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RESEARCH PAPER

Inverted L-slot triple-band antenna with defected ground structure for WLAN and WiMAX applications

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To incorporate two different communication standards in a single device, a compact triple-band antenna is proposed in this paper. The proposed antenna is formed by etching an inverted L-shaped slot on the patch with defected ground structure. The antenna is targeted to excite three separate bands first from 2.39–2.51, second from 3.15–3.91, and third from 4.91–6.08 GHz that covers entire Wireless Local Area Network (WLAN) (2.4/5.2/5.8 GHz) and Worldwide Interoperability for Microwave Access (WiMAX) (2.5/3.5/5.5) bands. Thus, the proposed antenna provides feasibility to integrate WLAN and WiMAX communication standards in a single device with good radiation pattern quality. Furthermore, a prototype of the proposed antenna fabricated and measured to validate the design, shows a good agreement between simulated and measured results. The simulation and measurement results show that the designed antenna is capable of operating over the 2.39–2.51 GHz, 3.15–3.91 GHz, and 4.91–6.08 GHz frequency bands while rejecting frequency ranges between these three bands. The proposed antenna offers a compact size of 20 × 30 mm² as compared with earlier reported papers.

Keywords: Defected ground plane, Triple-band antenna, Slot antenna, WiMAX/WLAN applications

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I. INTRODUCTION

Modern wireless communication devices are required to support multi-standards and multi-services operating at different frequency bands. Thus, the designing of multi-band antenna has been the focus of research in recent years as multi-band antennas are able to resonate over several bands which leads to integration of different communication standards operating at different and nearby frequency bands in a single device. Multi-band antennas can be thought of as an intermediate solution combining simplicity and multi-frequency operation. Some wireless communication applications of antennas are required to simultaneously operate for Wireless Local Area Network (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX) technology. The operating bands for these technologies as assigned by IEEE 802.11 are 2.4 GHz (2.4–2.484 GHz), 5.2/5.8 GHz (5.15–5.35 GHz/5.725–5.825 GHz), and 2.5/3.5/5.5 GHz (2.5–2.69/3.4–3.69/5.25–5.85 GHz). Several antenna configurations have been suggested for WLAN and WiMAX bands in recent years, such as a dual-band antenna [1], asymmetric M-shaped triple-band antenna [2], a compact triple-band microstrip slot antenna [3], miniaturized triple-band antenna with a defected ground plane [4], and dual wideband antenna [5]. In [6], a compact planar dielectric-loaded, multiple-band antenna is presented. A frequency agile triple-band microstrip antenna using defected ground structure (DGS) for WLAN/WiMAX application is presented in [7]. In [8], an antenna with symmetrical L-strips is presented. This antenna is composed of a square slot, a pair of L-strips, and a monopole radiator fed with coplanar waveguide (CPW) feed line which makes its structure complex. Furthermore, a H-shaped multi-band antenna is presented in [9]. A planar inverted-F antenna in conjunction with a parasitic element is reported in [10]. In [11], compact triple-band printed antenna is reported that consists of three simple circular-arc-shaped strips. It has complex structure which limits its practical application. A CPW-fed tri-band printed antenna with meandering split-ring slot for WLAN/WiMAX applications is presented in [12]. In [13], a square ring, an open ended stub, and an inverted T-shaped stub are used to achieve triple-band operation. The microstrip-fed antenna which consists of a rectangular patch, dual inverted L-shaped strips, and a defected ground is proposed for WLAN/WiMAX band [14].

In this paper, a compact triple-band antenna with DGS for WLAN and WiMAX applications is proposed. It provides three impedance bandwidths of 2.39–2.51 GHz (70 MHz), 3.15–3.91 (760 MHz), and 4.91–6.08 GHz (1170 MHz), respectively. The proposed antenna is compact in size (20 × 30 mm²) and simple in configuration. A prototype of the antenna has been constructed and demonstrates satisfactory

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Table 1. Performance comparison of the proposed antenna with other reported antennas.

