Progress In Electromagnetics Research Letters, Vol. 35, 155–164, 2012

COMPACT TRIPLE-BAND ANTENNA USING DEFECTED GROUND STRUCTURE FOR WLAN/WIMAX APPLICATIONS

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Abstract—A novel triple-band microstrip-fed planar monopole antenna with defected ground structure (DGS) is proposed for WLAN and WiMAX applications. The proposed microstrip-fed antenna consists of a rectangular patch, dual inverted L-shaped strips and a defected ground. The designed antenna can generate three separate resonances to cover both the 2.4/5.2 GHz WLAN bands and the 3.5 GHz WiMAX bands while maintaining a small overall size of 20 mm × 27 mm. A prototype is experimentally tested, and experimental results show that the antenna gives good radiation patterns and enough antenna gains over the operating bands.

1. INTRODUCTION

Recently, with the rapid development of wireless communication, the demand for the design of an antenna with multiband operation has increased. For this demand, the planar monopole antenna has become a candidate because of its attractive characteristics, such as low profile, simple structure, compact size, and easy integration with circuit. Also, the planar monopole antenna is capable of integrating both wireless local area network (WLAN) and worldwide interoperability for microwave access (WiMAX) into one single system. Currently, numerous printed multiband monopole antennas have been proposed by employing various promising feed structures such as the microstrip [1–5] and the coplanar waveguide (CPW) [6–10]. In these proposed monopole antennas, a large solid ground plane having the shape of a square, rectangle, circle, or ellipse is usually adopted. Different from these antennas, a novel ground structure named DGS

Received 28 August 2012, Accepted 22 October 2012, Scheduled 23 October 2012
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has recently been investigated and found to be a simple and effective method to reduce the antenna size as well as excite additional resonance modes [11–15].

In this letter, a novel triple-band monopole antenna with defected ground structure is proposed. The antenna consists of a radiating element with a pair of inverted L-shaped protruding strips, and the ground modified by loading it with a U-shaped strip and an E-shaped strip. By properly selecting the dimensions of the proposed antenna, it can provide three impedance bandwidths of 0.26, 0.34 and 0.24 GHz for the working bands of 2.37–2.52 GHz, 3.39–3.72 GHz, and 5.13–5.36 GHz, respectively. The antenna is simulated using ANSYS HFSS and fabricated. The simulated and measured results are presented in good agreement. The effects of the key structure parameters on the antenna performance are also analyzed and discussed in Sections 2 and 3.

2. ANTENNA DESIGN AND SIMULATION

The proposed triple-band antenna with DGS is shown in Fig. 1. It is designed on a 1 mm thick FR-4 substrate with relative permittivity of 4.4, and the overall dimensions are only $20.0 \times 27.0\,\text{mm}^2$.

The radiating patch of the antenna, which is printed on the top of the substrate, consists of a rectangular patch with dimensions of $h_3 \times pw_3$ and dual inverted L-shaped strips located two sides of rectangular patch. Each of the inverted L-shaped strips comprises

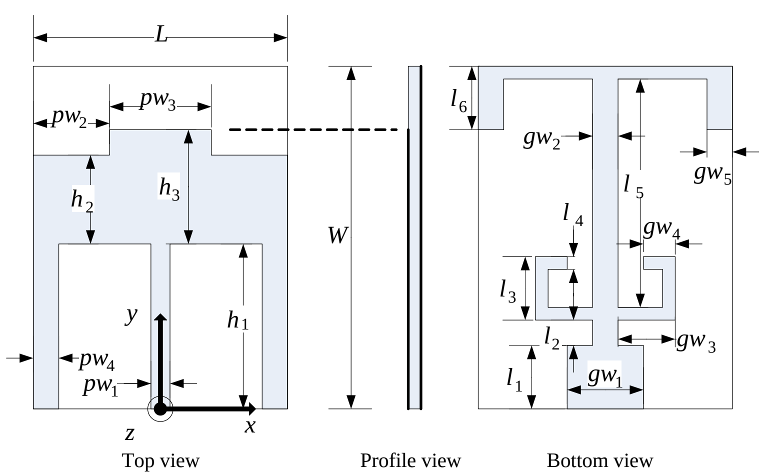

Figure 1. Schematic configuration of the proposed antenna.

