Compact and Small Planar Monopole Antenna With Symmetrical L- and U-Shaped Slots for WLAN/WiMAX Applications

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***Abstract*—A small and compact triple-band microstrip-fed printed monopole antenna for Wireless Local Area Network (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX) is presented. The proposed antenna consists of a rectangular radiating patch with L- and U-shaped slots and ground plane. A parametric study on the lengths of the U- and L-shaped slots of the proposed antenna is provided to obtain the required operational frequency bands—namely, WLAN (2.4/5.2/5.8 GHz) and WiMAX (2.5/3.5/5.5 GHz). The proposed antenna is small ($15 \times 15 \times 1.6$ mm^3) when compared to previously well-known double- and triple-band monopole antennas. The simulation and measurement results show that the designed antenna is capable of operating over the 2.25–2.85, 3.4–4.15, and 4.45–8 GHz frequency bands while rejecting frequency ranges between these three bands. Omnidirectional radiation pattern and acceptable antenna gain are achieved over the operating bands.**

***Index Terms*—Monopole antennas, multiband antennas, triple-band antennas.**

I. Introduction

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 specified spectrum for WLAN is centered at 2.4, 5.2, and 5.8 GHz, and for WiMAX at 2.5, 3.5, and 5.5 GHz. In recent years, several reports have appeared about the development of low-profile multiband antennas. However, most of them are relatively large and/or do not provide desired bandwidths. One method of improving the bandwidth and reducing the size is to use a planar monopole antenna with slots on the patch and ground plane. There are many reported antenna designs for wireless systems such as coplanar waveguide (CPW)-fed monopole antenna with embedded slots [1], meandered split-ring slot [2], and slot monopole antenna with rectangular parasitic elements [3]. However, most of these antennas are designed for either single- or dual-band operation [1]–[3]. These antennas are expected to have effective broadband matching, a proper antenna gain, and consistent radiation patterns throughout the designated frequency bands. For size reduction and bandwidth improvement, a monopole antenna is designed to generate multiple resonant modes. In [4] and [5], an antenna with an L-shaped strip is designed for this purpose. Moreover, combined technique is one of the important structures to access dual-band multiband characteristics. In [6] and [7], antennas with modified fork- and L-shaped parasitic plane and rectangular ring and an S-shaped strip with a crooked U-shaped strip, respectively, are designed to cover desirable bands. A compact multiresonator-loaded antenna for multiband operation is reported in [8]. Considerable approaches with ground structures named defected ground structure (DGS) have been proposed in [9] and [10]. Recently, asymmetric coplanar strip (ACS)-fed structure was introduced in [11]. However, these designs of the monopole antennas have a large physical size and the complex geometry to realize the required operating frequency bands as shown in Table I. A small-size, simple multiband antenna covering all WLAN/WiMAX frequency bands is desirable.

TABLE I
Dimensions of Multiband Antennas

Ref.	Dimensions (mm^3)	WLAN (2.4/5.2/5.8)	WiMAX (2.5/3.5/5.5)
[1]	30×25×1.6 mm^3	(2.4/5.2/5.8)	-
[2]	23×36.5×0.8mm^3	(2.4/5.8)	(2.5/3.5)
[3]	50×30×1.6 mm^3	(2.4/5.2/5.8)	-
[4]	25×30×1.6 mm^3	-	(2.5/3.5/5.5)
[5]	28×32×1 mm^3	(2.4/5.2)	(2.5/3.5)
[6]	18×34.5×1 mm^3	(2.4/5.2/5.8)	(3.5/5.5)
[7]	35×25×1 mm^3	(2.4/5.2/5.8)	(3.5/5.5)
[8]	18×19×1 mm^3	(2.4/5.2/5.8)	(3.5)
[9]	20×30×1.6 mm^3	(2.4/5.2/5.8)	(3.5/5.5)
[10]	38×25×1.59 mm^3	(2.4/5.2/5.8)	(2.5/3.5/5.5)
[11]	27.5×13×1.6mm^3	(2.4/5.2/5.8)	(3.5/5.5)
Proposed antenna	**15×15×1.6mm^3**	**(2.4/5.2/5.8)**	**(2.5/3.5/5.5)**

In this letter, a small and low-profile microstrip-fed monopole antenna is proposed and designed for triple-band operation. It satisfies the following operational bands: 2.4-GHz WLAN (2.4–2.484 GHz specified by IEEE 802.11b/g standards), mobile WiMAX (2.5–2.69 GHz specified by IEEE 802.16e standards), 3.5/5.5-GHz WiMAX (3.4–3.69, 5.25–5.85 GHz), and 5-GHz WLAN (5.15–5.35/5.725–5.825 GHz specified by IEEE 802.11a standards). Triple-band operation of the proposed antenna is achieved by a pair of symmetrical L- and U-shaped slots inside the compact patch with a step-by-step design procedure.

