometry of the proposed UWB antenna: (a) 2 D layout and (b) fabricated photograph.

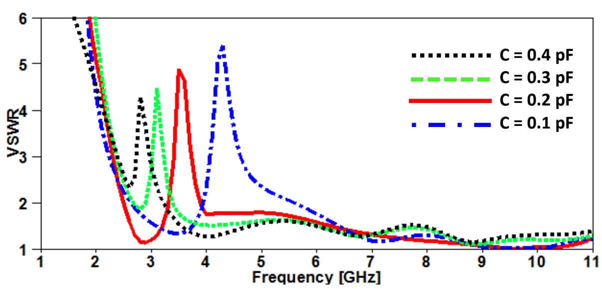


Fig. 11. The VSWR of the proposed antenna at different values of lumped capacitors.

The proposed UWB antenna has been simulated, fabricated, and tested using Agilent N9918A vector network analyzer (VNA). The fabricated photograph of the proposed antenna is illustrated in Fig. 10 (b). The VSWR of the antenna was measured and compared with the simulated one with lumped capacitors of 0.2 pF as demonstrated in Fig. 12. As depicted from the Fig. 12, there is a good consistency between simulated and measured VSWR but with small frequency shift due to the fabrication tolerance and misalignment of the welding process. Finally, it is concluded that the lumped capacitor can tune the center frequency of the notch from the WLAN operating band to WIMAX operating band.

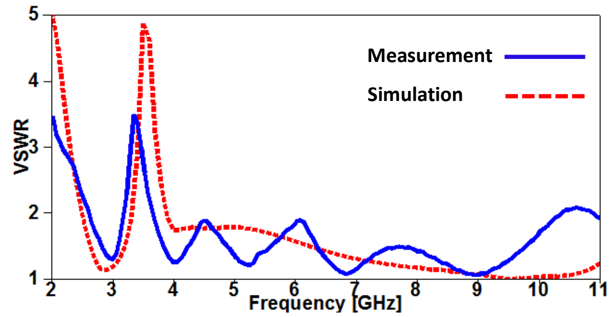
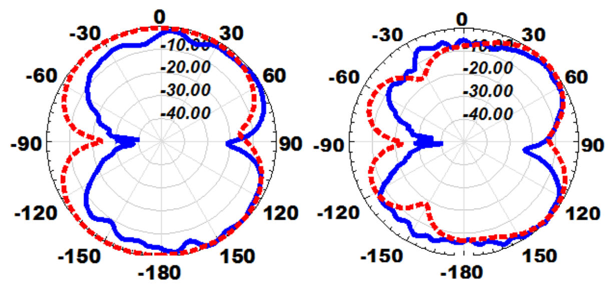
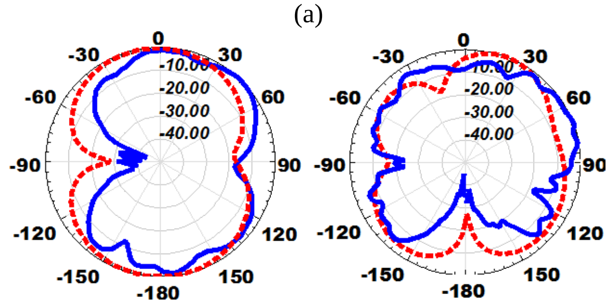


Fig. 12. The simulated and measured VSWR of the optimized structure against frequency with capacitor of 0.2 pF.



(a)



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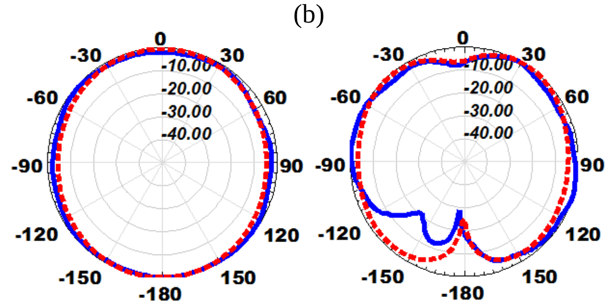

(c)

Measurement Simulation

Fig. 13. The simulated normalized radiation patterns at f = 4 GHz (left) and f = 9.3 GHz (right): (a) x-y plane, (b) y-z plane, and (c) x-z plane.