Ref. number	Size (mm × mm)	Operating bands (GHz)
[1]	63.865 × 52.96	2.4–2.52, 5.1–5.85
[2]	64 × 62	2.38–2.49, 3.49–3.63, 5.57–6.20
[3]	35 × 30	2.4–3.0, 3.25–3.68,4.9–6.2
[4]	38 × 25	2.4–2.7, 3.1–4.15, 4.93–5.89
[5]	28 × 33	2.24–2.81, 3.35–6.51
[6]	58 × 62	1.9–2.45, 5.1–5.85
[7]	20 × 30	2.0–2.15, 2.75–3.52, 5.4–5.9
[8]	28 × 32	2.34–2.82, 3.16–4.06, 4.69–5.37
[9]	60 × 60	2.395–2.695, 4.975–5.935
[10]	90 × 50	2.36–2.52, 5.10–5.90
[11]	18 × 37	2.38–2.78, 3.28–3.76, 4.96–5.96
[12]	23 × 36.5	2.33–2.76, 3.05–3.88, 5.57–5.88
[13]	24 × 36	2.3–2.76, 3.387–3.73, 4.97–6.28
[14]	20 × 27	2.37–2.52, 3.39–3.72, 5.13–5.36
Proposed antenna	20 × 30	2.39–2.51, 3.15–3.91, 4.91–6.08

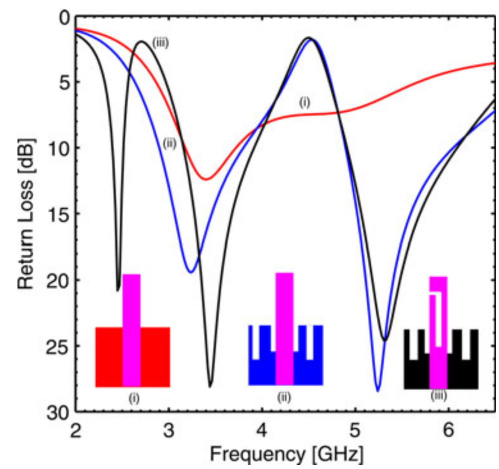

Fig. 2. Simulated return loss against frequency for the various antenna configurations.

performance. Table 1 illustrates the useful fact about the antennas recently proposed for WiMAX/WLAN applications. From the Table 1, it is evident that the proposed antenna has smallest size as compared with the other mentioned antennas with a sufficient bandwidth at all three bands to cover entire WLAN and WiMAX bands. Details of antenna design, the simulated and measured results are presented and discussed in the following sections.

II. ANTENNA DESIGN AND SIMULATION APPROACH

The schematic configuration of the proposed microstrip-fed planar monopole antenna for triple-band operation is shown in Fig. 1. The slot antenna is printed on a FR4 substrate with a thickness of 1.6 mm and a relative permittivity of 4.4 and loss tangent 0.02. For the purpose of compactness, the width of the radiator is set to be the same as that of the microstrip feed line. The antenna consists of a rectangular radiating patch with an inverted L-shaped slot of length L_{p1} and width W_{p2}. The conventional solid ground plane is converted into DGS by cutting rectangular slots to excite lower and higher resonant bands and to achieve compactness. The antenna is fed with 3 mm wide microstrip line to achieve 50 Ω-characteristic impedance.

Figure 2 illustrates the return loss of rectangular patch radiator and DGS. It is clearly evident from the Figure (curve (ii)) that by cutting three slots in a half solid ground, two resonant modes are excited, one at same resonant mode of the original ground plane and other resonant mode at the higher frequency due to DGS with good impedance matching in both the bands. Furthermore, curve (iii) illustrates that another resonant band at low frequency is also excited due to the insertion of the inverted L-slot in the radiating patch. Therefore, by cutting these rectangular slots in the ground plane (i.e. making DGS) and inverted L-slot in the rectangular radiating

