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Design of Compact Dual Notched Self-Complementary UWB Antenna

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Abstract

In this paper, a novel double notched UWB antenna is introduced. The proposed antenna is Quasi Self-Complementary (QSC) with wide impedance bandwidth from 2.2 GHz to more than 12 GHz. The antenna consists of semi-ring with rectangular tapered section for more matching and it is designed on FR-4 substrate with thickness 1.5 mm and has compact size of 11.5 × 14.5 × 1.5 mm^3. The dual notched bands are achieved by using a T-shaped slit etched in the radiating patch to reject interference with WIMAX band and two C-shaped are placed close to the microstrip feed line to reject the interference with the WLAN band. The proposed antenna is designed, simulated and measured. All simulation results are performed using the CST software. Good agreement is presented between the experimental and the simulated results.

Keywords

Monopole, Ultra Wide Band (UWB), Self-Complementary, Notch, Wireless Local Area Network (WLAN)

1. Introduction

The Ultra-Wide Band (UWB) technology has become more popular due to various applications such as medical imaging applications, multimedia connectivity, personal communications, ground penetrating radar and sensor networks. Also, the UWB system plays as one of the very important leading wireless communication systems due to low power consumption, high speed, and efficient frequency. In the current, the FCC has allocated at bandwidth of 7.5 GHz of ultra-wideband devices in the band from 3.1 to 10.6 GHz [1] [2]. Nowadays, the UWB antenna needs many requirements such as wide bandwidth, radiation stability, constant gain and compact size [3] [4]. Through the last years, different methods to integrate the Bluetooth band with UWB are introduced [5] [6] [7]. Xiong *et al.* [5] introduce an UWB antenna with wide bandwidth from 2.2 GHz to 10.6 GHz and add slot on the current path to filter out the band between Bluetooth and UWB [5]. In [6], a dual band U shaped monopole is introduced with adding strip line for Bluetooth band. The antenna is designed on FR4 substrate with thickness 1.6 mm, and size 50 mm × 24 mm where the length of the antenna is increased due to strip line.

On the other hand, extensive research efforts are exerted in minimizing the size of microstrip antenna especially UWB antenna [8] [9] [10] [11]. In 2012, a novel monopole antenna with Koch fractal boundary is introduced with compact size 20 mm × 15 mm to cover bandwidth from 4.3 to 12 GHz [9]. In 2013 [11], Quasi Self-Complementary Antenna (QSCA) with size 16 × 25 mm^2 was introduced for UWB. Moreover, In 2016 [12], Wahab *et al.* introduced Quasi self-complementary fractal UWB antenna with size 15 × 13 × 1.5 mm^3. In 2017 [13], Frequency Selective Surface (FSS) was used to improve the UWB antenna performance. The main property of the Self-Complementary Antenna (SCA) is having constant impedance where the antenna is SCA when the metal area and the open area are congruent. Moreover, the currently allocated UWB frequency band will cause interference in the existing wireless communication systems, such Wireless Local Area Network (WLAN) bands (5.15 - 5.35 GHz, 5.725 - 5.825 GHz), and the World Interoperability for Microwave Access (WiMAX) band (3.4 - 3.69 GHz), hence, the UWB antenna with single and dual band-stop performances is required [14]-[19]. The most common approach is embedding a slot into the radiating patch to change the current flow. Different shapes of the slots (such as U-shaped, Hilbert-curve, mender line, ring, square, C-shaped and T-shaped) are used to obtain the desired band notched [14]-[19].

