A Novel Printed Antenna with Square Spiral Structure for WiMAX and WLAN Applications

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Abstract **─** A new printed antenna with multiband characteristic suitable for WiMAX and WLAN operating frequency bands is presented. For this purpose, two square spiral arms as radiating elements and partial ground plane are considered in the antenna structure. By adding the square spirals and adjusting the number of turns of the square spirals, new resonances are excited and desired resonant frequencies at 2.56, 3.94, 5.20, 5.80, and 10.18 GHz can be achieved to cover WLAN and WiMAX systems. Parametric simulation of the main parameters affecting the antenna performance are presented and discussed. The designed antenna with full size of 20×20 mm^2 is fabricated and tested. The radiation pattern is approximately omnidirectional in operating bands. The simulated and the experimental results are in acceptive agreement and confirm good performance for the offered antenna.

Index Terms **─** Multiband characteristic, square spiral arms.

I. INTRODUCTION

It is now common practice to integrate several radios in a single wireless platform that uses one antenna or one single radio device to handle multiple standards. To this end, the antennas need to cover multiple frequency bands [1]. Multiband antennas are one of the desirable candidates to be employed in services with various operating bands. The characteristic of the printed antenna can easily satisfy the technical requirements for high performance, being light weight and low profile. So, printed monopole antennas and the dipole antennas play an important role in many aspects of multiband antennas [2]. Wireless local area network (WLAN) and worldwide interoperability for microwave access (WiMAX) with standard operating frequency bands including 2.4 GHz (2.4-2.484 GHz)/5.2 GHz (5.15-5.356 GHz)/5.8 GHz (5.725-5.825 GHz) and 2.56 GHz (2.5-2.69 GHz)/3.5 GHz (3.4-3.696 GHz)/5.5 GHz (5.25-5.85 GHz), respectively, have been widely applied in mobile devices such as handheld computers and intelligent phones [3]. Recently, several multiband printed monopole and dipole antennas for WLAN and WiMAX applications have been presented in [2-13]. A dipole antenna using double-side layer and the flared arms is presented in [2]. The proposed antenna consists of three branch strips. The longer strip is employed as a reflector and the shorter one is as a director. The desired operating bands can be achieved by optimizing the length of the branch strips. In [3], a hybrid design of a microstrip-fed parasitic coupled ring fractal monopole antenna is investigated. By adding fractal strip and inserting parasitic element in the back side, WiMAX and WLAN operating bands can be covered. In [4], a coplanar waveguide-fed (CPW) antenna includes a square spiral patch to increase resonance frequencies and two L-shaped strips for achieving wider impedance bandwith. In [5], a monopole antenna with one branch strip and two hook-shaped strips suited for WLAN/WiMAX applications is designed.The return loss curves of the presented antenna is significantly influenced by the rectangular slit in the ground plane. In [6], two rectangular split-ring resonators subjoined on the radiating patch to obtain a tri-band resonant characteristic. In [7], folded Γ-shaped arms are used to tune frequency bands. Also, H-shaped slot on the ground plane has an important effect on producing wider impedance bandwidth. In [8], a novel PIFA configuration is proposed of T-shaped on the radiating patch and rectangular slot in the ground plane. These modifications lead to enhanced impedance bandwidth. In [9], a monopole antenna has a dual-layer metallic structure which is embedded on both sides of the substrate. 3 GHz and 5 GHz frequency bands can be achieved by adding the S-shaped strip to the feed line and a special structure on the bottom layer, respectively. In [10], a monopole antenna with several narrow strips, acted as resonance paths, are connected to a 50-ohm CPW feed line. In the offered antenna, multiband characteristic can be obtained by using quarter-wavelength long patch.

