A Compact UWB Band-Notched Printed Monopole Antenna With Defected Ground Structure

A. Nouri and G. R. Dadashzadeh

***Abstract*—A simple and compact UWB printed monopole antenna with filtering characteristic is presented. The proposed antenna consists of a defected ground structure (DGS) and a radiating patch with arc-shaped step that is notched by removing two squares at the bottom. By using a modified shovel-shaped defected ground structure, band-notched characteristic that involves both operating frequency band of Dedicated Short-Range Communication (DSRC) systems and WLAN is obtained. Omnidirectional H-plane radiation patterns and appropriate impedance characteristic are the main features of the proposed antenna that are achieved by designing the lower edges of the radiating patch in the form of arc-shaped step. The designed antenna has a small size of 15×18 mm^2 and provides the impedance bandwidth of more than 128% between 3.1 and 14 GHz for $\mathrm{VSWR} < 2$, with notch frequency band at 5.13–6.1 GHz.**

***Index Terms*—Band-rejection characteristic, defected ground structure (DGS), omnidirectional, ultrawideband (UWB).**

I. Introduction

WITH development of ultrawideband (UWB) technology, there is increasing demand for small low-cost antennas with omnidirectional radiation patterns and wide frequency bandwidth. The printed monopole antennas have received great attention in UWB applications due to their advantages of low cost, low profile, light weight, simple structure, wide impedance bandwidth, easy fabrication, and easy integration with other microstrip circuits. With respect to frequency band defined by the Federal Communications Commission (FCC) for UWB applications, which is from 3.1 to 10.6 GHz [1], several printed monopole antennas with different geometries have been reported recently [2], [3].

Over the operating bandwidth of the UWB systems, there exist several narrow bands that are used by wireless communication systems, such as Dedicated Short-Range Communication (DSRC) systems for IEEE 802.11p operating in the 5.850–5.925-GHz band and WLAN operating in 5.15–5.35 and 5.725–5.825 GHz. In order to minimize such frequency interferences, the UWB antennas with band-notched characteristics can be used. Throughout the literature, various methods to achieve the band-rejection characteristics are proposed. The conventional methods include cutting a slot (i.e., π-shaped and ELC resonator) on the patch [4], [5], inserting a slit on the patch [6], using conductor-backed plane [7], and embedding a tuning stub within a slot on the patch [8], [9]. Moreover, band-rejection characteristics are generated by using a resonator at the center of a fork-shaped antenna [10] and with a pair of inverted-L-shaped slots on the ground plane [11]. Such antennas have large dimensions in comparison to that proposed in this letter. Moreover, they do not have appropriate H-plane radiation patterns at the high frequencies.

TABLE I
DIMENSIONS OF SOME OF THE EARLIER PUBLISHED ANTENNAS IN COMPARISON TO THE PROPOSED ANTENNA

Some of band-notched UWB monopole antennas	Size of antenna
Slotted planar binomial monopole antenna [4]	30 × 27.4 × 1mm^3
Slotted circular monopole antenna [5]	26 × 27 × 1mm3
Slitted rectangular monopole antenna [6]	16 × 20 × 1 mm3
Conductor-backed plane rectangular antenna [7]	22 × 22 × 1 mm3
Slotted rectangular monopole antenna [8]	18 × 20 × 1 mm3
Slotted arc-shaped edge rectangular antenna [9]	24 × 35 × 0.8 mm3
Fork-shaped antenna [10]	35 × 30 × 0.769 mm3
Rectangular antenna with slotted ground [11]	35 × 35 × 1.6 mm3
Proposed antenna in this letter	15 × 18 × 1 mm3

In this letter, a new band-notched UWB printed monopole antenna with compact size and proper radiation characteristics is presented. Stable H-plane radiation patterns at the high frequencies and wide impedance bandwidth are achieved by designing the lower edges of the radiating patch in the form of arc-shaped step. In order to compensate the effect of minimizing the size of the antenna on the lowest frequency, the radiating patch is notched by removing two squares at the bottom. A vertical metal strip connected to the rectangular ring is embedded in the shovel-shaped slot at the center of the ground plane to achieve the band-stop performance. The band-stop frequency may be controlled by adjusting the dimensions of the filter structure. The simulated antenna using Ansoft High Frequency Structure Simulator (HFSS) provides a VSWR less than 2 in the frequency band from 3.05 to 13.9 GHz, with notch frequency band from 5.13 to 6.01 GHz. The size of this antenna is smaller than the band-notched UWB antennas reported previously [4]–[11]. Dimensions of the proposed antenna and some of the previously published antennas are presented in Table I for comparison.