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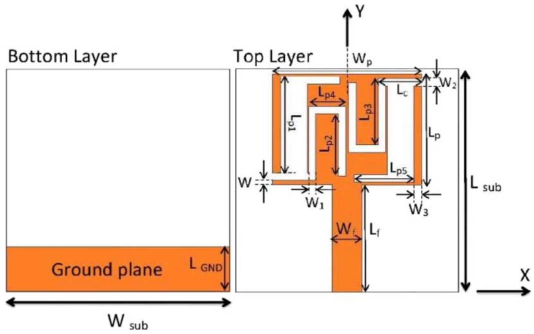

Fig. 1. Configuration of the proposed antenna.

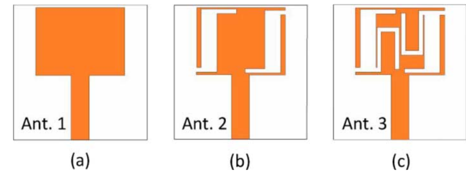

Fig. 2. Configuration of antennas with (a) an ordinary patch (Ant. 1), (b) a pair of symmetrical L-shaped slots on the patch (Ant. 2), and (c) a pair of symmetrical L- and U-shaped slots (Ant. 3).

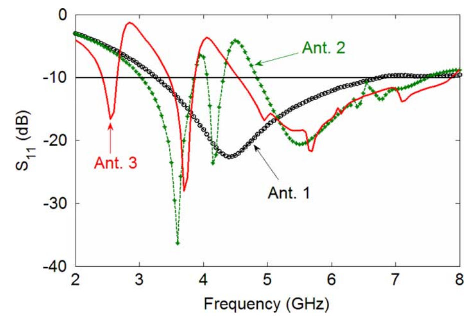

Fig. 3. Simulated magnitude of S_{11} for Ant.1, Ant. 2, and Ant. 3.

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 antenna consists of a rectangular radiating patch with a pair of symmetrical L- and U-shaped slots, a feedline, and a ground plane. The design of the proposed antenna is based on a microstrip-fed monopole antenna that is low-profile and simple, but it has relatively large dimensions with a quarter-guided-wavelength at first resonant frequency and does not satisfy all the requirements for WLAN/WiMAX applications.

To design a small and compact antenna that provides the desired performance that includes omnidirectional radiation patterns at WLAN/WiMAX frequency bands, the following design procedure has been used. The dimensions of the patch antenna were significantly reduced, and the symmetrical L- and U-shaped slots were made/cut out within the patch. The design of the two pairs of slots is based on the expectation that the four slots can be cut out within a relatively compact patch when they provide the desired resonant frequencies. For this purpose, the initial lengths of each part of the slots were selected in such a way that the total length $L_{\rm t}$ of each their three combinations is about a quarter of the guided wavelength at the desired resonant frequency $(L_{\rm t} \sim \lambda_{\rm g}/4)$ using the approximate effective permittivity approach. For instance, a resonant response at 3.7 GHz (WiMAX band) can be provided by the L-shaped slot if the total length of its parts $(L_{\rm p1} + L_{\rm p5} + W_3)$ is close to a quarter of a wavelength corresponding to the resonant frequency of 3.7 GHz. The lower resonant frequency is mainly controlled by the total length of the U-shaped slot extending from the edges of the patch $(\rm L_c + L_{p3} + L_{p2} + L_{p4})$, which is approximately a quarter of wavelength at 2.54 GHz.

The proposed antenna is fed by a microstrip line partially backed by a ground plane to provide the connection of the antenna to an external circuit. It is also expected that the far-field radiation patterns of the antenna will be omnidirectional since the patch with the slots is small and it is not backed by the ground plane. Based on this design formulation, the optimized dimensions of the proposed antenna including the size of the substrate and the ground plane are obtained using a parametric study. Extensive simulation including reflection coefficient S_{11}, surface current distributions, and gain has been performed using the Ansoft simulation software High Frequency Structure Simulator (HFSS). The proposed antenna is imprinted on FR4 substrate with permittivity of 4.4, a loss tangent of 0.024, and a thickness $t_{\rm sub}$ of 1.6 mm. The total dimension (i.e., a substrate dimensions, $L_{\rm sub} \times W_{\rm sub} \times t_{\rm sub}$) is only $15 \times 15 \times 1.6$ mm ^{3}. A 10×7.5-mm^2 rectangular patch is connected to a 2-mm-wide microstrip feedline. The ground plane is partially backed under the microstrip feed line (cf. Fig. 1) to provide the connection between the antenna and an external circuit through a 50-Ω SMA connector for signal transmission. Fig. 2 shows the different configurations of the patch including the ordinary patch antenna [cf. Fig. 2(a)], the antenna with the L-shaped slots [cf. Fig. 2(b)], and the antenna with both L- and U-shaped [cf. Fig. 2(c)] slots.

