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Dual-Band Slotted Patch Antenna with Defective Ground for WLAN/WiMAX Applications

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Abstract—A novel printed antenna with a slotted patch and a defected ground structure (DGS) for dual-band operation is presented. By inserting an I-shaped slot into the patch and defecting the ground plane, triple-mode resonance for achieving dual operation bands, especially an extremely wide bandwidth for the higher band, can be excited. The measured bandwidths are 100 MHz (2.38–2.49 GHz) and 2.94 GHz (3.4–6.34 GHz) for the lower and upper bands, respectively, which agree well with the simulation. The experimental average gains across the two operating bands are 1.0 and 3.9 dBi, respectively, with typical radiation patterns for a patch antenna having a defective ground. The proposed antenna with a compact size of only $22 \times 25\,\mathrm{mm}^2$ sufficiently covers performance requirement of the 2.4/5.2/5.8 GHz WLAN and the 3.5/5.5 GHz WiMAX operation systems.

1. INTRODUCTION

During the last decades, as wireless communication systems such as the wireless local area network (WLAN) and the worldwide interoperability for microwave access (WiMAX) have become more and more popular and important, the need of an antenna designed with a compact size, simple structure, low profile, flush mounted, and single-feed but with an enhanced dual- or multiband capability to simultaneously satisfy the multisystem standards increases. Thus far, many efforts and a lot of antenna prototypes have been made and designed. The adopted techniques for these antennas generally include notching or slotting the radiating patch, or increasing number of the radiating strip for additional-mode excitation [1–8], and defecting the ground for bandwidth enhancement [9–11] with using various feed structures, which may be the probe, stripline and co-planar waveguide (CPW) feeders. However, a large size or a complicated structure is the usual problem for most of these proposed antennas to thus reduce their practical application in a wireless communication system.

In this paper, we attempt to design a compact planar antenna with both a simple structure and multi-band operation simultaneously suitable for use in a full-band WLAN/WiMAX communication system. Different from most of the appeared designs, which usually have a large ground plane, a technique of using a defected ground has been tested with the aim of miniaturizing the antenna as well as enhancing the bandwidth. Accordingly, a novel design of a compact and simple dual-band printed antenna consisting of a patch inserted with a shaped slot and a defective ground is presented. By properly adjusting dimensions of both the slot and the defective ground, triple resonances with good impedance bandwidths, especially for the higher band, and good radiation characteristics suitable for the 2.4/5.2/5.8 GHz WLAN and the 3.5/5.5 GHz WiMAX communication systems can be achieved.

2. DESCRIPTION OF THE ANTENNA

Figure 1 presents the geometrical configuration with detailed dimensions for the proposed dual-band printed antenna. As shown in the figure, the antenna was printed on the FR4 microwave substrate

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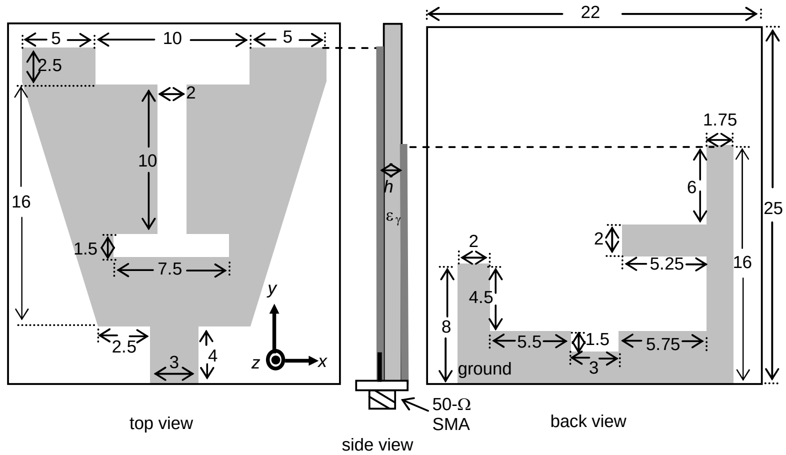

Figure 1. Configuration of proposed dual-band planar slotted patch antenna for WLAN/WiMAX operations (dim. in mm).