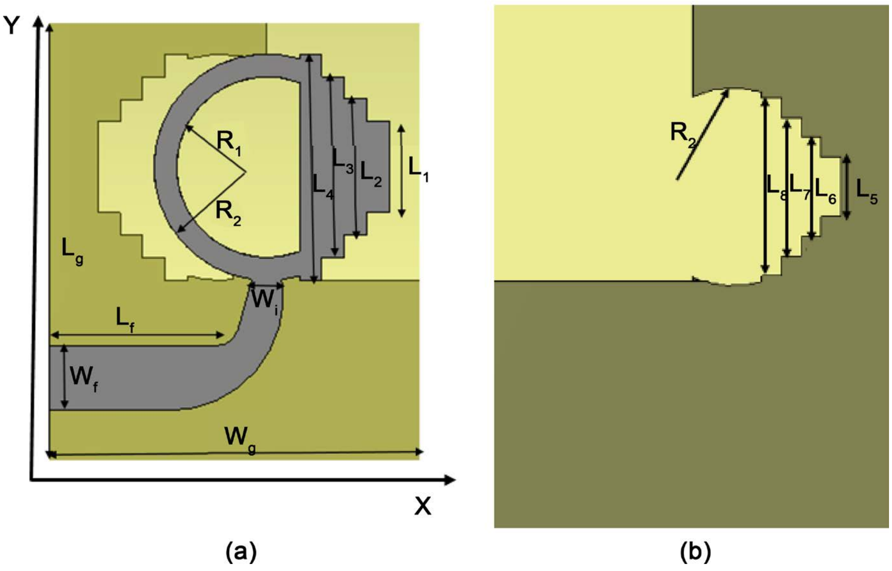
In this paper, a QSCA is introduced to achieve wide impedance bandwidth integrated with Bluetooth. The proposed antenna has compact size of 11.5 × 14.5 mm^2. The UWB antenna is fabricated on a FR4 substrate with relative permittivity of 4.5, and thickness of 1.5 mm.

The paper is organized as follows: Section 2 describes the design of antenna without notch and its results. Section 3 explains the antenna performance with notch and compares it between simulated and measured results. Finally, Section 4 presents the conclusions for this paper.

2. Antenna Design without Notch

2.1. Antenna Geometry

The QSCA fed by a 50-microstrip line is shown in **Figure 1**, which is designed on an FR4 substrate of thickness 1.5 mm, permittivity 4.5, and loss tangent 0.025 with compact size (11.5 × 14.5 × 1.5) mm^3. The proposed antenna consists of semi ring with staircase shape and tapered fed line 50 Ω of width W_f at the feed point and linear tapered to width W_i at the patch to match with high impedance of semi ring. All the labelled dimensions are tabulated in **Table 1**. The antenna is



(a) (b)

Figure 1. Geometry of the proposed antenna. (a) Front View; (b) Back view.

Table 1. Antenna Parameters (all dimensions in mm).

Parameter	R_1	R_2	L_1	L_2	L_3	L_4	L_5	L_6
Value	4	5	4	6	8	11	4	6
Parameter	L_7	L_8	L_g	L_f	W_f	W_g	W_i	
Value	8	11	14.5	5	2.58	16	1.4	

designed through 5 steps, the following section shows the antennas design procedures and results.

2.2. Design Procedures

The important criteria in the design of the desired UWB antenna are adjusting the impedance bandwidth. So, the proposed antenna is designed through five steps as shown in Figure 2. The first configuration, Ant. 1 is designed as conventional planar circular disc monopole antenna with radius 15 mm and the partial ground plane is used to enhance the matched impedance of the UWB antenna from 2.2 GHz to 12 GHz. To accomplish a compact size design, the second configuration is introduced to minimize the size, the semi-circular is designed with the same radius but the return loss is not matched with the overall UWB. In Ant. 3, the semi-circular with step rectangular is introduced for enhancement the bandwidth and semi-circular is opened in the ground plan to complementary with the patch. Ant. 4 and Ant. 5 are introduced for more matching, compact size and integrate the Bluetooth. Figure 3 shows the comparison between the return losses of different configurations. From the figure we note that Ant. 1 have large size and good performance at the same time and to minimize the size, the others antennas are introduced. Ant. 2 don't have good matching through overall band. So, the self-complementary is introduced to enhance the bandwidth of the antenna as shown in the figure.