The effect of slots on the reflection coefficient is illustrated in Fig. 3. It can be seen in Fig. 3 that by using an ordinary patch (Ant. 1), a wide operating frequency band is obtained. However, this frequency band does not cover the desired frequency bands in particular at lower frequencies (i.e., between 2 and 3 GHz). In addition, it includes all frequencies between $\sim$ 3.5 and $\sim$ 6.5 GHz while rejecting frequency ranges between the desired bands is required in the wireless communication applications. On the other hand, the antenna with a pair of symmetrical L-shaped slots (Ant. 2) has three resonant frequency responses. However, these frequencies do not cover the 2.4-GHz band for WLAN and 2.5/3.5-GHz bands for WiMAX operations. The desired performance of the proposed antenna is obtained by introducing a pair of symmetrical U-shaped slots in addition to the L-shaped slots and optimizing their dimensions using a parametric study. The resonant responses of the antenna with optimized dimensions of the L- and U-shaped are shown in Fig. 3 (cf. Ant. 3). The optimal parameters of the antenna are as follows: $W_{\rm sub} = 15$ mm, $L_{\rm sub} = 15$ mm, $L_{\rm GND} = 3$ mm, $W_{\rm f} = 2$ mm, $L_{\rm f} = 7.2$ mm, $W_{\rm p} = 10$ mm, $L_{\rm p} = 7.5$ mm, $W = 0.3$ mm, $W_1 = W_2 = W_3 = 0.5$ mm, $L_{\rm p1} = 6.5$ mm, $L_{\rm p2} = 4.2$ mm, $L_{\rm p3} = 4.5$ mm, $L_{\rm p4} = 2.5$ mm, $L_{\rm p5} = 4$ mm, and $L_{\rm c} = 2.9$ mm. The simulation results display three resonant bands at frequencies of 2.42, 3.7, and 5.7 GHz, with bandwidths specified for $S_{11} < -10$ dB, of about 300 MHz (2.39–2.69 GHz), 450 MHz (3.4–3.85 GHz), and 3300 MHz (4.55–7.85 GHz), respectively.

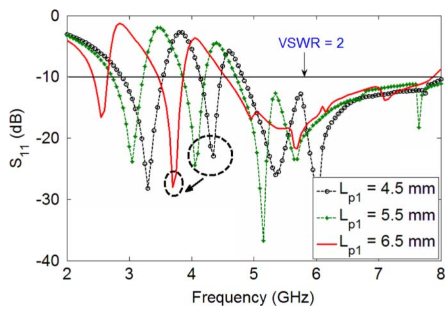

Fig. 4. Simulated magnitude of S_{11} of the proposed antenna for various L_{p1} at $L_{\mathrm{p4}} = 2.5$ mm.

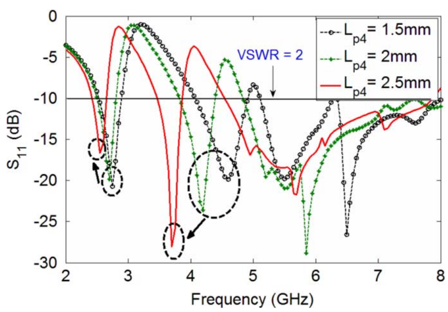

Fig. 5. Simulated magnitude of S_{11} of the proposed antenna for various L_{p4} at $L_{\mathrm{p1}} = 6.5$ mm.

III. Results and Discussion

An antenna prototype with the dimensions given is fabricated and tested, and its numerical and experimental results for S_{11} and radiation patterns are presented and discussed. From the parametric study, the optimum value for each parameter of the proposed antenna is obtained. The lengths of the L-shaped slots are critical parameters in determining the sensitivity of impedance matching. The effect of the value of L_{p1} on the magnitude of the reflection coefficient of the antenna can be seen in Fig. 4. As shown in Fig. 4, when L_{p1} increases from 4.5 to 6.5 mm, the second resonant frequency decreases from around 4.2 to 3.4 GHz. By tuning L_{p1}, the 3.5-GHz WiMAX frequency band can be achieved. To generate a resonant response at 2.4 GHz for WLAN and also to control the upper-frequency resonant responses, the pair of symmetrical U-shaped is used. The simulated magnitude of reflection coefficient S_{11} for various values of the length of the U-shaped slot length is plotted in Fig. 5. The results indicate that the lowest resonant band of the proposed antenna can be effectively controlled by adjusting L_{p4}.

