A Simple UWB Tapered Monopole Antenna with Dual Wideband-Notched Performance by Using Single SRR-Slot and Single SRR-Shaped Conductor-Backed Plane

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Abstract **─** This paper presents the design of a compact UWB antenna with dual band-notch characteristics in the 5 GHz band and X-band satellite communications. The proposed antenna consists of a tapered antenna fed by a microstip feed-line presenting a modified ground plane to achieve a wide impedance bandwidth, in the interval 2.8-12 GHz, with VSWR<2. The electromagnetic coupling of the tapered patch with the rectangular split ring resonator shaped parasitic conductor placed in the ground plane yields the first frequency notch which ranges from 5.05 to 5.95 GHz, in order to eliminate the dedicated short-range communications and wireless local area network interferences. The rejection of the X-band from 7.25 to 8.4 GHz, is achieved by etching a single rectangular split ring resonator slot in the radiator patch. Prototypes of the proposed antenna design were measured and compared to simulations, and good agreement was obtained.

Index Terms **─** Antenna, filter, complementary split ring resonator, notch, rectangular single split-ring resonators, ultrawideband, X-band.

I. INTRODUCTION

In the last decades the ultrawideband (UWB) technology has attracted a great interest both in the industry and academia research field especially since the Federal Communication Commission (FCC) allocated the spectrum portion from 3.1 to 10.6 GHz to be used for commercial purpose of the UWB technology [1]. An enormous attention has taken place for designing UWB microstrip antenna due to its attractive characteristics of low profile, miniaturization, capability to be integrated with the design of other devices, and low cost. Mitigating interference between UWB antennas and co-existing narrow band systems have prompted the design of UWB antennas doted of frequency notch filtering characteristics. Different configurations can be found in the scientific literature proposing the use of planar monopole printed antennas with modified radiator and/or ground plane in order to achieve a frequency notch characteristic [2-14]. Single, dual or triple notched frequencies can be obtained by using parasitic elements [2], [3], inserting rod-shaped parasitic structures [4], utilizing a small resonant patch [5], embedding a slot in the feed line, or cutting different shapes of slots in both the radiation patch and the ground plane [6-8]. Other designs include split ring resonators (SRR), and its complementary structure (CSRR), as shaped-slot and/or shaped-conductor, to produce a desired frequency notch filtering property [9-16].

This paper describes a novel and simple design of a UWB tapered monopole antenna doted of a dual wideband frequency notch feature. The first notch is generated at 5.5 GHz by introducing a single SRR-shaped parasitic conductor in the ground plane to reject the interference due to the dedicated short-range communications (DSRC) and wireless local area network (WLAN) systems that operate within the range from 5.15 to 5.925 GHz. A single rectangular SSR-slot is etched in the tapered radiator to eliminate the wideband interference (7.25-8.4 GHz) corresponding to the uplink and downlink

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signals of the X-band satellite communication systems.

The modified ground plane is responsible of achieving the desired wider impedance bandwidth matching over the entire UWB frequency range. This technique implemented in our design can be employed on any UWB monopole antenna design doted of a partial ground plane to obtain any frequency notch requisite with a necessary stopband impedance bandwidth.

In the following sections we describe the experimental validation with discussion of measurement results in order to demonstrate the performance of the proposed antenna design.

II. ANTENNA CONFIGURATION

The geometrical configuration of the proposed UWB tapered monopole antenna is shown in Fig. 1. It consists of a tapered radiation patch with modified ground plane to achieve the impedance bandwidth matching requisite over the UWB range. The tapered patch was connected to the microstrip line providing a characteristic impedance of 50 **Ω**. The antenna was printed on the Rogers ULTRALAM 2000 high performances substrate with dielectric permittivity of 2.5, thickness of 0.762 mm and loss tangent of 0.0019.

In order to obtain the frequency notch filtering function and eliminate the undesired frequencies so avoiding possible interference within the UWB band (3.1 GHz to 10.6 GHz), this design introduces two additional simple structures in the basic antenna geometry. By loading the SRR-shaped conductor in the ground plane, we achieve the lower notched-band at 5-6 GHz. The suppression of the radiation at this notch frequency is due to the effect of the electromagnetic coupling between the tapered radiator and the single SRR embedded on the radiator backside. The higher notched-band 7.25-8.4 GHz is obtained by embedding a single rectangular SRR-slot in the tapered patch. Moreover the stop-band property can be controlled by adjusting the width and the length of the SRR element for both cases [18,19]. Simulation results have been obtained with the CST MW Studio^{TM}.