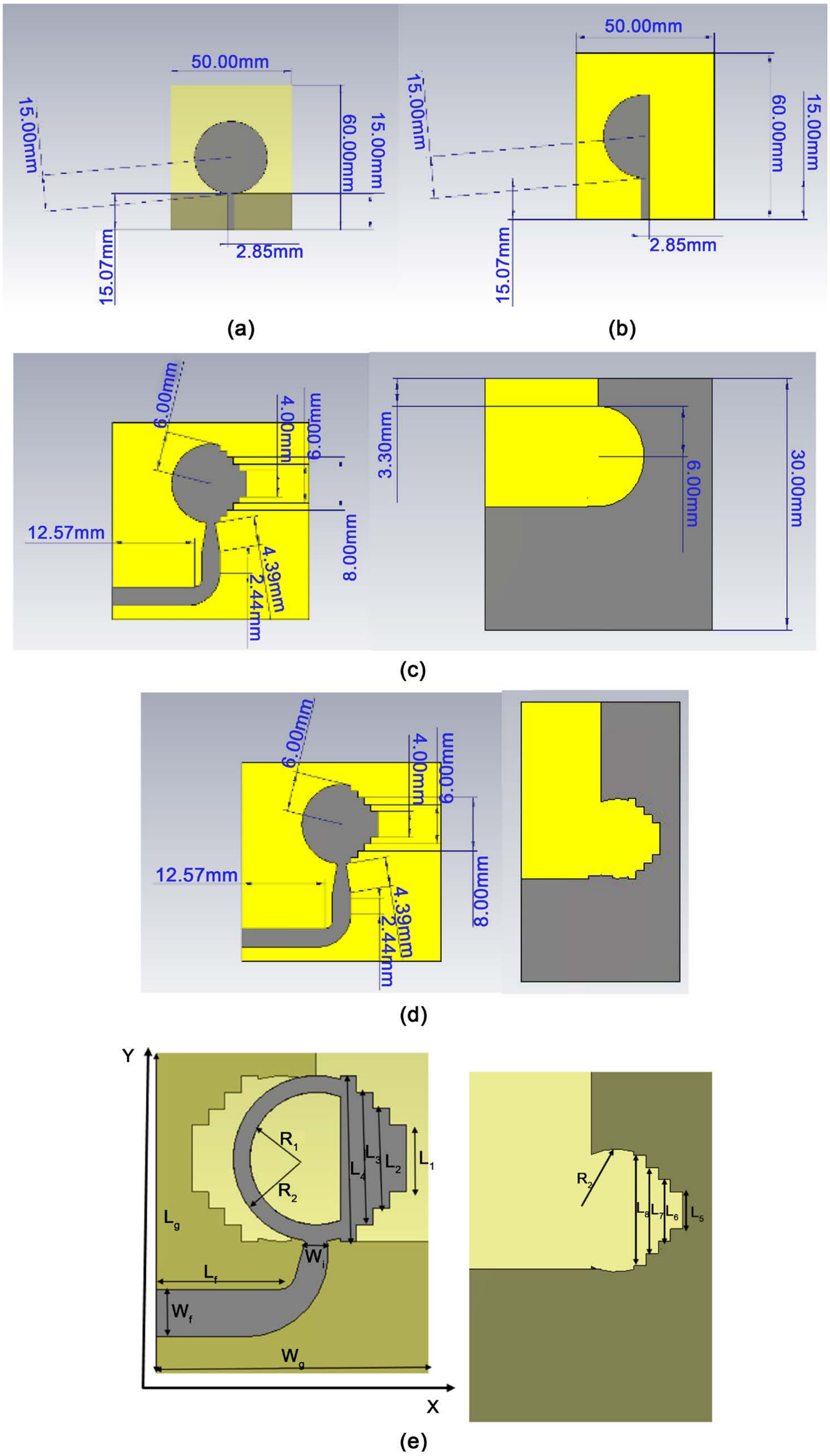


Figure 2. Design steps of the proposed antenna. (a) Antenna 1; (b) Antenna 2; (c) Antenna 3; (d) Antenna 4; (e) Antenna 5.