with a dielectric constant of 4.4 (ε_γ) and a substrate thickness of 1.6 mm (h). Based on previous design [12], the initial prototype of the proposed antenna was selected for its simple structure and easy excitation for multi-frequency resonance. For reducing the antenna size, dimension of each side of the antenna was first set within $0.2\lambda_0$ (free-space wavelength) with respective to the desired lowest resonant frequency, 2.45 GHz. Thereafter, the initial antenna dimensions were obtained using the commercially available simulator, HFSS, and the optimal dimensions were finally obtained through some iterative simulations and experiment check. For the radiator, it initially comprises an isosceles trapezoid patch with dimensions of 20, 8 and 16 mm for its topline, baseline and height, respectively, and a protrudent rectangular patch with size of $20 \times 2.5\,\text{mm}^2$ on top of the trapezoid patch. The radiator is fed by a stripline with 3 mm in width and 4 mm in length. However, an I-shaped slot is embedded into the radiator from its top edge for exciting a new resonant mode. The obtained optimal dimensions of this inserted slot are $10 \times 2.5\,\text{mm}^2$ and $7.5 \times 1.5\,\text{mm}^2$, respectively, for its upper and lower horizontal sections, and $10 \times 2\,\text{mm}^2$ for its vertical section. As for the ground, it came from a rectangle patch with a size of $18 \times 8\,\text{mm}^2$ and thereafter was not only defected by a T-shaped slot but also extended with an inverted-L shaped strip. These skills have been found with significant effects in improving the matching condition for the lower-band resonance as well as exciting an additional resonance over the higher band to thus result in a broad continuous bandwidth. The T-shaped slot has a horizontal section of $14.25 \times 4.5\,\text{mm}^2$ and a vertical section of $3 \times 1.5\,\text{mm}^2$, while for the inverted-L strip it has $7 \times 2\,\text{mm}^2$ and $6 \times 1.75\,\text{mm}^2$ for the horizontal and vertical sections, respectively. The overall size of the proposed antenna is $22 \times 25\,\text{mm}^2$, which is only about $0.18\sim0.2\lambda_0$ (free-space wavelength) with respective to the lowest resonant frequency, 2.42 GHz, of the proposed antenna.

3. RESULTS AND DISCUSSION

To investigate the performance of the proposed antenna configuration in terms of achieving the dual-band operation the HFSS was used for required numerical analysis. The simulated frequency response of impedance match for the proposed optimal prototype, as depicted in Figure 1, was shown as case (v) of Figure 2. Obviously, triple resonances at 2.42, 4.08 and 5.68 GHz were excited. The produced impedance bandwidths, defined with 10-dB reflection coefficient, are 110 MHz (2.38–2.49 GHz) and 2.43 GHz (3.4–5.83 GHz) for the lower and upper operating bands, respectively. Clearly, the obtained bandwidths sufficiently cover the requirements of the 2.4/5.2/5.8 GHz WLAN and 3.5/5.5 GHz WiMAX operations. For examining the effects of embedding the shaped slot into the patch as well as defecting the ground plane, the evolution process of impedance match for the proposed antenna is also shown in Figure 2. For the antenna denoted as case (i), it is the initial prototype (i.e., without shaped slot and defective ground) and has a forming resonant mode at around 4.2 GHz. The result is reasonable since that the antenna has

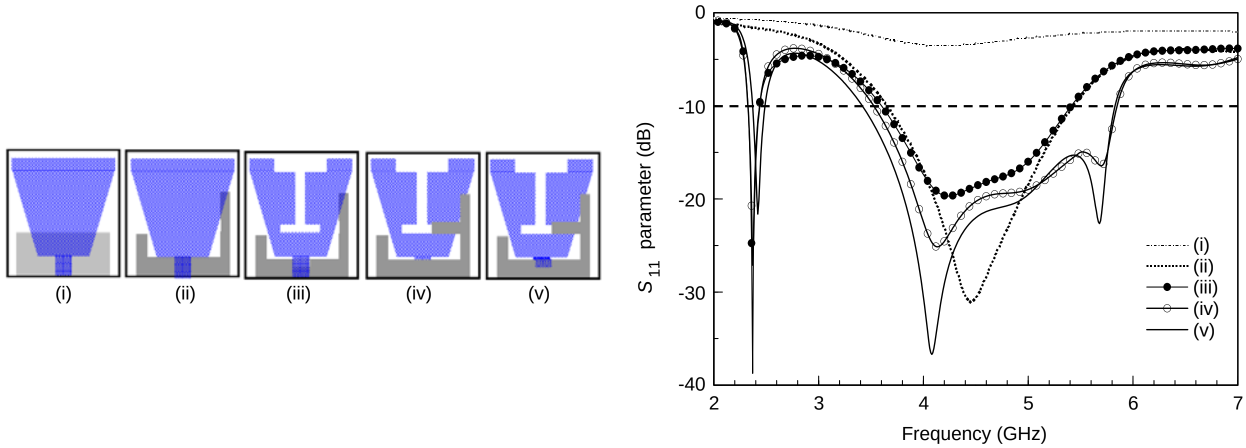

Figure 2. Simulated S_{11} parameters of the proposed antenna with different structures.