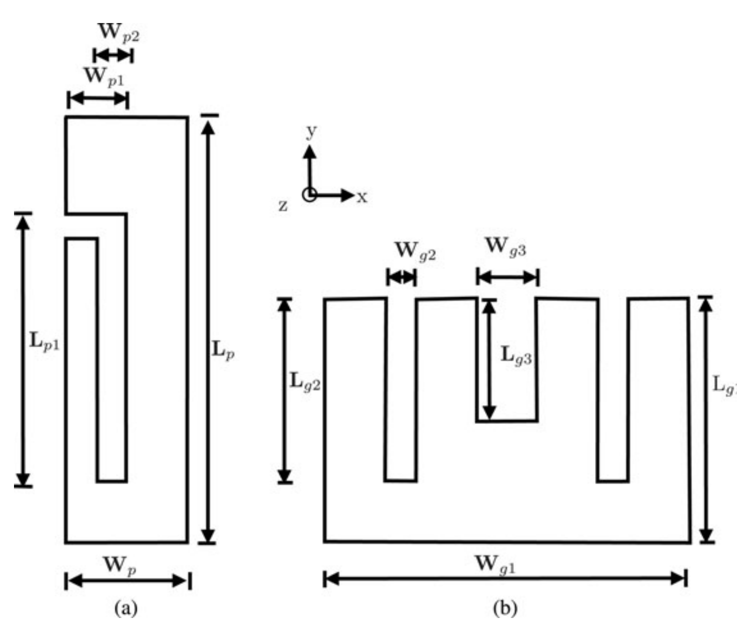

Fig. 1. Schematic configuration of the proposed inverted L-slot triple-band antenna.

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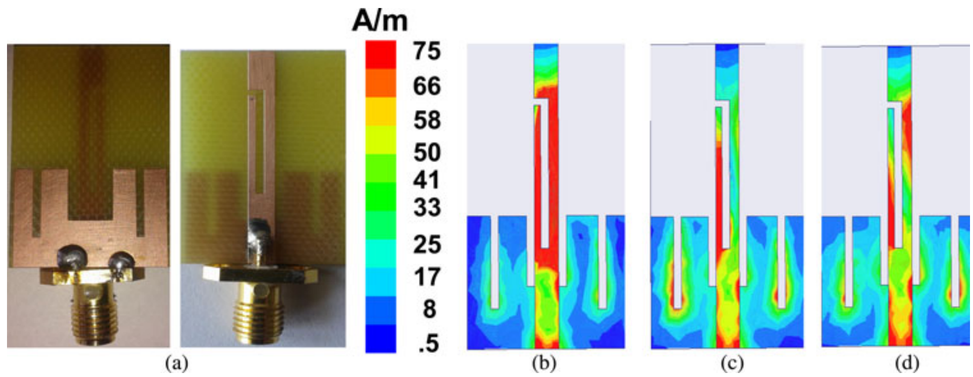

Fig. 3. Simulated surface current distributions at various frequencies of the proposed antenna.

Table 2. Design parameters of the proposed antenna.

Parameters	Unit (mm)	Parameters	Unit (mm)
L_p	30	W_{g2}	1
L_{p1}	14.7	W_{g3}	5
W_{p1}	1.8	L_{g1}	13
W_{p2}	1	L_{g2}	9.1
W_{g1}	20	L_{g3}	6.9

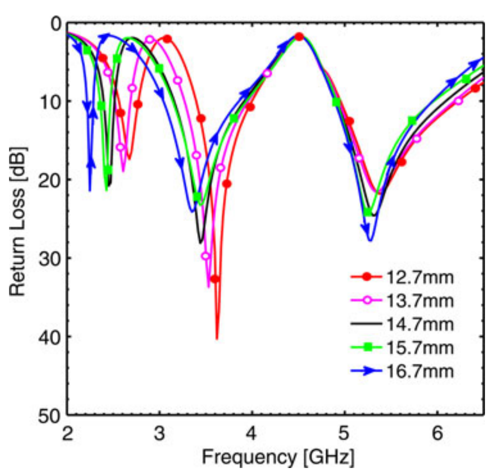

Fig. 4. Simulated return loss against frequency for the proposed antenna with various L_{p1} other parameters are the same as listed in Table 2.