II. Antenna Design

The geometry of proposed small antenna is shown in Fig. 1. The proposed antenna has a notched and arc-shape stepped rectangular patch connected to the microstrip feed line on the top side of the substrate. The width of the microstrip feed line W_{f}

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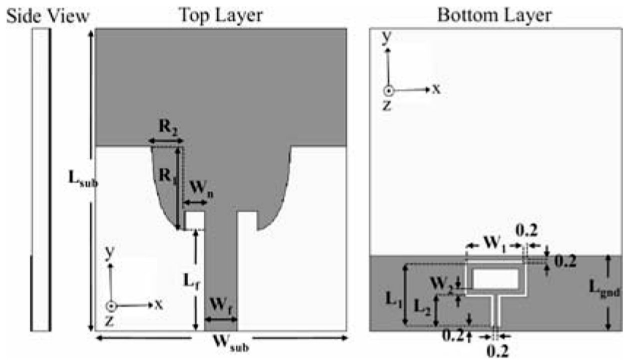

Fig. 1. Geometry of proposed antenna with defected ground structure.

is fixed at 1.9 mm to achieve 50-Ω characteristic impedance. On the other side of the substrate, a conducting ground plane of width W_{sub} and length L_{gnd} is printed.

By designing the lower edges of the radiating patch in the form of arc-shaped step, additional resonance is generated and the impedance bandwidth of the antenna is improved [12], [13]. Moreover, the arc-shaped step balances the vertical and horizontal surface currents on the patch, which results in stable radiation patterns at the high frequencies. The equality between the width of patch and width of the ground plane is also an important factor for having the stable radiation characteristics [2]. The arc-shaped edges of the radiating patch are a quarter-ellipse with major radius of 5 mm and the axial ratio of 2.5. In addition, since the longest current path along the monopole determines the lowest frequency of the band [10], two square notches with the size of 1.2×1.2 mm^2 are created at the bottom of the radiating patch to achieve the desired lowest frequency. The gap distance between the radiating patch and ground plane $(d = L_{\mathrm{f}} - L_{\mathrm{gnd}})$ is another effective parameter on the impedance matching. By adjusting it, the electromagnetic coupling between the lower edge of the patch and ground plane can be properly controlled [14]. In this design, the gap distance is fixed at 1.5 mm. Moreover, in this structure, different and unequal coupling distances between the patch and ground plane are generated due to arc-shaped step on the patch that could help to improve the impedance properties.

To generate notched band, a vertical metal strip connected to the rectangular ring is embedded in the shovel-shaped slot that is located under the feeding line at the center of ground plane. The notch frequency can be controlled by adjusting the dimensions of the filter structure, i.e., L_1 and W_1. In this structure, the center-rejected frequency f_n is approximated by

$$f_n \approx \frac{c}{4L_n\sqrt{\varepsilon_{\mathrm{eff}}}} \tag{1}$$

$$L_n = L_1 + W_1 \approx \frac{\lambda_g}{4} \tag{2}$$

$$\varepsilon_{\mathrm{eff}} \approx \frac{\varepsilon_{\mathrm{r}} + 1}{2} + \frac{\varepsilon_{\mathrm{r}} - 1}{2\sqrt{1 + \frac{12h}{W_{\mathrm{f}}}}} \tag{3}$$

where $c, \varepsilon_{\mathrm{eff}}, \varepsilon_{\mathrm{r}}, h$, and W_{f} are the speed of light in free space, effective dielectric constant, dielectric constant, thickness of substrate, and the width of the feed line, respectively. L_n is the current path along the vertical metal strip and rectangular ring. The bandwidth of the filter is affected by the width W_2 and length L_2. Moreover, the filter structure is simulated on the number of substrates with different thicknesses. As a result, the VSWR at the notched band is decreased with increasing the thickness of the substrate, and vice versa. Therefore, the performance of the filter structure is affected by the feed-line structure.