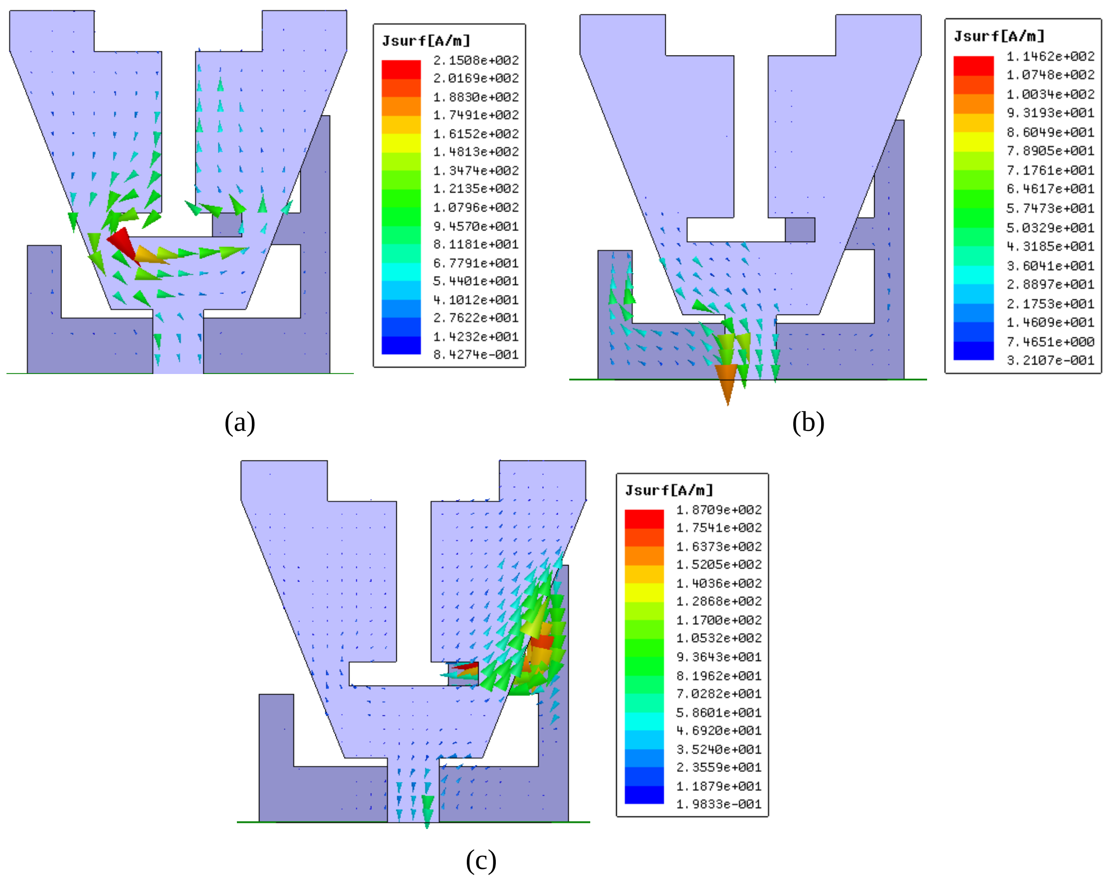

Figure 3. Simulated surface current distributions for the proposed antenna studied in Figure 1: (a) $f = 2.42$ GHz; (b) $f = 4.08$ GHz; (c) $f = 5.68$ GHz.

a shortest current path of about 18.5 mm $(16 + 2.5)$ and which has a correspondent resonant frequency of about 4.1 GHz according to the quarter-wavelength rule in free space. As the ground is defected (i.e., case (ii)), the resonance is found to be not only enhanced but also be accompanied with a much wider bandwidth. Meanwhile, the resonant frequency was shifted to a higher frequency of 4.45 GHz with a wide bandwidth of 1.77 GHz, ranging from 3.65 to 5.42 GHz. Thereafter, the radiator was further inserted with an I-shaped slot. An additional resonant mode at lower frequency was therefore achieved. The lower resonant mode is excited at 2.37 GHz with an operating band over 2.33–2.44 GHz. However, the match condition of the higher band becomes worse, compared to case (ii), though its bandwidth is almost not affected. To improve such a matching degradation at the higher band, a protrudent vertical strip was added to the right-side strip of the defective ground. The modified antenna is shown as case (iv) in Figure 2. Obviously, both the matching condition and the impedance bandwidth are improved for the higher-frequency band due to the third mode excited at 5.7 GHz, while unchanged for the lower-frequency band. The obtained new bandwidth for the higher band is about 2.3 GHz across the frequency of 3.53–5.83 GHz. Finally, a trial of selecting a small rectangle notch and embedding it into the center of the ground from its upper edge has been made. The modified prototype is shown as case (v) in Figure 2. The obtained result clearly shows that the lower band is moved toward a higher frequency of 2.42 GHz, and impedance bandwidth of the upper band is effectively further increased. This case is finally deemed as the obtained optimal design.