To obtain the desired frequency bands and impedance matching a parametric study at different values of L_{GND} and W_{sub} has been performed. By maintaining L_{f}-L_{GND} constant, we investigate reflection coefficient by increasing L_{GND} that will be resulted to increase L_{sub}. It can be seen from Fig. 6 that the desired resonant responses are obtained at $L_{\mathrm{GND}} = 3$ mm. Fig. 6 also shows that at higher L_{GND} (i.e., L_{sub}), the antenna has a poor performance at the 3.5/5.5-GHz WiMAX and 5.2/5.8-GHz WLAN.

Fig. 7 shows magnitude of reflection coefficient at three values of W_{sub} and unchanged values of $L_{\mathrm{GND}} = 3$ mm and $L_{\mathrm{f}} = 7.2$ mm. It can be seen from Fig. 7 that the best performance of the triple-band antenna can be obtained at $W_{\mathrm{sub}} = 15$ mm.

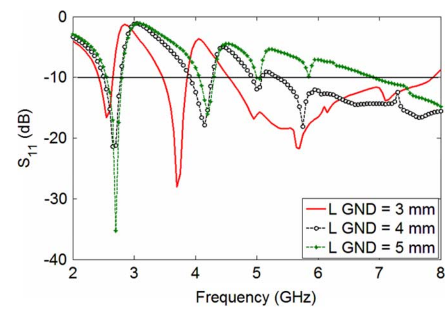

Fig. 6. Simulated magnitude of S_{11} of the proposed antenna for various values for L_{GND} ($L_{\mathrm{f}} - L_{\mathrm{GND}}$ is constant).

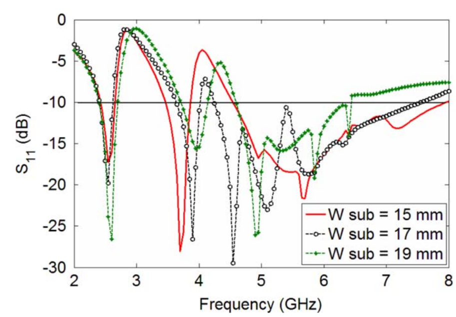

Fig. 7. Simulated magnitude of S_{11} of the proposed antenna for various values for W_{sub}.

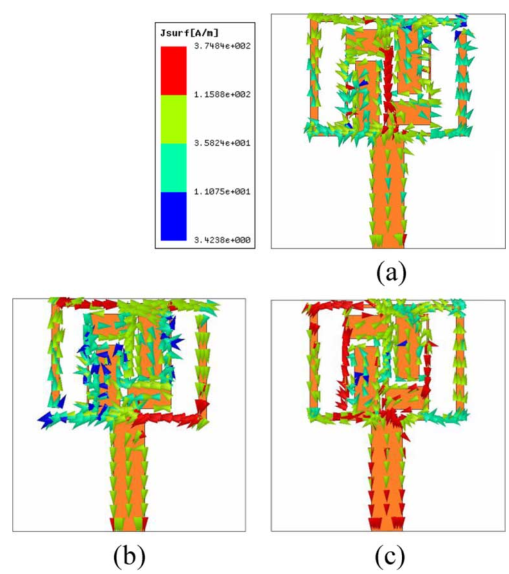

Fig. 8. Surface current distribution on the patch antenna at various resonance frequencies (a) 2.54, (b) 3.7, and (c) 5.8 GHz.

For further examining of the whole proposed antenna, the excited surface current distributions on the patch are provided. The simulated current distribution of the antenna at the three resonant frequencies of 2.54, 3.7, and 5.8 GHz is shown in Fig. 8. From this simulation, it is found that for the lowest frequency band [cf. Fig. 8(a)], a large surface current density is observed along the gap in between the symmetrical U-shaped slots. For the second and the highest frequency bands, the current distributions are concentrated around the symmetrical L- and U-shaped slots [cf. Figs. 8(b) and (c)].