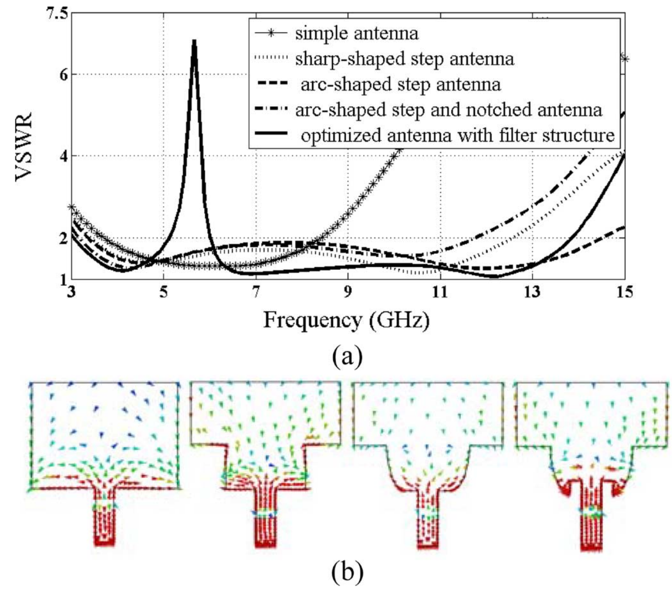

Fig. 2. (a) Simulated VSWR curves for the proposed antenna with different structures of radiation patch. (b) Simulated current distributions on the different structures of the patch for the proposed antenna without filter structure at 12 GHz.

The design values of the antenna parameters are $W_{\mathrm{sub}} = 15$ mm, $L_{\mathrm{sub}} = 18$ mm, $W_{\mathrm{f}} = 1.9$ mm, $L_{\mathrm{f}} = 6$ mm, $R_1 = 5$ mm, $R_2 = 2$ mm, $W_n = 1.2$ mm, $L_1 = 3.8$ mm, $W_1 = 3.4$ mm, $L_2 = 2$ mm, and $W_2 = 0.4$ mm. This antenna is fabricated on an inexpensive FR4 substrate with size of 15×18 mm^2, thickness of 1 mm, and relative permittivity of 4.4, which is connected to a 50-Ω SMA connector for signal transmission.

III. Results and Discussions

To understand the effects of the antenna's geometry on its performance, in this section the parametric study is carried out by changing one parameter at a time and fixing the others. Fig. 2 shows the effects of different structures of the patch and filter structure on the impedance matching and surface current distributions on them. It is found that by creating a step on the lower edges of the patch, impedance bandwidth is improved especially at the high frequencies. This phenomenon occurs because the step affects the electromagnetic coupling between the rectangular patch and the ground plane [14]. Because of the existence of discontinuity on the patch and more flexibility of the surface current path compared to the simple antenna, the higher resonant mode of the antenna can be excited [15]. As a result, an additional resonant frequency appears that is tunable by adjusting the parameters of the step. As illustrated in Fig. 2(a), the new resonant frequency occurs at 10.6 GHz for the optimized sharp-shaped-step antenna, and it increases to 12 GHz for the same antenna with optimized arc-shaped step. Hence, much enhanced impedance bandwidth at the high frequencies and so

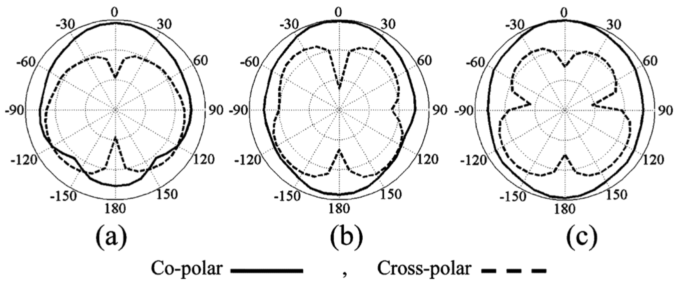

Fig. 3. Normalized H-plane patterns of the (a) simple antenna, (b) sharp-shaped-step antenna, and (c) proposed antenna at 12 GHz using optimal parameters mentioned in Fig. 1.

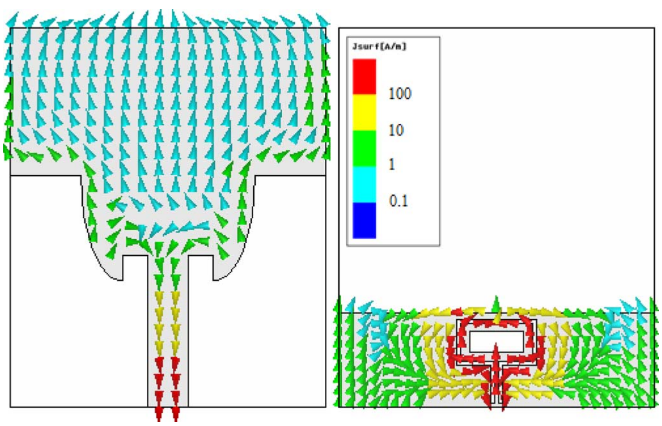

Fig. 4. Simulated current distributions on the patch and ground plane at the notch frequency.