The surface current distribution on the proposed design (i.e., case (v) in Figure 2) when operating at the three resonant frequencies, 2.42, 4.08 and 5.68 GHz has been simulated and shown in Figure 3. As discussed for cases of Figure 2, at 2.42-GHz band operation, most surface current is concentrated along the edge of I-shaped slot due to that this band is effectively excited by embedding such a slot into the radiating patch. However, at 4.08-GHz band operation, significant current density is distributed on the defective ground as well as the slotted patch near the defective ground. The reason for this is that this band is produced by defecting the ground. Finally, Figure 3(c) shows most current flows along the inverted-L shaped ground strip when operating at 5.68 GHz. This gives explanation for that the 5.68-GHz resonant mode is mainly excited by adding the horizontal strip to the right-side strip of the DGS.

The prototype of the proposed antenna, denoted as case (v) of Figure 2, was constructed and experimentally investigated. Figure 4 presents the results of the measured and simulated reflection coefficient against frequency. The measurement shows dual impedance bandwidths of 100 MHz (2.38–2.49 GHz) and 2.94 GHz (3.4–6.34 GHz) at the lower and the upper bands, respectively. Agreement between the simulation and measurement is generally good beyond a frequency deviation for the second and third resonances. The normalized far-field radiation patterns obtained from simulation and measurement in azimuthal direction (x-z plane) and the elevation direction (y-z and x-y planes) at WLAN/WiMAX bands, 2.45/3.5/5.25/5.75 GHz, for the proposed antenna are shown in Figure 5. It is seen that the co-polarization (E_θ) and cross-polarization (E_ϕ) are generally comparable due to the comparable vertical and horizontal components of currents distributed on the slotted patch and DGS. According to this, an approximately omnidirectional pattern is produced. Please note that the pattern slightly leaning to one side is mainly caused by longitudinal asymmetry of the DGS. Meanwhile, it is also found the patterns are somewhat different between the lower and the upper bands. This could be attbributed to that the current is most concentrated on center of the patch at the lower band, whereas it is more distributed at side of the patch at the upper band. Finally, Figure 6 presents the measured

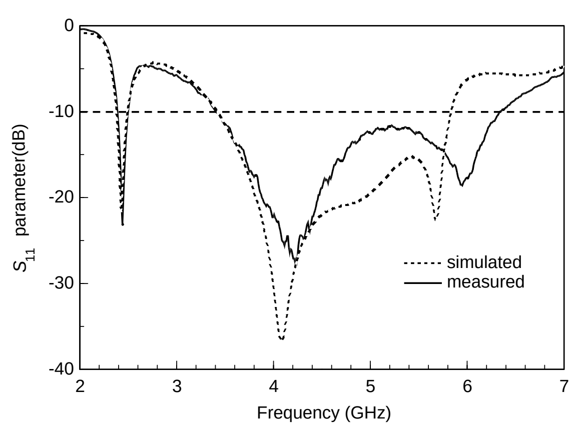

Figure 4. Measured and simulated S_{11} parameters against frequency for the proposed dual-band antenna.