In this paper, a simple printed antenna with a novel configuration is suggested for WLAN and WiMAX applications. The proposed antenna consists of two square spiral arms connected to a microstrip feed line

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on the top layer of the substrate and a defected ground plane on the bottom layer. By using square spirals, new resonances are generated, and so multiband operation can be achieved. Modified turns of the square spirals and optimized dimensions of the ground plane lead to favorable frequency bands of 245 MHz (2.498-2.743 GHz), 254 MHz (3.789-4.043 GHz), 365 MHz (5.063-5.428 GHz), 397 MHz (5.601-5.998 GHz), and 580 MHz (9.911-10.491 GHz). The presented structure has an efficient performance with the lower cost and simple design. The final size of presented antenna is smaller than most multiband antennas which are mentioned recently. Good return loss and radiation characteristics are gained in the frequency band of interest.

II. ANTENNA CONFIGURATION AND DESIGN

Figure 1 shows geometrical configuration of the suggested antenna which is printed on an FR4 substrate with a size of 20(x-axis)×20(y-axis)×1 mm^3, relative permittivity of 4.4, and loss tangent of 0.022. Two square spirals as radiating element and 50 Ω microstrip line with fixed width (W_0) and length (L_0) is used on the upper side of the substrate. The partial ground plane with constant width of L_G = 6 mm is embedded on the other side of substrate. The square spirals have critical effects on exciting new resonances and controlling frequency resonances. To investigate the importance of square spirals, four steps of the designing process, as illustrated in Fig. 2, for different turns of the square spirals are presented and studied. Ansoft simulation software high-frequency structure simulator (HFSS) [14] is used for the parametric analysis and optimization of the designs. All the optimized values of the parameters are written in Table 1.

At first, the main innovation of the design including two special arms with unequal strips [see Fig. 2 (a)] is considered. In the second, third, and last steps [see Figs. 2 (b), 2 (c), and 2 (d)], excess strips are sequentially added to the arms to configure the turns of the square spirals. By connecting any strip to the arms, additional current paths on the radiating elements is generated. In this case, the new coupling paths between square spirals and ground plane can be obtained, and thus, the number of frequency resonance is increasing. Return loss curves for all the mentioned steps are demonstrated in Fig. 3.

Table 1: The final dimensions of the designed antenna

Param.	mm	Param.	mm	Param.	mm
L_0	8	L_1	9	L_2	7
L_3	2.4	L_4	4	L_5	2.4
W_0	1.7	W_1	0.3	W_2	7.4
W_3	6.5	W_4	4.5	W_5	4.4
W_6	3.5	L_G	6	h_{sub}	1
W_{sub}	20	L_{sub}	20		

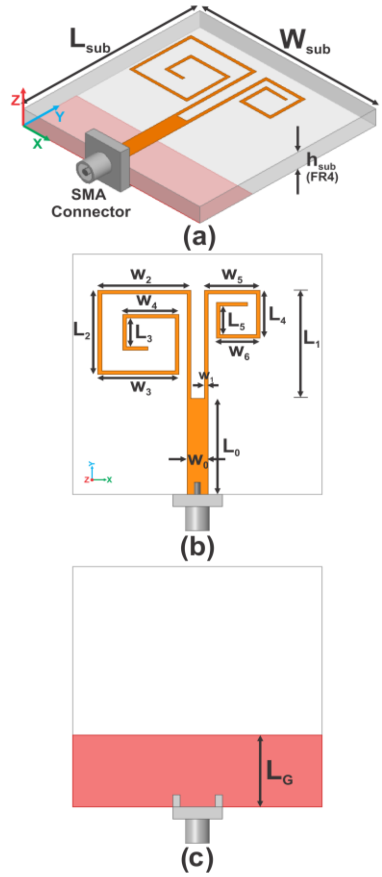

Fig. 1. Geometry of the proposed antenna: (a) side view, (b) top view, and (c) bottom view.

