Band-Notched Split-Ring Resonators Loaded Monopole Antenna for Ultrawideband Applications

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Abstract **─** A compact printed ultrawideband (UWB) monopole antenna with triple band-notched characteristics is presented. By adding a Split-Ring Resonator (SRR) on the radiating patch, the notched band in 3.3 GHz - 3.7 GHz for the WIMAX system is achieved. Furthermore, the proposed approach that utilizes the folded rectangular SRR structure is proven to be an effective way for band-notched designs. The antenna exhibit good band stop characteristics to reject the WLAN bands (5.15 GHz - 5.825 GHz bands) and downlink of X-band satellite communication systems (7.25 GHz - 7.75 GHz bands). The VSWR, gain, and radiation patterns of the proposed antenna are presented, which prove that the designed antenna is a good candidate for various UWB applications.

Index Terms - Band-notched, split-ring resonator, and UWB antenna.

I. INTRODUCTION

Because of the advantages such as compact size, light weight, low profile, and low cost [1], the planar monopole ultra-wideband (UWB) antennas are usually used for high-data-rate wireless communication [2], high-accuracy radar [3-4], and subsurface sensing applications [5]. However, electromagnetic interference (EMI) problems are quite serious for UWB systems since there are several other wireless narrowband standards that already occupy frequencies in the UWB band, such as worldwide interoperability for microwave access (WIMAX) operating in 3.3 GHz - 3.7 GHz, wireless local area network (WLAN) operating in 5.15 GHz - 5.825 GHz, and downlink of X-band satellite communication systems in 7.25 GHz - 7.75 GHz. An additional requirement for UWB antennas is to reject certain frequencies within the ultra-wide passband [6-9].

Recently, various band-notched designs have been developed and several UWB antennas with frequency band-notched function have been reported [10-16]. The most popular approach is cutting several slots on the patch or in its ground plane [17-21], the slots using U-shaped, and C-shaped or arc-shaped. In [22], an embedded slot with the length of about a quarter of the guided wavelength at the desired notch frequency tuning stub in a monopole is also proposed.

As for the structure of the broadband planar antenna introduced in this paper, the new antenna's impedance bandwidth covers the bands of 3.1 GHz - 10.6 GHz, which is released by the Federal Communications Commission (FCC). An SRR is embedded in the patch to reject the WIMAX bands (3.3 GHz - 3.7 GHz bands). Two pair of SRRs nearby the feeding microstrip are designed to achieve the WLAN bands (5.15 GHz - 5.825 GHz bands) and the downlink of X-band satellite communication systems (7.25 GHz - 7.75 GHz bands). Measured results of the fabricated antenna prototype verify simulations with reasonably good agreements.

II. ANTENA DESIGN

The configuration of the proposed antenna is shown in Figs. 1 and 2. The final optimized dimensions are offered in Table 1. Basically, the antenna consists of a radiating monopole with an arc-shaped edge, a 50 Ω microstrip feeding mechanism, a simple rectangular ground plane on the back side of the substrate, an SRR embedded

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in the radiating patch, and two folded rectangular SRRs nearby the feeding microstrip.

A. Baseline UWB Design

As shown in Fig. 3 (a), the UWB monopole antenna with 25 × 29 × 0.508 mm^3 dimensions is fabricated on the Rogers Duroid 5880 board material substrate. The substrate is of thickness 0.508 mm and relative permittivity $\varepsilon_r = 2.2$, loss tangent of $\tan\delta = 0.0009$. The monopole is fed by a 50 Ω microstrip line. On the back side of the substrate, the ground plane with length of 13 mm only covers the section of the microstrip feed line. The VSWR of the antenna is shown in Fig. 3 (b). It indicates that the working bandwidth of the antenna covers the entire UWB band (3.1 GHz - 10.6 GHz) under the condition of VSWR < 2.