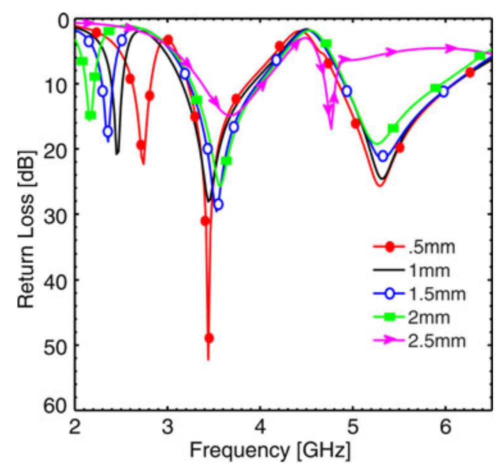

Fig. 5. Simulated return loss against frequency for the triple-band antenna with various W_{p2} other parameters are the same as listed in Table 2.

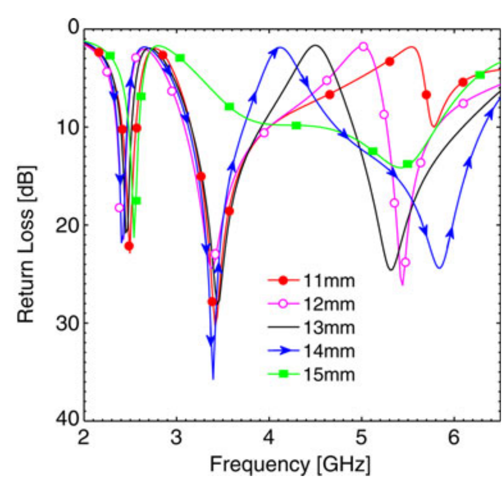

Fig. 6. Simulated return loss against frequency for the triple-band antenna with various L_{g1} other parameters are the same as listed in Table 2.

patch, three resonances will be excited with a good impedance matching.

To clarify the phenomenon behind the excitation of triple-bands in inverted L-slot antenna with DGS, the surface electrical currents of the proposed antenna at three frequencies 2.5, 3.5, and 5.5 GHz are shown in Fig. 3. It is evident from the Fig. 3(b) that the lower band around 2.5 GHz is excited mainly due to the inverted L-slot. Fig. 3(c) and 3(d) reveals that the other two bands are excited mainly due to DGS.

III. PARAMETRIC STUDY

The final antenna design is achieved by tuning the length, width, and the slot dimensions of the radiating patch and the DGS. To understand the influence of these parameters on the antenna performance, a parametric study on the triple-band antenna is carried out. From the parametric study, the optimum value for each parameter of the proposed antenna is obtained as listed in Table 2. Ansoft "High Frequency Simulation Structure" (HFSS) simulator [15] is used to perform the parametric study of the design.

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A) Variation of patch parameters

The dimensions of patch slot are critical parameters in determining the sensitivity of impedance matching at lower resonant band. The effect of the parameter L_{p1}, length of the inverted L-slot, on the magnitude of the reflection coefficient of the antenna is depicted in Fig. 4 as L_{p1} is varied from 12.7 to 16.7 mm. It can be seen from the Fig. 4 that the lower frequency band shifts toward lower frequency as L_{p1} is increased from 12.7 to 14.7 mm. It is also found that L_{p1} slightly affects the middle band while the third resonant band almost remains unchanged. Thus, the results indicate that the optimum value of L_{p1} is 14.7 mm. The effects of slot width W_{p2} on the impedance bandwidth and reflection coefficient are depicted in Fig. 5. It can be observed from the simulation results that as the value of W_{p2} increases from 0.5 to 2 mm, the lower band shifts toward lower frequency with a degradation in impedance matching with minimum effect on the middle and higher bands. The antenna shows dual band operation with furthermore increase in the value of W_{p2}. Thus, the value of W_{p2} is chosen 1 mm as optimum to excite the lower band 2.5 GHz.