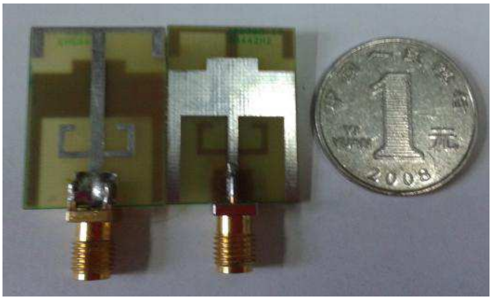

Figure 2. Photograph of fabricated antenna.

Table 1. Optimal parameters of the proposed triple-band antenna (mm).

L	W	h_1	h_2	h_3	pw_1	pw_2	pw_3	pw_4	l_1
20	27	13	7	9	1.5	6	8	2	5
l_2	l_3	l_4	l_5	l_6	gw_1	gw_2	gw_3	gw_4	gw_5
2	5	2	18	5	6	2	4.5	2.5	2

both the vertical and horizontal strips with dimensions of $h_1 \times pw_4$ and $h_2 \times pw_2$, respectively. The antenna is fed by a $50\,\Omega$ microstrip feed line with dimensions of $h_1 \times pw_1$. In regard to the defected ground plane, it consists of three sections. The first section is a step-shaped rectangular ground, with the dimensions of $l_1 \times gw_1$ and $l_2 \times gw_2$. The second part is a U-shaped strip, which consists of vertical and horizontal rectangles. An E-shaped strip with extended middle transverse line is the third part. For detailed model, all parameters of the proposed antenna are optimized using the ANSYS HFSS commercial software and shown in Table 1. Fig. 2 shows the photograph of the fabricated antenna.

The design evolution of the proposed antenna and its corresponding return losses are shown in Fig. 3. Trace (III) shows three resonant bands at frequencies of 2.43, 3.54 and 5.25 GHz with bandwidths of about 160, 340 and 240 MHz, respectively. Other traces show the return losses of the antenna without DGS or dual inverted L-shaped strips. Note that in these cases all the unmentioned parameters are the same as listed in Table 1. For the antenna without defected ground structure (i.e., using the $20 \times 27\,\mathrm{mm}^2$ solid ground plane for the proposed antenna), Trace (I) indicates that there is only one band about 3.5 GHz and a worse matching condition. It is generated by the radiator patch with dual inverted L-shaped strips, where the electric length of radiator route is almost $0.25\lambda_0$ (λ_0 is the free space wavelength at