Figure 2 illustrates the three stages of the antenna design. Initially, a reference UWB tapered monopole antenna is designed without notch band characteristics (antenna#1). Later this configuration is modified to introduce the rejection of a single band by loading a SRR-shaped parasitic conductor in the ground plane (antenna#2). Finally, the dual-band notched UWB antenna is achieved loading the SRR-shaped parasitic conductor in the ground plane and etching the SRR-slot in the tapered patch, and it is presented as antenna#3.

The SRR and CSRR elements embedded within the antenna are designed by considering the corresponding resonant frequency derived from their respective quasi-static resonance [17]. The specific geometrical details of each element are provided in the following section.

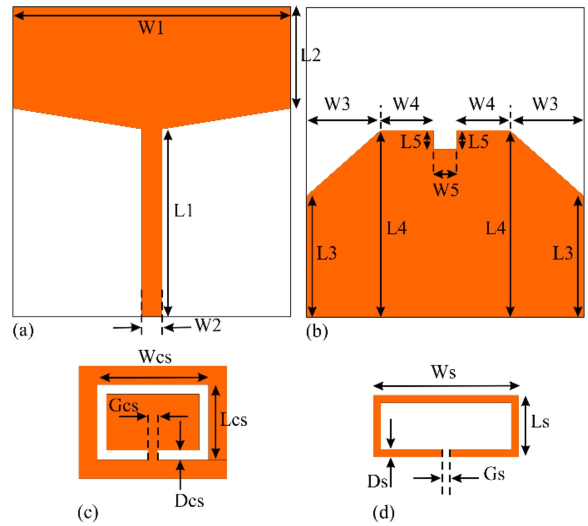


Fig. 1. Schematic of the proposed antenna design: (a) radiator tapered element, (b) modified ground plane, (c) rectangular CSRR-shaped slot, and (d) rectangular SRR-shaped parasitic conductor.

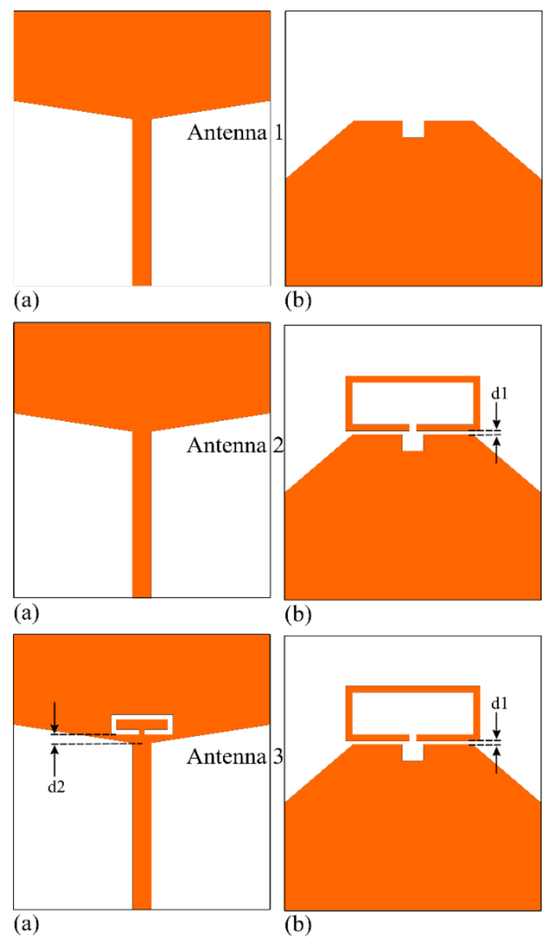


Fig. 2. Configuration of the antennas used for our study: top and bottom layers.

III. MEASUREMENT RESULTS

Following we compare the performance of the three stages of the antenna design: the reference design case (antenna#1), single notched band case (antenna#2), and the dual-band notched case (antenna#3).

A. UWB tapered monopole antenna

Figure 3 shows the VSWR performance of the basic UWB tapered monopole antenna without any embedded notch filtering element. As can be seen in the plot, the UWB antenna operates from 2.8 to 12 GHz with a voltage standing wave ratio (VSWR) lower than 2. Good agreement between the measured and simulated plots is inferred from the comparison. The parameters of the UWB reference antenna without notch function are as follows, in mm: L_1=20, L_2=10.8, L_3=13, L_4=20, L_5=2, W_1=30, W_2=2.2, W_3=8, W_4=6 and W_5=2.5.