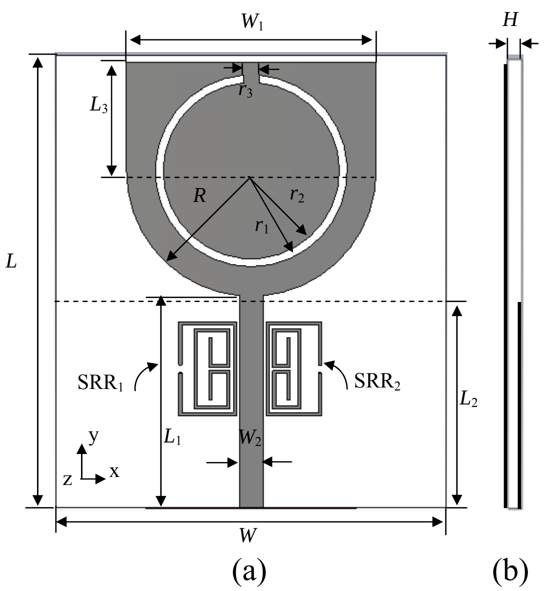


Fig. 1. Geometry of the antenna (a) top view and (b) side view.

B. Single-Notch UWB Antenna Design

In order to reduce the EMI with the WIMAX band, the antenna with an SRR covering the interval 3.3 GHz - 3.6 GHz is desired. The proposed single-notched UWB antenna is illustrated in Fig. 4 (a). It is found that the parameters of $r_1 = 6.15$ mm and the size of its gap $r_3 = 0.5$ mm play critical roles in defining the band-notched frequency. Figure 5 shows that the band-notched frequency can be improved. It can be seen that a greater r_1 causes lower band-notched frequency. For instance, obviously the band-notched frequency increases from 3.36 GHz to 3.60 GHz as r_3 is varied from 0.2 mm to 0.8 mm.

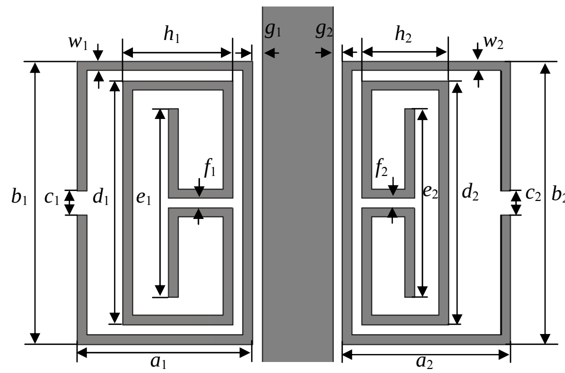


Fig. 2. Geometry of the SRR$_1$ (left side) and SRR$_2$ (right side).

Table 1: Optimal dimension of the design antenna.

Parameter	mm	Parameter	mm	Parameter	mm
L	29	r_2	5.6	w_1	0.2
L_1	13.6	r_3	0.5	a_2	3.55
L_2	13	a_1	3.7	b_2	6
L_3	7	b_1	6	c_2	0.5
W	25	c_1	0.5	d_2	5.17
W_1	16	d_1	5.1	e_2	4
W_2	1.5	e_1	4	f_2	0.2
H	0.508	f_1	0.2	g_2	0.2
R	8	g_1	0.2	h_2	1.82
r_1	6.15	h_1	2.3	w_2	0.2

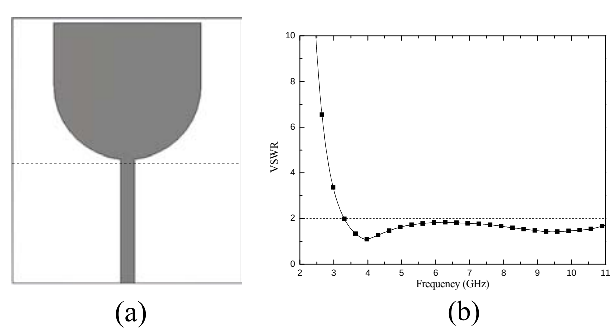
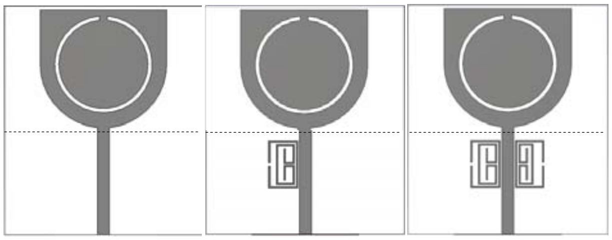
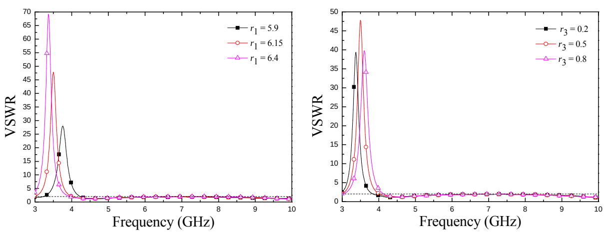