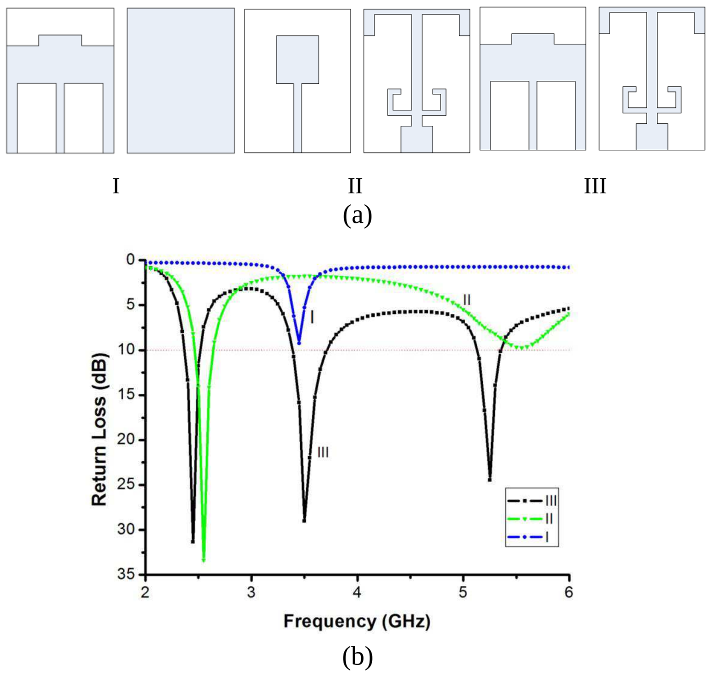

Figure 3. (a) Design evolution of the proposed triple-band antenna, and (b) its corresponding simulated return loss results.

3.5 GHz). In regard to the antenna without dual inverted L-shaped strips, trace (II) shows two resonant modes at 2.5 and 5.5 GHz. Meanwhile, the matching condition of the highest band is worse. It is worth noticing that the current path length of the E-shaped strip is close to $0.25\lambda_0$ at 2.5 GHz. Meantime, the current path length of the U-shaped strip is almost $0.25\lambda_0$ at 5.5 GHz. Comparing with the three traces, it is seen that the radiator patch with dual inverted L-shaped strips not only significantly improve the impedance matching conditions for the highest bands, but also can make the lowest and highest bands shift slightly.

3. RESULTS AND DISCUSSION

The prototype of the proposed antenna with optimal dimensions, as listed in Table 1, was constructed and experimentally investigated. The simulated and measured return losses of the proposed antenna are shown in Fig. 4. The return loss of proposed antenna was measured by

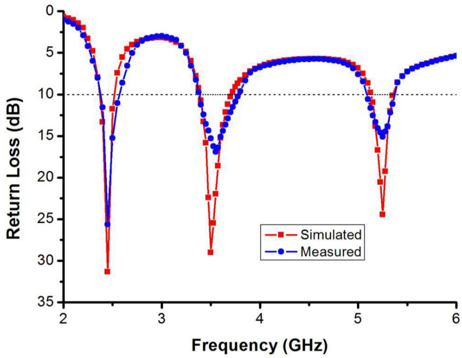

Figure 4. Simulated and measured return losses of the proposed antenna.

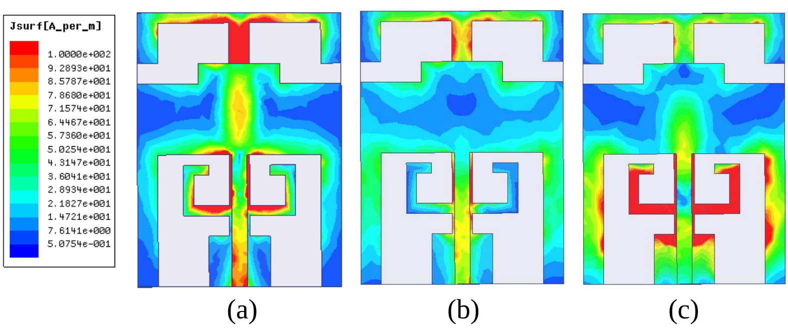

Figure 5. Simulated surface current distribution at (a) 2.45 GHz, (b) 3.5 GHz, (c) 5.25 GHz.

using the Agilent E8357A vector network analyzer. Obviously, three resonant modes at frequencies of 2.43, 3.54, and 5.25 GHz are obtained. The measured impedance bandwidths are about 180 MHz (2.38–2.56 GHz), 380 MHz (3.39–3.77 GHz), and 280 MHz (5.08–5.36 GHz), which cover both the 2.4/5.2 GHz WLAN bands and 3.5 GHz WiMAX bands.