The normalized simulated and measured radiation patterns in x-z, y-z and x-y planes of the proposed antenna are shown in Fig. 13. It follows from Fig. 13 that the UWB monopole antenna has nearly omnidirectional patterns in x-z plane and almost bi-directional patterns in y-z and x-y planes. From the previous results, it is clear that the proposed antenna is convenient for UWB application.

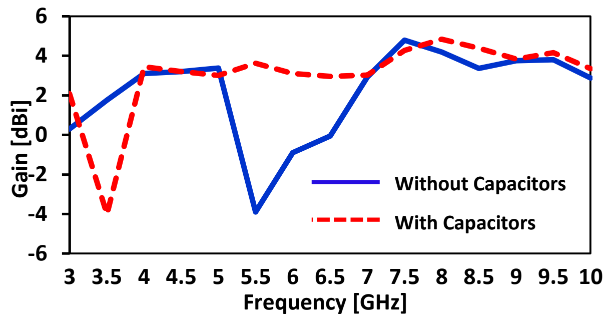

Fig. 14. The measured realized gain of the band-notched UWB antenna.

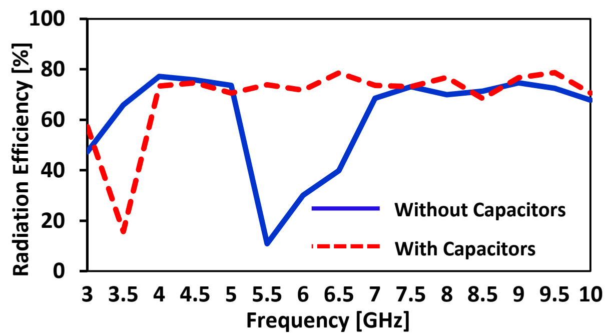

Fig. 15. The measured efficiency of the band-notched UWB antenna

Table 2: Comparison between different band-notched UWB antenna designs

Ref.	Size [mm^2]	Freq. Range [GHz]	Notch Frequencies [GHz]	Realized Gain [dBi]
[9]	58 × 65.5	3.1-11	–	–
[10]	24 × 32	2.9-12.5	5.5	-4.9
			7	-3.9
[11]	12.3 × 28	3-12.8	3.5	-3.3
			8.2	-2.5
[12]	30 × 32	3.1-14	5.5	-2
			6.8	-0.9
			11.5	-0.7
[13]	24 × 32	2.7-12	3.5	-4.3
			8	-2.1
This work	32 × 32	3-19.3	5.6/3.5	-4

A comparison between measured realized gains of the proposed UWB monopole antenna with/without lumped capacitors is demonstrated in Fig. 14. The average measured realized gain of the UWB antenna is nearly constant around 3 dBi, except the notched frequency bands with values equal -4 dBi at 5.6 GHz and 3.5 GHz for the two cases of without and with using lumped capacitors respectively. Figure 15 shows a comparison between measured radiation efficiencies of the proposed band-notched UWB antenna with/without lumped capacitors. The average measured efficiency over the entire frequency band is 74% except the notched frequencies with values 15.7% and 10.8% at 3.5 GHz and 5.5 GHz, respectively.

A comparison between the proposed antenna and other reported UWB antennas is illustrated in Table 2. It can be concluded from this comparison that the proposed antenna has compact size and higher bandwidth. The gain at the center frequency of the notched band is comparable, or somewhat higher.

IV. CONCLUSION

A compact band-notched monopole antenna printed on 3.2×3.2 cm^2 low cost FR4 substrate has been proposed for UWB systems. A frequency band rejection has been investigated by embedding open loop resonators in the antenna structure to avoid the interference of UWB systems with WLAN applications. The experimental results confirm that the fabricated antenna is suitable for UWB systems by covering frequency range 3.1–19.3 GHz with the band-notched characteristic at 5.1–6.5 GHz. Moreover, good omnidirectional radiation characteristics and gain have been achieved throughout the UWB frequency band except the undesired notched band. The tunablility of the notched band has been investigated by embedding two lumped capacitors. The proposed tunable band-notched UWB monopole antenna provides very interesting specifications to be presented for various wireless communication systems.

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