Fig. 3. (a) Basic structure of monopole antenna and (b) the simulated VSWR.



(a) (b) (c)

Fig. 4. (a) Basic structure with an open circuit slot, (b) basic structure with SRR_1, and (c) basic structure with both, SRR_1 and SRR_2.



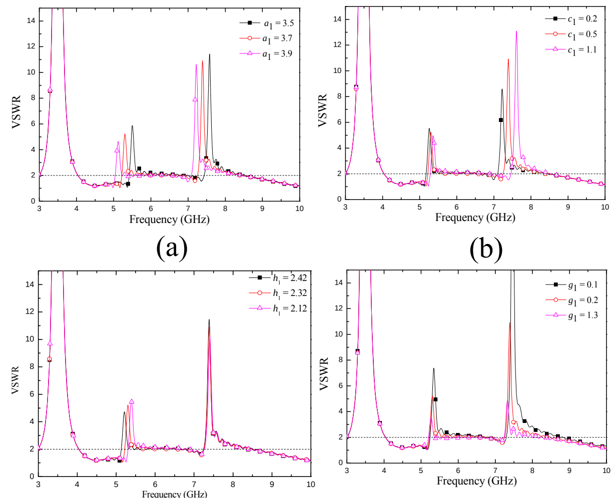
(a) (b)

Fig. 5. Simulation results with some important parameters: (a) Impact of parameter r_1 changes and (b) impact of parameter r_3 changes.

C. Tri-Band-notched UWB Antenna Design

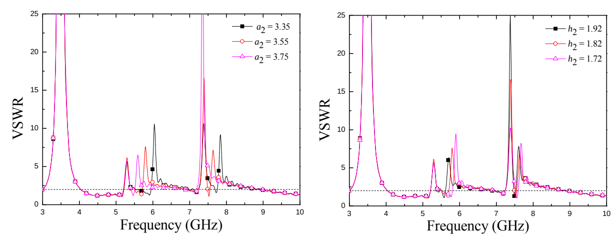
As shown in Fig. 4 (b) and (c), SSR_1 and SSR_2 are designed nearby the feeding microstrip to achieve the notched-band of WLAN and the downlink of X-band satellite communication systems. The simulation results suggest that the notched bands of 5.15 GHz - 5.35 GHz and 7.15 GHz - 7.35 GHz are determined by SRR_1. Moreover, the notched bands of 5.65 GHz - 5.85 GHz and 7.55 GHz - 7.75 GHz are determined by SSR_2 synthetically. As an example, Figs. 6 and 7 show the optimization procedure of two of the notched-bands.

The notched-band of 5.15 GHz - 5.35 GHz is mainly decided by the dimensions of the inner part of SRR_1 shown in Fig. 4 (b), especially the parameter of h_1. Figure 6 (c) indicates that the notched-band drifts to higher frequency obviously as the h_1 is decreasing. However, as shown in Fig. 6 (a) and (b), the notched-band just drifts slightly while the parameters such as a_1 and c_1 of the external part of SRR_1 is changing. Figure 6 (d) shows that the notched-band also drifts slightly and the value of VSWR increases significantly as the parameter g_1 is changing. It can be explained by the coupling effects between the SRR and the feeding microstrip.



(c) (d)

Fig. 6. Simulation results with some important parameters: (a) Impact of parameter a_1 changes, (b) impact of parameter c_1 changes, (c) impact of parameter h_1 changes, and (d) impact of parameter g_1 changes.