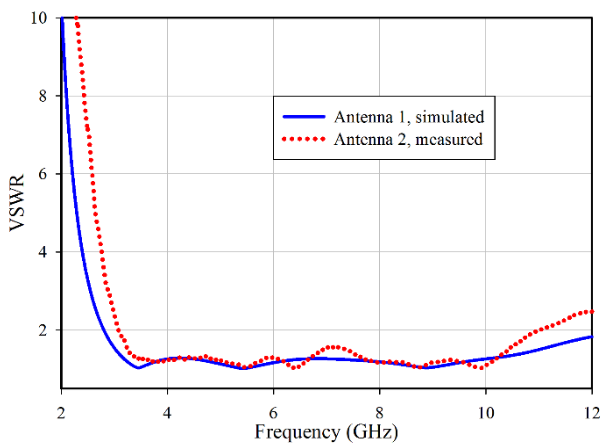


Fig. 3. Simulated and measured VSWR for antenna#1.

B. UWB tapered monopole antenna with single band-notch

In order to reject the WLAN/DSRC frequencies (5.05-5.95 GHz), we loaded a single SRR-shaped parasitic on the backside of the tapered patch, so obtaining the namely antenna#2 case. This notch filtering property is due to the electromagnetic coupling occurring between the radiating patch element and the resonant SRR-shaped parasitic element. The selection of critical parameters of the SRR structure is related to important effects arising on the antenna performance.

Figure 4 shows the VSWR of antenna#2 obtained for different values of the total length of the SRR-shaped parasitic, given by $L_t = L_s + W_s$. It can be observed that when the total length of the SRR structure increases, the center of the notch frequency decreases without affecting the stop-band impedance bandwidth. Then, the notch frequency is controllable by varying the total length L_t of the embedded SRR-shaped parasitic.

Furthermore, the band rejection is influenced by the width of the SRR-shaped parasitic, D_s. This effect was investigated and shown in Fig. 5. We observe that the notched frequency depends of the SRR-shaped parasitic width D_s, in a similar way to that one due to the influence of the total length L_t, as previously described.

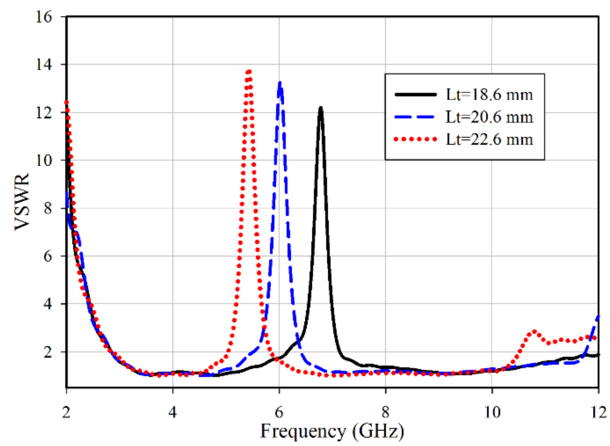


Fig. 4. Simulated VSWR for antenna#2 with different values of L_t.

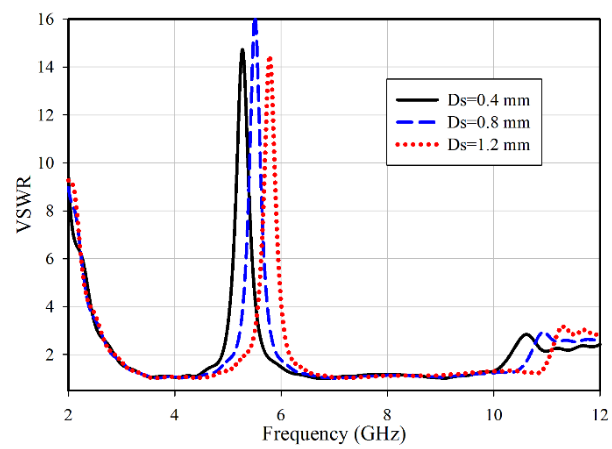


Fig. 5. Simulated VSWR of antenna#2 for different values of D_s with L_t = 22.3 mm.