B) Variation of ground parameters

Keeping all the dimensions invariant, the simulated return loss for different values of ground length L_{g1} is depicted in Fig. 6. The impedance bandwidth of the third band is improved with the length L_{g1}. With $L_{g1} = 11$ mm only two resonating bands are formed. Furthermore, at the length = 12 mm, three resonating bands are obtained but third band has very less bandwidth. Finally, at 13 mm value of L_{g1}, all desired three resonating bands are obtained and further increase in length reduces the bandwidth of the second band and dual resonating bands are obtained. Hence, the value of $L_{g1} = 13$ mm is chosen as an optimum. The effect of length L_{g2} of the ground plane on the performance of antenna is depicted in Fig. 7. It is keenly observed that as the length is varied from 7.1 to 9.1 mm, impedance bandwidth of second and third resonating bands are greatly increased. Furthermore, increase in length increases the bandwidth of the third band but simultaneously decreases bandwidth of second resonating band. Thus, the optimum value for the length L_{g2} of the ground plane is chosen as 9.1 mm.

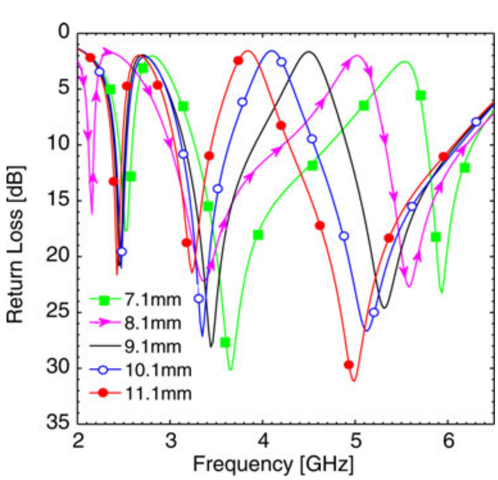

Fig. 7. Simulated return loss against frequency for the triple-band antenna with various L_{g2} other parameters are the same as listed in Table 2.

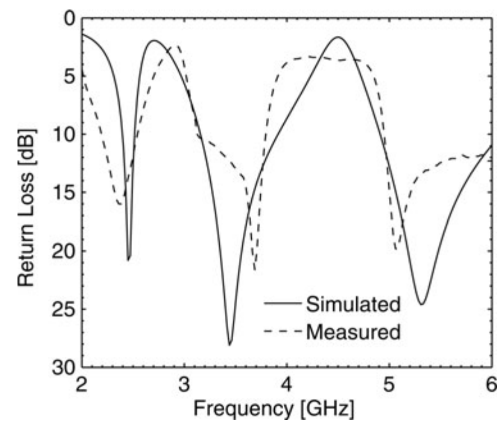

Fig. 8. Measured and simulated results of the return loss of proposed triple-band antenna.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

To verify the design, antenna is practically fabricated on epoxy FR4 substrate, the photograph of the fabricated antenna is illustrated in Fig. 3(a). An Agilent N5230A vector network analyser is used to measure the electrical performance of the proposed antenna such as return loss, radiation patterns. Measured and simulated results for the return loss of the antenna are shown in Fig. 8 that shows a good agreement between simulation and measurement for the relative bandwidth. It is found that proposed design shows triple-band operation i.e. first band from 2.39 to 2.51 GHz, second band from 3.15 to 3.91 GHz, and third band from 4.91 to 6.08 GHz which evidently covers entire WiMAX (2.5/5.8/3.5-GHz) and WLAN (2.4/5.2/5.8-GHz) bands.