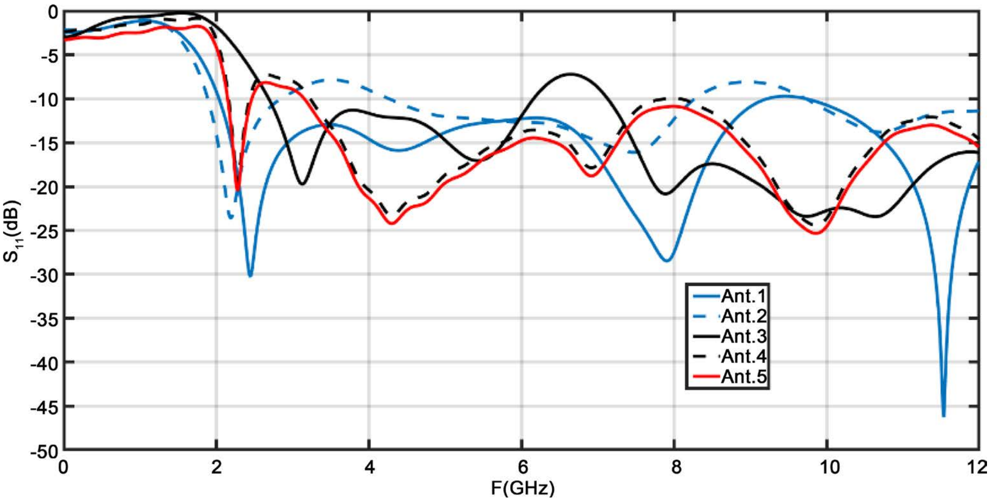


Figure 3. Return loss of the different antennas.

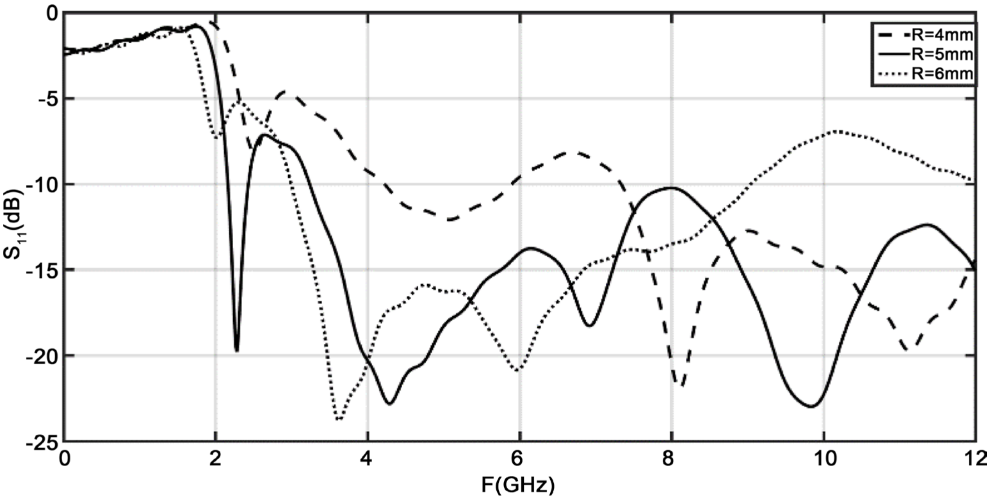


Figure 4. The return loss of the proposed antenna for different values of R_2.

Figure 4 illustrates the effect of varying outer radius R_2; it is noted that the optimum value is $R_2 = 5$ mm. The impedance matching is controlling by W_i as shown in **Figure 5** to yield the best matching at $W_i = 1.4$ mm. It is observed that as W_i decreases more than 1.4 mm the matching is not good. **Figure 6** shows the return loss of the antenna at different values of $L_1 = L_5$, with $L_6 = L_2 = L_1 + 2$, $L_7 = L_3 = L_1 + 4$, $L_8 = L_4 = L_1 + 7$. The increasing of the length L_1 will result in improves of the return loss and the bandwidth. Even though the $L_1 = 5$ mm provides the lowest return loss.