The capacitive coupling between the introduced SRR-shaped parasitic and the modified ground plane also affects the stop-band performance, as illustrated in Fig. 6. We can deduce that the impedance bandwidth of the stop-band increases as the distance d_1 between the ground plane and the SRR-shaped parasitic element decreases. Rejection levels are enhanced when distance d_1 decreases, corresponding to an intensification in the effective capacitive value provided by the gap between the antenna and the SRR loading element [17]. Thus, the variation of the distance d1 introduces an easy way for controlling both the stop-band impedance bandwidth and the corresponding maximum value of VSWR.

The values of the design parameters selected for the SRR-shaped parasitic conductor backed-plane are as follows, in mm: W_s=15.7, L_s=6.6, G_s=0.8, D_s=0.8 and d_1=0.3.

Figure 7 shows comparison between the simulated and measured VSWR characteristics of the single-band-notched UWB antenna (antenna#2) and the reference antenna (antenna#1). This plot clarifies that the achieved notched frequency bandwidth is achieved from 5.05 to 5.95 GHz with a maximum VSWR higher than 10. Obviously, the achieved notched bandwidth can suppress the DSRC and WLAN bands for UWB communications.

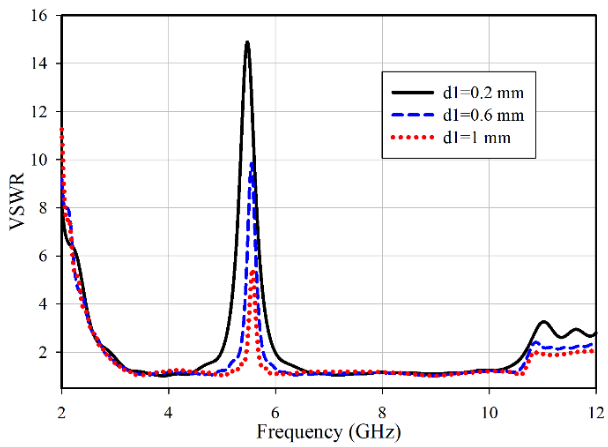


Fig. 6. Simulated VSWR for antenna 2 with different values of d_1 (L_t = 22.3 mm, D_s = 0.8 mm).

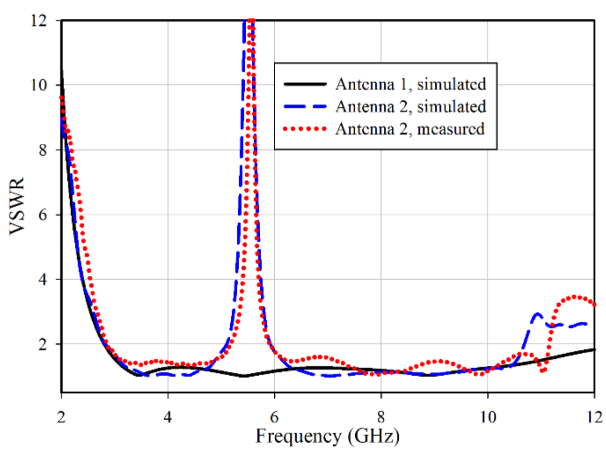


Fig. 7. Simulated and measured VSWR of the proposed UWB antenna with single frequency notch.

C. Dual band-notched UWB tapered monopole antenna

The next step was to achieve a dual band notched feature to reject the uplink and downlink signals of the X-band satellite communications. Then, a SRR-slot was etched in the tapered patch, as shown in Fig. 2, so obtaining the namely antenna#3 case.

The proposed dual band-notched UWB antenna with was fabricated and tested. The measured and simulated VSWR of the antenna#3 are illustrated in Fig. 8. It can be seen that for this case the impedance bandwidth is 8.2 GHz, covering the band 2.8-11 GHz along to achieving the required dual band-notched performance. The simulated notched frequency bandwidth of the proposed antenna is achieved from 4.95 GHz to 6.05 GHz and from 7.25 GHz to 8.45 GHz, while the measured stop-band frequency ranges are from 4.95 GHz to 5.95 GHz and from 7.5 GHz to 8.9 GHz for VSWR>2 with maximum VSWR of more than 10 and 4 respectively. The suppression of the WLAN/DSRC and X-band narrow band systems was completely obtained. The frequency shifting observed in the second frequency notch of measurement results is due to the fabrication tolerance limit when etching the SRR-slot.