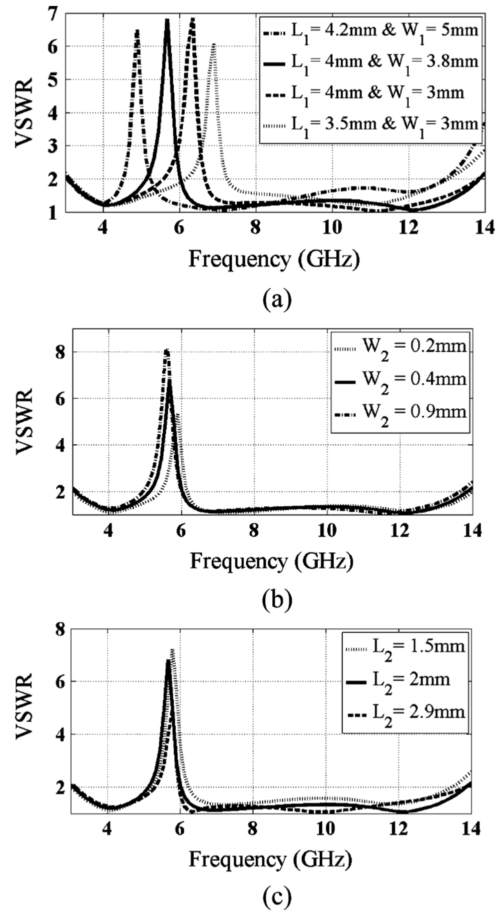

Fig. 5. Simulated band-rejection characteristics of the proposed antenna for (a) various L_1 and W_1, (b) various W_2, and (c) various L_2.

maximum bandwidth from 3.4 to 14.5 GHz is generated for the arc-shaped-step antenna. However, with respect to frequency band defined by the FCC for UWB applications, which is from 3.1 to 10.6 GHz, the desired lowest frequency of the band has been not obtained by the step. Therefore, two squares are removed at the bottom of the radiating patch to achieve the desired lowest frequency. With the square notches at the bottom of patch, the lowest frequency decreases from 3.4 to 3.1 GHz, and the upper frequency shifts downward from 14.5 to 11.8 GHz. Therefore, the required frequency band for UWB applications is achieved by using the arc-shaped step and notches on the patch simultaneously.

The simulated current distributions on the different structures of the patch for the proposed antenna without filter structure are presented in Fig. 2(b) at 12 GHz. By using the step, we try to obtain a balance between the vertical and horizontal surface currents on the patch. As shown in this figure, the vertical and horizontal surface currents are more balanced by designing the lower edges of the patch in the form of arc-shaped step. This causes stable H-plane radiation patterns at the high frequencies.

To see the effects of different structures of the antenna on the radiation patterns at the higher frequencies, the normalized H-plane patterns of these antennas, at 12 GHz, are presented in Fig. 3. It is clearly seen that by using the step on the patch structure, the stability of the H-plane radiation patterns is improved. However, the H-plane radiation pattern for the arc-shaped-step antenna is considerably more omnidirectional compared to the sharp-shaped-step antenna. Fig. 4 shows the current distributions on the patch and defected ground plane at the center-rejected frequency of 5.7 GHz. The currents mainly concentrate around the filter structure, and they are oppositely directed between the interior and exterior edges of the modified shovel-shaped slot. Also, the direction of the currents in the interior edges of the slot is opposite to the direction of the distributed currents on the feeding line. As a result, the resultant addition fields cancel out, which leads to high attenuation near the notch frequency. Hence, the antenna does not radiate efficiently.

The simulated VSWR curves with different values of the filter structure's parameters, i.e., L_1, W_1, W_2, and L_2 are plotted in Fig. 5. As shown in Fig. 5(a), when total values of L_1 and W_1 increase, the rejection-band region moves toward lower frequency. From these results, we can conclude that the notch frequency is controllable by changing the dimensions of the modified shovel-shaped slot. Also, the effects of variation in the values of W_2 and L_2 on the filter bandwidth are presented in Fig. 5(a) and (b), respectively. It can be seen that the bandwidth of the filter increases upon increasing W_2 and decreases with increasing L_2. Therefore, the bandwidth of notch frequency is tunable by adjusting W_2 and L_2. The proposed antenna was fabricated according to the optimized dimensions, as shown in Fig. 6. The impedance bandwidth was measured by using an Agilent vector network analyzer.