The antenna is fabricated on FR4 substrate and the prototype of the antenna is shown in **Figure 7**. The proposed antenna is simulated using the CST Microwave Studio 2016. **Figure 8** shows the comparison between the simulated and the experimental results of the return loss. The simulated and the experimental results ensure that the antenna covers the UWB integrated with Bluetooth. It is clear that the simulated and measured have some little difference due to substrate loss, soldering and connectors which cannot be totally avoided.

3. Antenna Design with Notch

In order to achieve the desired frequency band notch from 3.4 - 3.7 GHz (WIMAX applications), a T-Shaped slit which equals half wavelength of the notched frequency is etched in radiating patch as illustrated in **Figure 9**.

Also, in order to reject frequency band of WLAN from 5.2 - 5.8 GHz, two C-shaped operate as parasitic elements with electrical length 0.5 λg are placed on

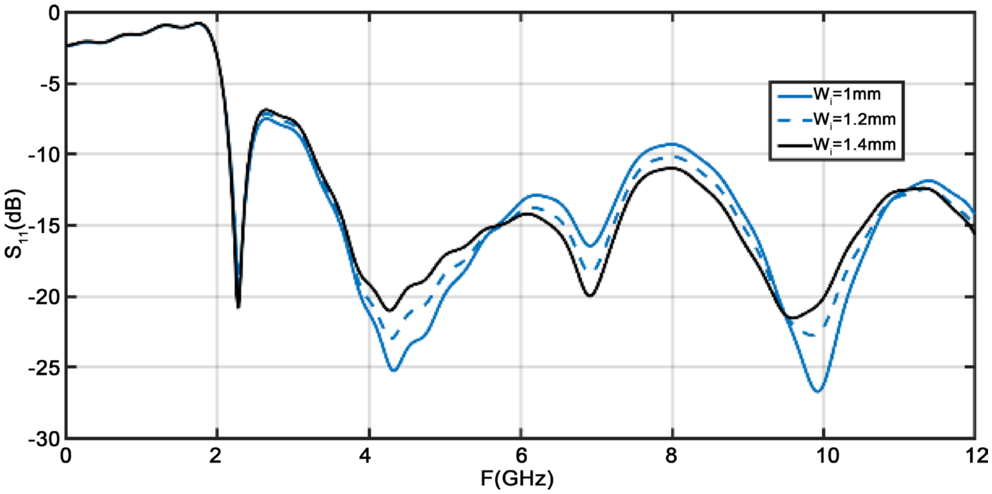


Figure 5. The return loss against frequency at different W_i.

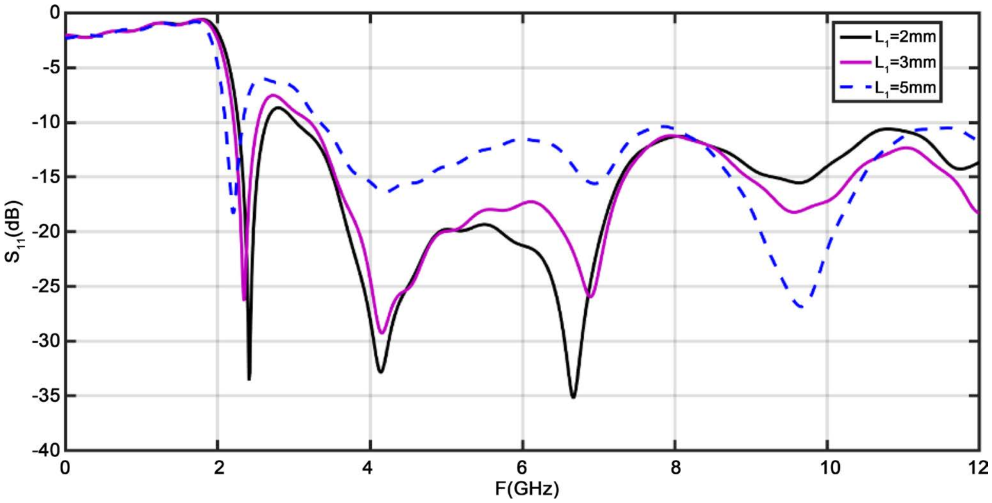
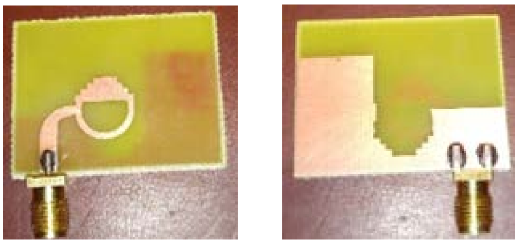


Figure 6. The return loss against frequency at different L_1.