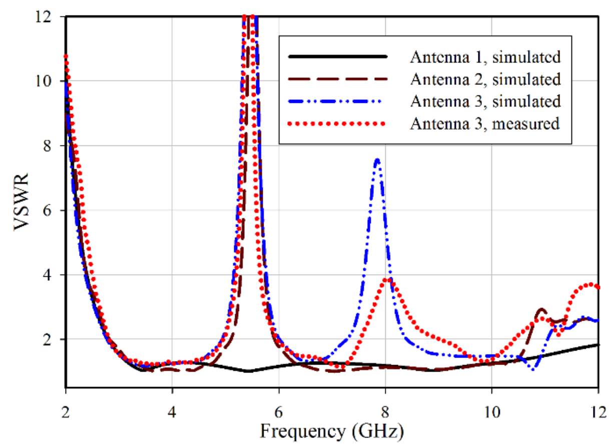
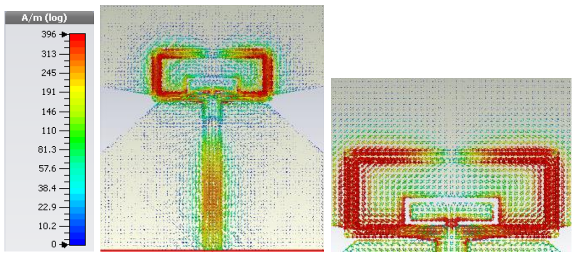


Fig. 8. Simulated and measured VSWR of the proposed dual bad-notched UWB antenna.

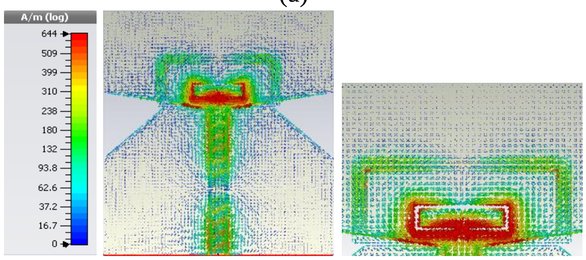
The design parameters of the etched SRR-slot are as follows, in mm: W_s=7.2, L_{cs}=2.4, G_{cs}=0.6, D_{cs}=0.6 and d_2=1.

For the case of antenna#3, we analyzed the surface current distribution. In Fig. 9, we depicted at two frequencies of operation, (5.5 and 7.85 GHz, corresponding to the center frequencies of the notched bands. It is visible that the quasi-static resonance frequencies of the SRR/CSRR elements are located precisely at 5.5 GHz and 7.85 GHz. For those frequencies the tapered monopole is then not excited and so resulting in the radiation suppression.

The radiation pattern of the proposed antenna#3 is presented in Fig. 10. The figure shows good directive pattern in the E-plane and omnidirectional pattern for the H-plane. General good agreement is observed between measured and simulated results.

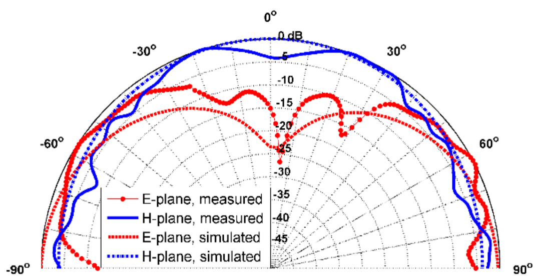


(a)

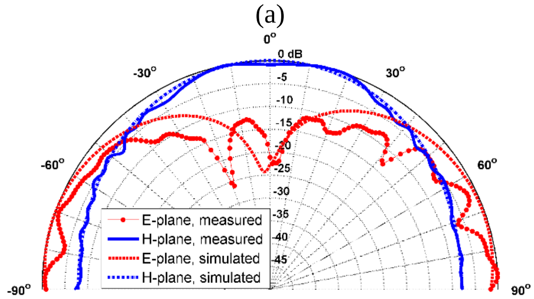


(b)

Fig. 9. Simulated surface current distribution of the dual band-notched case (antenna#3): (a) at 5.5 GHz and (b) at 7.85 GHz.