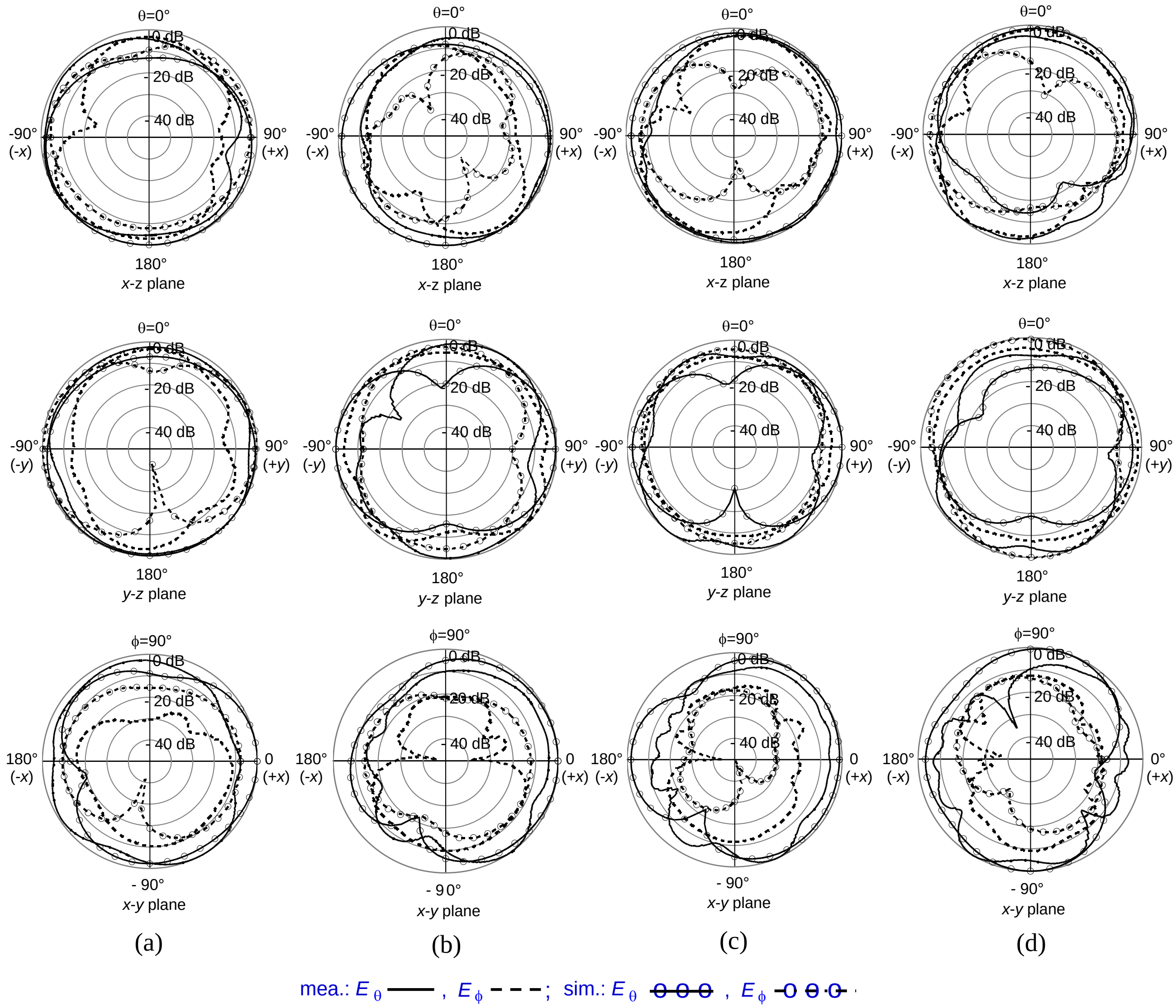

Figure 5. Normalized radiation patterns obtained from simulation and measurement for proposed antenna at (a) 2.45 GHz, (b) 3.5 GHz, (c) 5.25 GHz, and (d) 5.75 GHz.

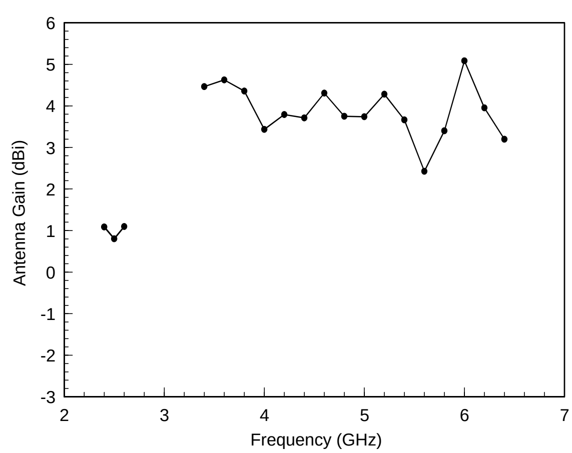

Figure 6. Measured peak antenna gains across the lower and upper bands for the proposed antenna.

peak antenna gain for frequencies across the two operating bands. The antenna provides an average gain of about 1. dBi (0.8–1.1 dBi) and 3.9 dBi (2.4–5.1 dBi) over the lower and upper band, respectively.

4. CONCLUSIONS

A simple and compact dual-band slotted antenna having a DGS has been presented with simulated and experimental results. The fundamental resonance for higher band and new resonant mode for lower band can be respectively enhanced and excited by defecting the ground and embedding slots into the patch. Particularly, by adjusting the DGS a third mode at higher band can be obtained and thus produces a continuous broad bandwidth. Constructed prototype of the proposed antenna shows good radiating characteristics including bandwidth, pattern and gain, and is with potential for use in the modern multifrequency wireless communication systems.

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