(a) (b)

Figure 7. Prototype of the antenna. (a) Front View; (b) Back View.

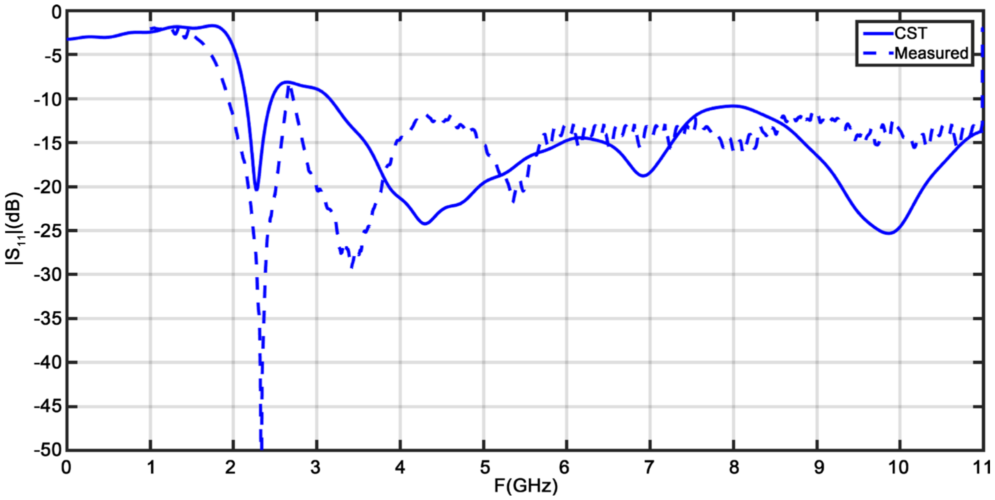


Figure 8. The return loss of the proposed antenna.

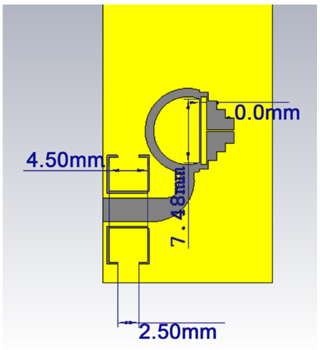


Figure 9. Antenna geometry with two notched.

top and below the horizontal feed line, as shown in Figure 9. The T and C Shapes are design using the following equations,

$$f_{T-notch} = \frac{c}{4\left(L_T + W_T\right)\sqrt{\varepsilon_{eff}}}, \quad f_{C-notch} = \frac{C}{2L_C\sqrt{\varepsilon_{eff}}}$$

The Prototype of the antenna is shown in Figure 10. Both Voltage Standing Wave Ratio (VSWR) for simulated and fabricated antenna are shown in Figure 11. Very good agreement is observed.

Figure 12 and Figure 13 show a comparison between the simulated maximum gain and efficiency of the proposed antenna with and without notch, respectively. As shown in the figures, it is clear that in the case of without notch, the average gain equals approximately 3.5 dB, and the averaged efficiency equals 75%. On the other hand, the average peak gain and efficiency equal 3.5 dB and 70% except the two notched frequency bands. The peak gain and efficiency equal −4 dB, −1 dB and 23%, 43%, respectively in the case of the presence of the notch. Figure 14 illustrates comparison between the simulated and measured radiation patterns in both the E- plane and H-plane at different frequencies. The radiation pattern of the proposed antenna is nearly figure of eight. Table 2 shows a comparison between the proposed antenna design and other published works.