Gain and efficiency variations with the frequency are shown in Fig. 9. It is found that the gain remains consistent through all three bands and varies from 1.9 to 6 dB. It is also observed from the Fig. 9 that the radiation efficiency of the antenna is varied from 60 to 90%. Both gain and efficiency drop drastically for frequencies other than resonant bands. Figure 10(a)–10(c) shows the 2D far-field radiation patterns in the H- and E-planes at sampling frequencies of 2.5, 3.5, and 5.5 GHz, respectively. In these figures, good omni-directional radiation characteristics are observed. However, the measured result shows some deviation from the simulated

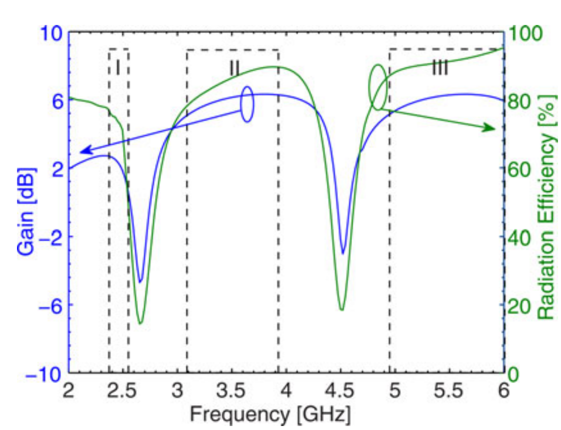

Fig. 9. Gain and Efficiency of proposed compact triple-band antenna.

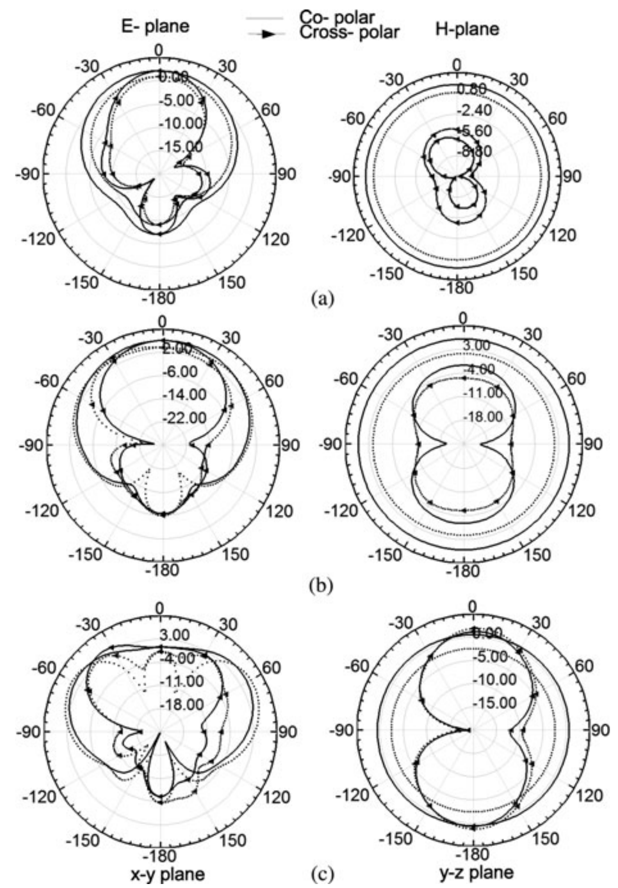

Fig. 10. Measured and simulated radiation patterns at (a) 2.5 GHz, (b) 3.5 GHz, and (c) 5.5 GHz resonance frequencies. Measured – and Simulated –.

result; this may be due to fabrication imperfection or because measurement is carried out in the scattering environment.

V. CONCLUSION

A compact triple-band planar antenna with an inverted L-slot on the radiating patch with DGS is presented for WLAN/WiMAX applications. The antenna generates three resonant bands to integrate WiMAX and WLAN communication standards in a single device. The measured and simulated results show that the omni-directional radiation characteristics and the impedance bandwidth are very suitable for the WLAN and WiMAX applications. The proposed antenna provides sufficiently large band width in all three frequency bands with compact and simple structure.

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