In order to further study the excitation mechanism of the proposed antenna, the simulated surface current distributions of the whole antenna at the frequencies of 2.45, 3.5, and 5.25 GHz are given in Fig. 5. It can be clearly seen that the current distributions are different in the three bands. Obviously, for the lowest band excitation at 2.45 GHz, most of the surface current flow along the extended middle transverse line of E-shaped strip of the DGS to other transverse lines as shown

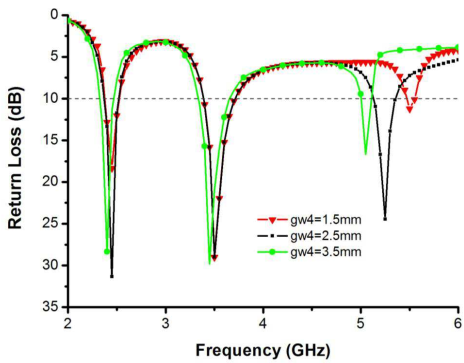

Figure 6. Simulated return losses for different gw_4.

in Fig. 5(a). It indicates that the E-shaped strip generates the first resonant mode at 2.45 GHz. The strong surface current at 3.5 GHz are concentrated along both the radiator with dual inverted L-shaped strips and longitude portion of the DGS as shown in Fig. 5(b). Fig. 5(c) shows that the current distributions are mainly around the U-shaped strip of DGS at 5.25 GHz.

According to the current distribution on the proposed antenna, we studied the influence of the related geometrical dimensions on the impedance matching conditions. Fig. 6 presents the simulated return loss curves for different values of gw_4. Obviously, varying the strip length would seriously affect the third operation band impedance matching, whereas less change is seen for the first and second operation bands. As for other bands, corresponding parameters have similar effect on them. The above analyzed results are in accordance with the current distribution and vital for designing the triple-band antenna.

The simulated and measured far-field radiation patterns at 2.45, 3.5, and 5.25 GHz in the yoz plane (E-plane) and xoz plane (H-plane) are plotted in Fig. 7, respectively. Because of the symmetrical structure, rather symmetrical radiation patterns are seen in the xoz and yoz planes as depicted in the plots. The radiation patterns are omni-directional in the H-plane and monopole-like in the E-plane. In addition, it is also found that the Cross-polar in the highest band is comparable to the Co-polar. This electromagnetic phenomenon may be caused by the fact that the horizontal components and vertical components of the surface current are comparable.

The measured and simulated antenna peak gains are shown in Fig. 8. The peak antenna gains were measured by applying the gain comparison method, in which a precalibrated standard gain antenna