4. Conclusion

In this paper, a novel compact UWB antenna with notch for wireless applications is introduced. The proposed antenna is quasi-self-complementary feed by microstrip line and consists of semi-ring with tapered section for more matching. The prototype of the antenna is fabricated on FR-4 material. The dual

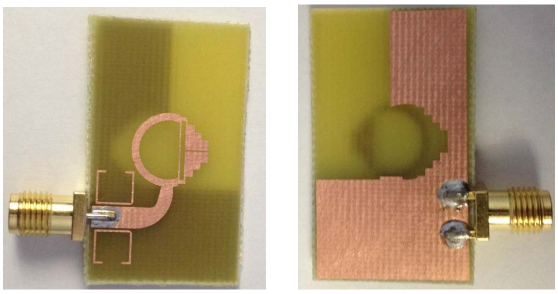


Figure 10. Fabrication antenna with two notches.

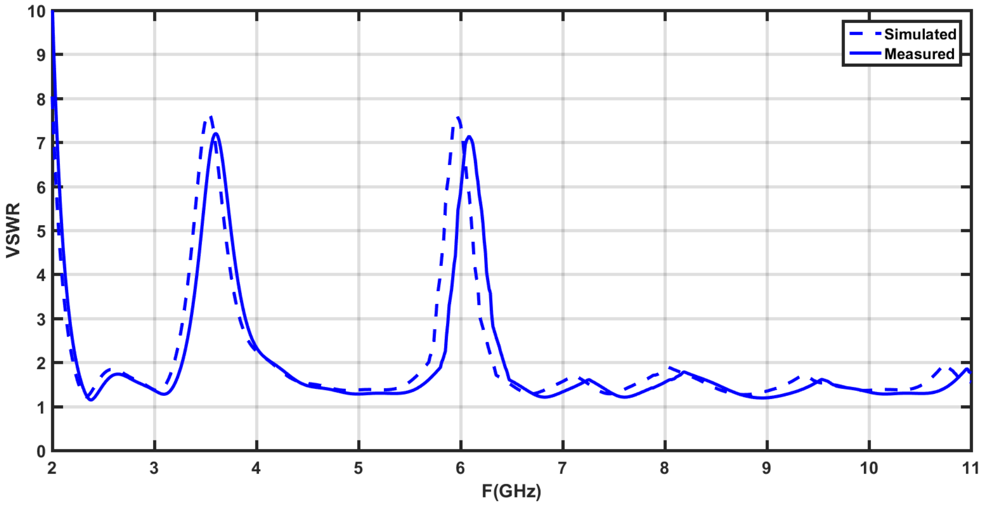


Figure 11. VSWR of the proposed antenna.

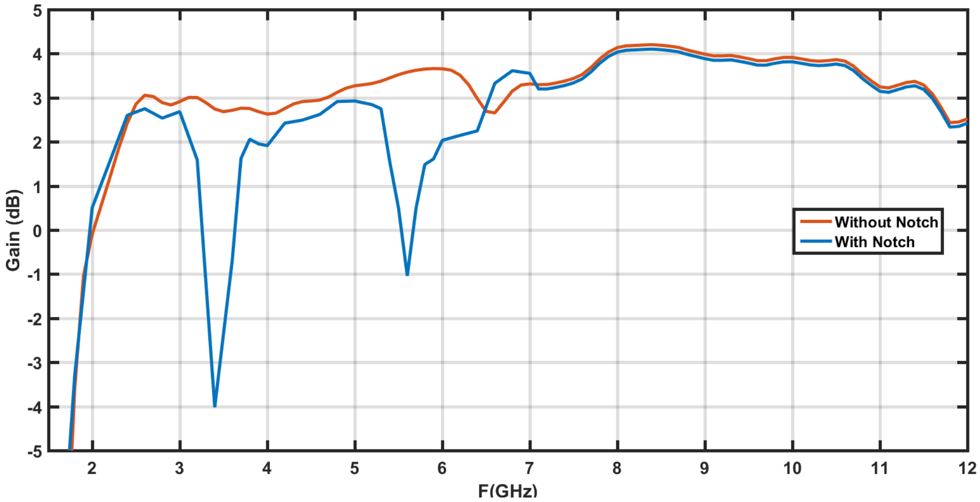


Figure 12. Simulated gain of the proposed antenna.