Fig. 6 shows the measured and simulated VSWR characteristics of the proposed antenna, in which the good agreement

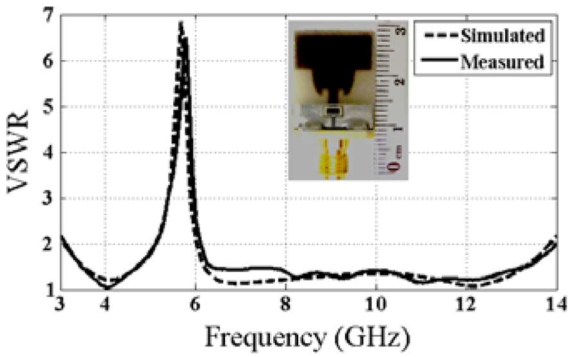

Fig. 6. Measured and simulated VSWRs with the photograph of the fabricated prototype for the proposed antenna.

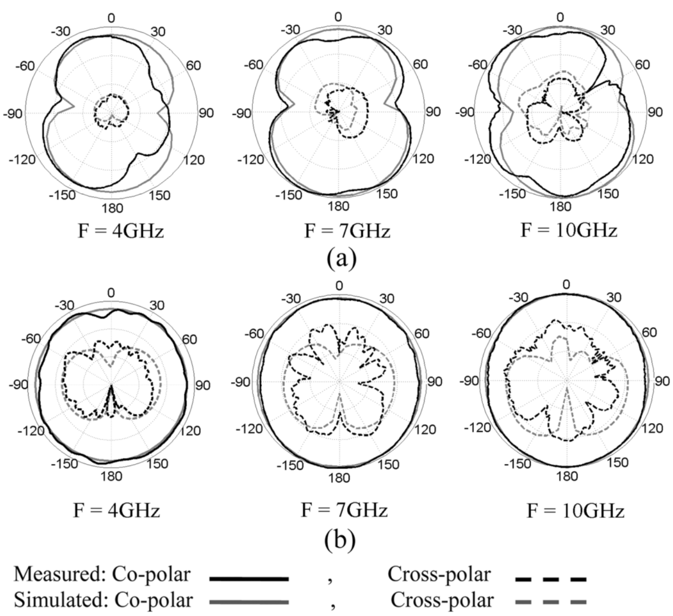

Fig. 7. Measured and simulated radiation patterns at (a) yz-plane and (b) xz-plane.

between the measured and simulated results is observed. The discrepancy between the simulated and measured results could be mainly due to errors in processing and effect of the SMA connector. The fabricated antenna covers the frequency range for UWB systems between 3.1–14 GHz with a rejection band around 5.13–6.1 GHz. Fig. 7 shows the measured and simulated radiation patterns in the H-plane (xz-plane) and E-plane (yz-plane) at the frequencies of 4, 7, and 10 GHz. It can be seen that the radiation patterns in the xz-plane are nearly omnidirectional for the three frequencies. Fig. 8 presents the measured and simulated antennas gain with and without filter structure, where the acceptable agreement between the measured and simulated results is observed. As shown in this figure, by using the filter structure, gain decreases drastically in the notched frequency.

IV. Conclusion

In this letter, a new compact printed monopole antenna with desired band-rejection characteristic, in the frequency band of DSRC systems and WLAN, has been proposed for UWB applications. The fabricated antenna operates in the frequency range

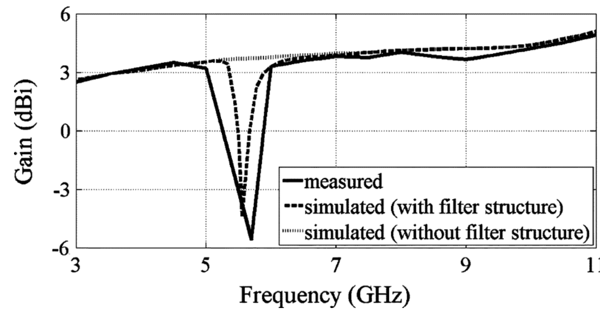

Fig. 8. Comparison between the measured and simulated peak gain of the proposed antenna.

for UWB systems between 3.1–14 GHz with a notched band from 5.13 to 6.1 GHz. The proposed antenna has simple structure and stable omnidirectional H-plane radiation patterns in UWB frequency bandwidth. Measurement results show that the fabricated antenna is suitable for UWB applications.

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