(a) (b)

Fig. 7. Simulation results with some important parameters. (a) Impact of parameter a_2 changes. (b) Impact of parameter h_2.

The notched-band of 7.15 GHz - 7.35 GHz is mainly decided by the dimensions of the external SRR_1 shown in Fig. 4 (b), especially the parameter of a_1 and c_1. Figure 6 (a) and (b) indicate that the notched-band drifts to lower frequency obviously as the a_1 is increasing and c_1 decreasing. Figure 6 (c) indicates that the parameter h_1 of the inner SRR just affects the notched-band slightly. Taking the optimization into account significantly, the notched-band of 5.15 GHz - 5.35 GHz and 7.15 GHz - 7.35 GHz can be achieved while the parameters of a_1, c_1, h_1 and g_1 are assigned as shown in Table 1. In a similar way, the parameters of a_2 and h_2 can also be optimized. As shown in Fig. 7, one can notice that the band-stop frequency of SSR_1 and SSR_2 did not affect each other, the notched-band of 5.15 GHz - 5.35 GHz and 7.15 GHz - 7.35GHz stay the same while the parameter a_2 and h_2 are optimized.

III. RESULT AND DISSCUSSION

Figure 8 shows the photograph of the proposed antenna. The simulated results are offered by the commercial software (CST MWS) based on the Finite Integration Technology (FIT). The measured curves are performed by an Agilent E5071C network analyzer. Figure 9 shows the simulated and measured VSWR of the proposed band-notched antenna. The working bandwidth covers the full frequency range from 2.8 GHz to 11.8 GHz except for the three notched-bands of 3.3 GHz - 3.7 GHz for the WIMAX system, 5.15 GHz - 5.825 GHz for the WLAN, and 7.25 GHz - 7.75 GHz for the downlink of the X-band satellite communication systems.

The simulated current distributions at 3.5 GHz, 5.25 GHz, 5.75 GHz, and 7.4 GHz of the proposed antenna are shown in Fig. 10. The simulated and measured radiation patterns of the E-plane (yz-plane) and H-plane (xz-plane) at 4 GHz, 6.5 GHz, and 9 GHz are plotted in Fig. 11, respectively. It indicates that the radiation patterns of the H-plane are nearly omni-directional over the working bandwidth except for the three notched-bands. The radiation pattern is similar to that formed by a typical monopole antenna. The simulated and measured gain at the operating bandwidth is shown in Fig. 12. The simulated results are in good agreement with the measured results within the experimental errors.

Fig. 8. Photograph of the fabricated antenna prototype.

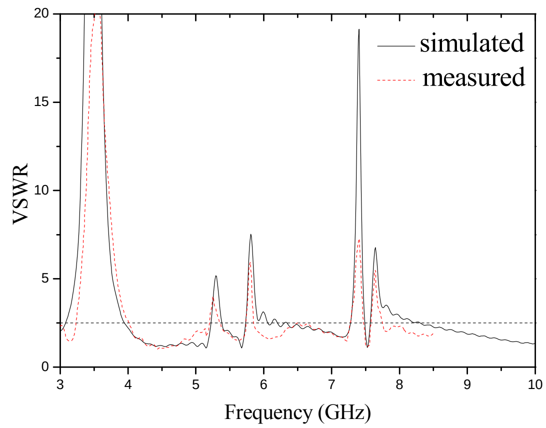


Fig. 9. Simulated and measured VSWR of the proposed antenna.