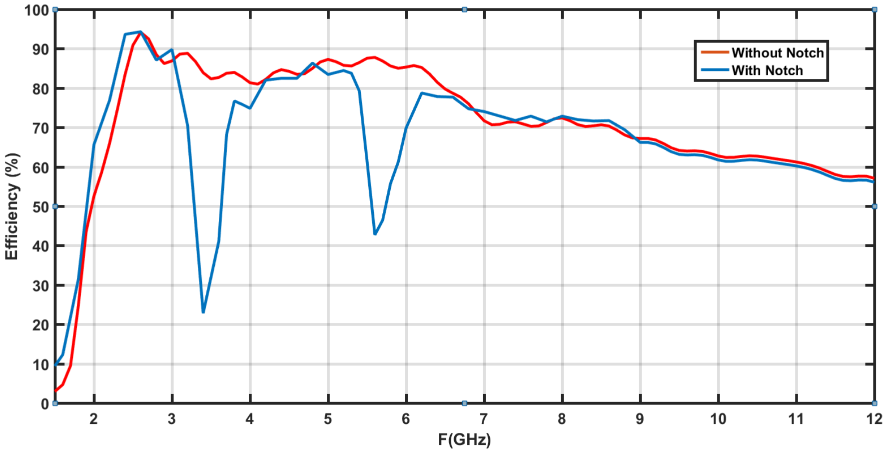


Figure 13. Simulated radiation efficiency of the proposed antenna.

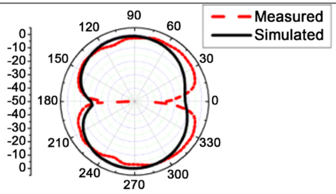
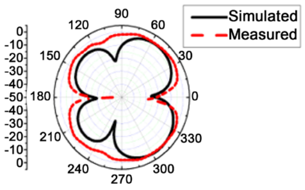
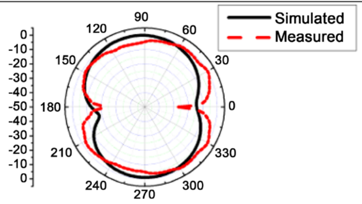
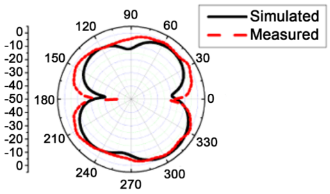
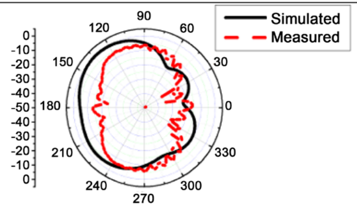
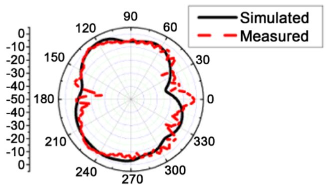
F (GHz)	XZ	YZ
2.4		
6.5		
10		

Figure 14. The radiation pattern of the proposed antenna at different frequencies.

Table 2. A comparison between the proposed antenna and other published papers.

Reference	Size (mm^2)	BW (GHz)	Notch F (GHz)	Realized Gain
[5]	30 × 18	2.28 - 12	3.5	0.1
			5.5	0.2
[11]	16 × 25	2.8 - 14	5.6	−2.5
[17]	12 × 18	2.7 - 12	3.5	−4
			5.5	−4.5
[20]	12.3 × 28	3 - 12.8	3.5	−3.3
			8.2	−2.5
[21]	30 × 30	3.1 - 12	3.6	−4
			5.5	−2.5
This Work	11.5 × 14.5	2.2 - 14	3.5	−4
			5.5	−1

notched bands are achieved by employing a T-shaped slit etched in the radiating patch and two C-shaped are placed close to the microstrip feed line. The antenna has more compact size when compared to other published antennas. The antenna is simulated using the CST simulator and fabricated using the photolithographic technique. Very good agreement is obtained between the simulated and the experimental results.

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