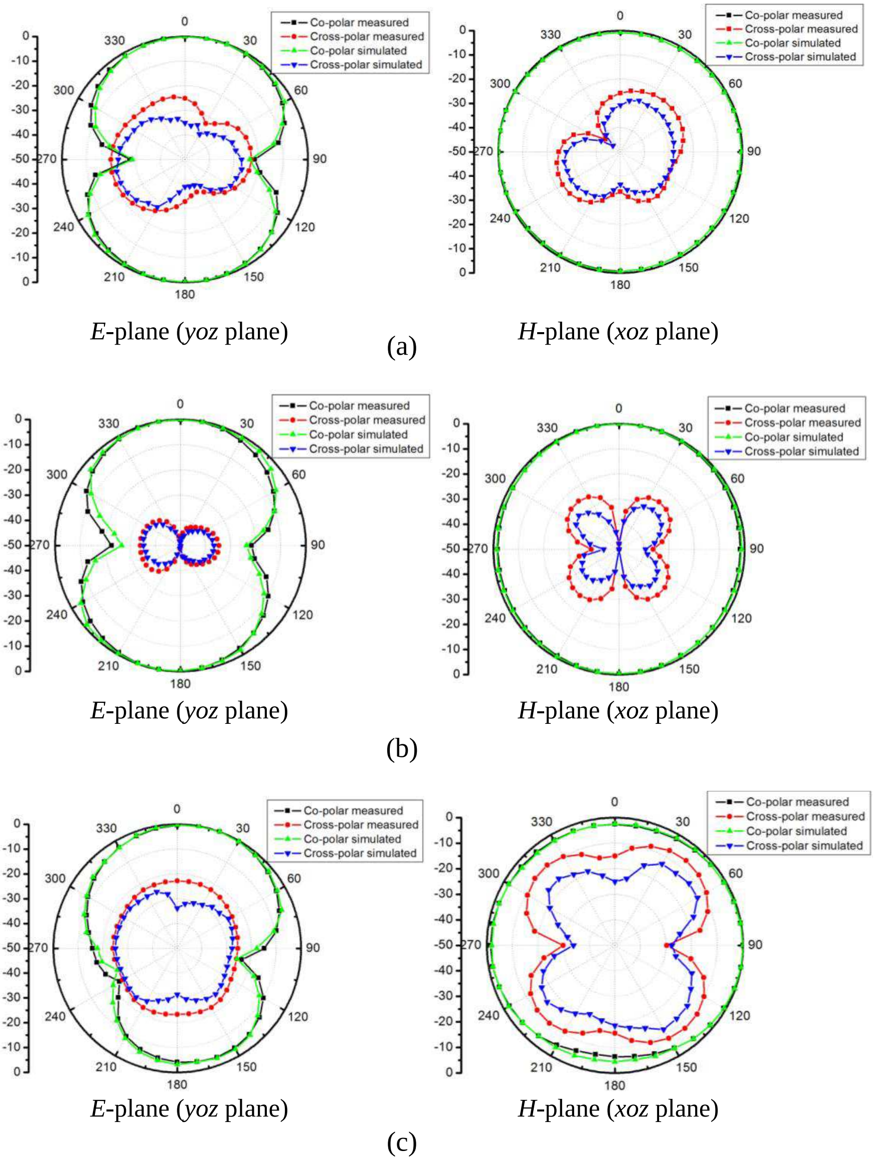

Figure 7. Simulated and measured radiation patterns for proposed antenna at (a) 2.45 GHz, (b) 3.5 GHz, and (c) 5.25 GHz.

is used to determine the absolute gain of the antenna under test. As can be seen, stable gain variation across the three desired bands has been obtained. For the 2.37–2.52 GHz working band, the gain

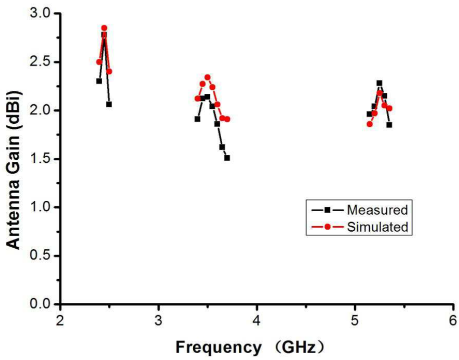

Figure 8. Simulated and measured peak gains across operating bands of proposed antenna.

varies from 2.06 to 2.78 dBi. Results in the medium band of 3.39–3.72 GHz, the peak gain and gain variation are 2.14 dBi and 0.75 dBi, respectively. The measured peak gain within the highest operating band is stable, which varies from the 1.84 to 2.14 dBi. Therefore, the gain of the proposed antenna within the operating bands satisfies the requirement of wireless communication terminals for WLAN and WiMAX operations.

4. CONCLUSION

A compact triple-band DGS antenna for WLAN/WiMAX applications has been proposed. By employing the DGS and dual inverted L-shaped strips, the proposed antenna can excite suitable triple-resonances while maintaining small size and simple structure. The antenna prototype has been fabricated and measured, which shows reasonable agreement with the numerical prediction. Effects of varying dimensions of key structure parameters on the antenna performance are studied. The proposed antenna features compact size, good operating bandwidth, and stable radiation patterns, indicating it can be a good candidate for some wireless communication systems.

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