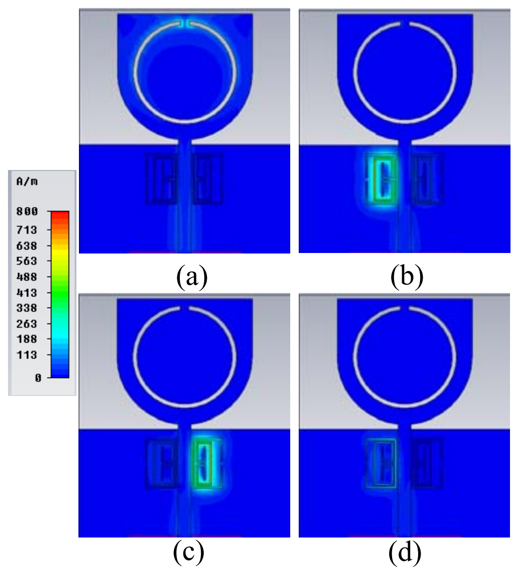


Fig. 10. Simulated surface current distributions on the radiating patch for the proposed antenna at (a) 3.5 GHz, (b) 5.25 GHz, (c) 5.75 GHz, and (d) 7.4 GHz.

IV. CONCLUSION

In this paper, a novel compact printed monopole antenna with three band-notched characteristics used for UWB applications has been presented and analyzed in detail. By successfully using SRRs elements and adjusting the parameters, the antenna has not only triple band-notched characteristics but also good omni-directional radiation patterns at the frequencies of interest. The antenna was fabricated and measured, showing good results and good agreement between simulations and measurements. It provides a simple and practical method in the notched-bands antenna designing.

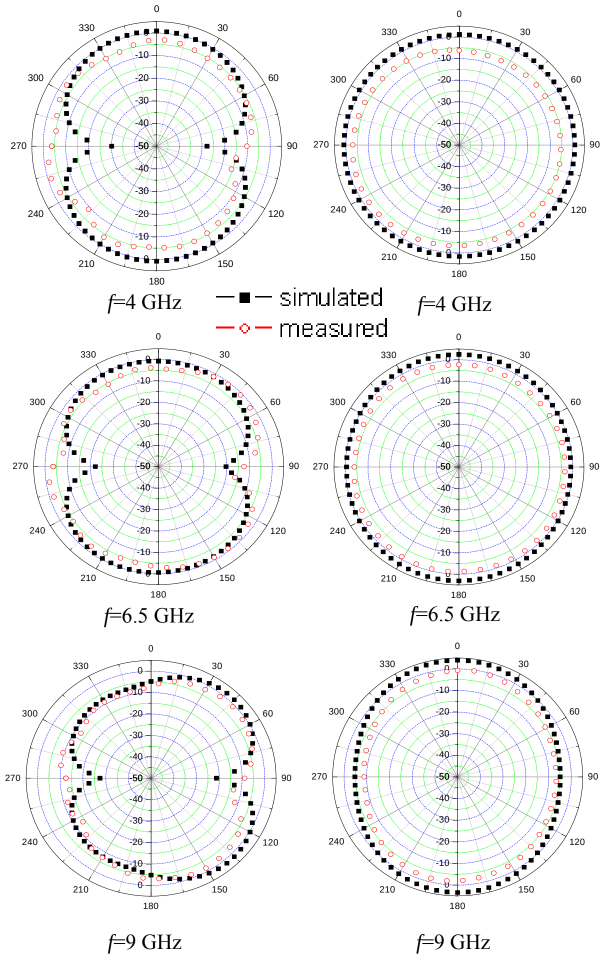


Fig. 11. Simulated and measured radiation patterns in the E-plane (left side) and H-plane (right side) of the proposed antenna.

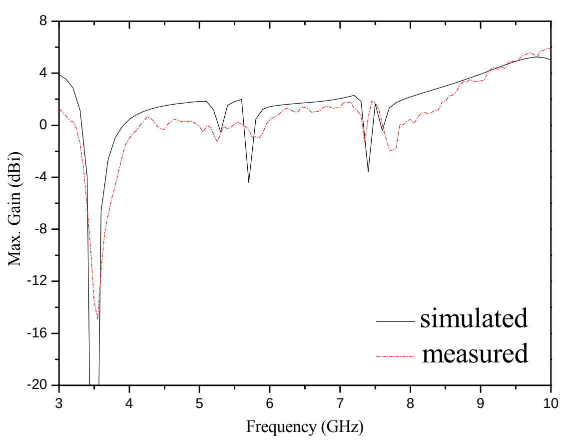


Fig. 12. Simulated and measured gain of the proposed antenna.

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