The developed antenna was manufactured and tested using an Agilent 8722ES vector network analyzer (VNA). A photograph

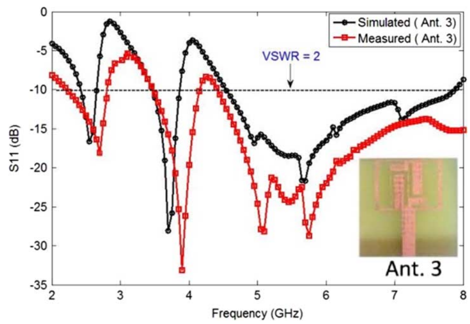

Fig. 9. Measured and simulated magnitude of S_{11} for Ant. 3.

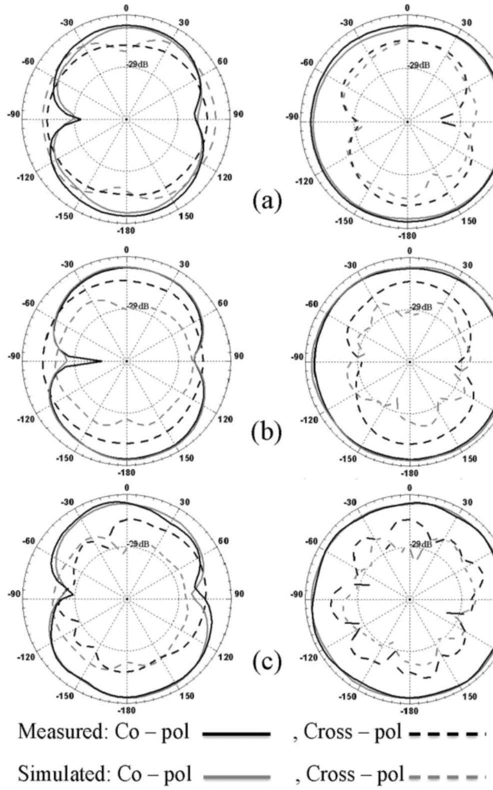

Fig. 10. Measured and simulated *(left)* E-plane and *(right)* H-plane radiation patterns of the proposed antenna at (a) 2.54, (b) 3.7, and (c) 5.65 GHz.

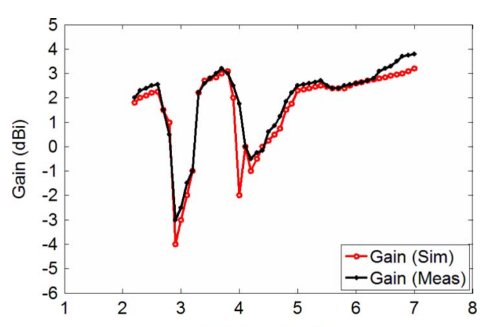

Fig. 11. Measured and simulated peak gain across operating bands for the proposed triple-frequency monopole antenna.

of the antenna is shown in the insert of Fig. 9. The measured and simulated magnitudes of the reflection coefficients S_{11} of the antenna are shown in Fig. 9. It can be clearly seen that there is good agreement between the measured and simulated results. The shift between the measured and simulated results can be attributed to the tolerance in material specifications, in particular, the tolerance in the dielectric constant of the substrate.

Fig. 10 shows the simulated and measured radiation patterns at 2.54, 3.7, and 5.65 GHz in the H-plane (xz-plane) and the E-plane (yz-plane), respectively. As shown, the measured and simulated radiation patterns are in good agreement. It can also be seen from Fig. 10 that the proposed antenna provides omnidirectional radiation patterns in the H-plane and bidirectional patterns in the E-plane over the desired operating bands.

The measured and simulated antenna peak gain across the desired bands is depicted in Fig. 11. It can be seen that there is a reasonable agreement between the simulated and measured results. The ranges of measured gains from lower to higher frequency bands are about 2–2.6, 2.6–3.2, and 2.5–3.8 dBi. Fig. 11 also clearly shows that gain values at off-band frequencies are significantly lower than at the desired frequency bands.

IV. Conclusion

A novel microstrip-fed monopole antenna design for a triple-band operation is presented. The proposed antenna is composed of a pair of symmetrical L- and U-shaped slots inside the rectangular patch that enables proper adjusting of the resonant bands. Simulation and measured results are in good agreement, and they show that the desired operating bandwidths, gain, and radiation patterns for WLAN (2.4/5.2/5.8 GHz) and WiMAX (2.5/3.5/5.5 GHz) applications can be achieved. The antenna is of relatively small dimensions ($15 \times 15 \times 1.6$ mm^3). The proposed antenna can be an excellent choice for WLAN/WiMAX applications due to its small size, simple structure, good multiband characteristics, and omnidirectional radiation pattern over the aforementioned bands.

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