(a)



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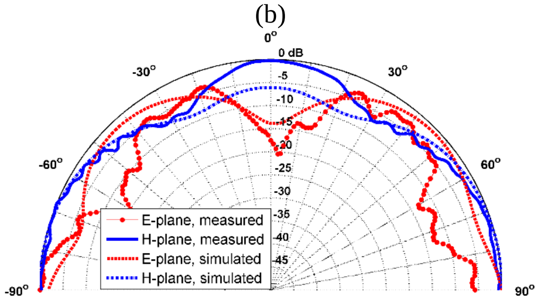


(c)

Fig. 10. Simulated and measured radiation patterns of the proposed antenna#3 case for E- and H-planes: (a) 4.5 GHz, (b) 6.5 GHz, and (c) 9.5 GHz.

In Fig. 11 we illustrate the variation of the peak gain with the frequency for the single and dual frequency notched antennas#2 and #3 over the frequency range (2-12 GHz) along to the reference case (antenna#1). Sharp dips in the value of the far-field peak gain are observed in the two desired notched bands, confirming the fact that loading the basic antenna with single SRR-shaped parasitic and SRR-slot provides excellent intrinsic notch filtering.

Furthermore, it can be checked that, in the radiating band, the gain variation is almost the same for the three antennas. Photographs of fabricated antenna prototypes are shown in Fig. 12.

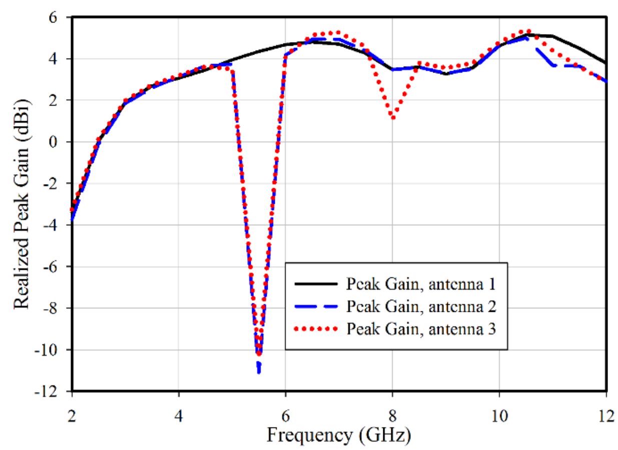
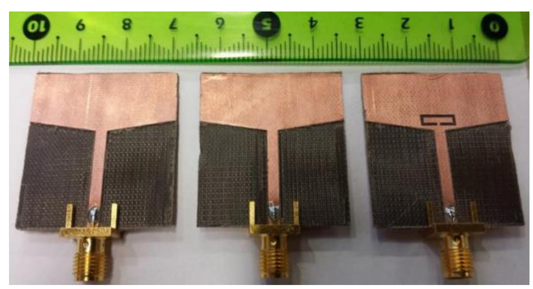
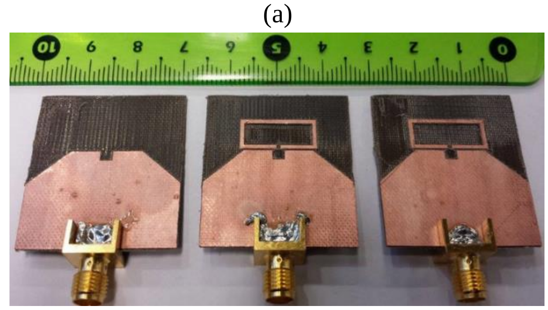


Fig. 11. Peak gain for the three cases of UWB tapered antennas.



(a)



(b)

Fig. 12. Photograph of prototyped antennas: (a) top later and (b) bottom layer. Left: Antenna1. Center: Antenna 2. Right: Antenna 3.

VI. CONCLUSION

A simple and symmetric tapered monopole UWB antenna with a single SRR-shaped parasitic and single SRR-slot etched in the tapered patch, exhibiting dual-frequency notch performance is presented in this paper. The electromagnetic coupling between the tapered patch and the SRR-shaped parasitic introduced on the back side of the tapered element, yields the first notch at 5.5 GHz, with a large bandwidth, filtering the interferences due to the co-existence of DSRC/WLAN systems. Moreover, the uplink and downlink signals of the X-band satellite communication systems are rejected by embedding a single SRR-slot on the radiation patch. The notched frequencies can be easy controlled by modifying the dimensions of the SRR structures. Fabricated antennas demonstrate overall good match between simulated and measured results. In summary, a simple design procedure, valid to obtain a good omnidirectional radiation pattern, with relative stable gain and low profile, as well as manufacturable at low cost make the proposed antenna a suitable candidate for UWB systems needed of multiple frequencies notches.

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