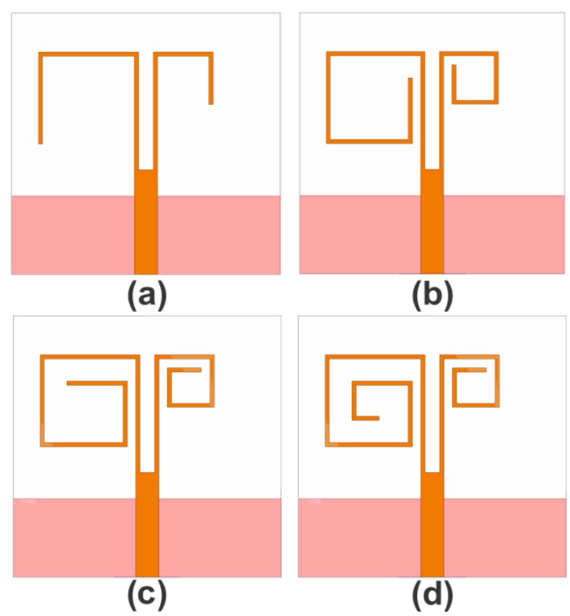

Fig. 2. (a) The antenna in step 1, (b) the antenna in step 2, (c) the antenna in step 3, and (d) the proposed antenna in step 4.

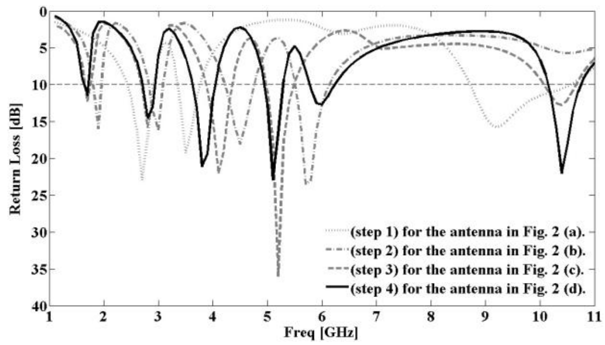

Fig. 3. Simulated return loss characteristics for antennas shown in Figs. 2 (a), (b), (c) and (d).

In the optimized case, resonant frequencies at 1.6, 2.7, 3.7, 5.1, 5.8, and 10.4 GHz are educed. For more expression of the significance of the dimension of square spiral arms, parametric study for the substantial parameters of the arms have been done. Note that in parametric analysis, one parameter is changed while the others are fixed. Simulated return loss curves with different values of key parameters named W_3, W_6, L_3, L_5, and W_4 are shown in Fig. 4, Fig. 5, and Fig. 6. From Fig. 4, it is found that the increment of the W_3 and W_6 has a great effect on moving resonant frequency to lower frequencies. As illustrated in Fig. 5, various values of the L_3 and L_5 control the impedance matching of the higher resonant frequencies. Finally, as indicated in Fig. 6, by increasing W_4, the matching and the location of higher frequency bands can be improved.

For more clarification of the frequency performance of the square spirals, current distribution of the exhibited proposed antenna for desirable resonant frequencies at 2.7, 3.7, 5.1, and 5.8 GHz are displayed in Fig. 7. From Fig. 7 (a) and Fig. 7 (b), it is clearly observed that the surface current distribution is concentrated around small and large square spiral arms at 2.7 and 3.7 GHz, respectively. Furthermore, as seen in Fig. 7 (c) and Fig. 7 (d), surface currents are nearly equal around both arms. Therefore, multiband operation can be achieved by different radiated parts of square spirals.

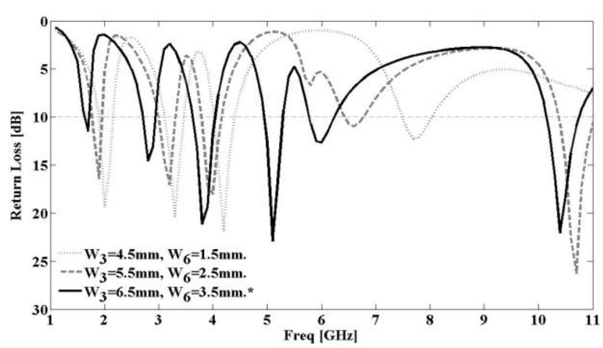

Fig. 4. Simulated return loss characteristics for the antenna with different values of the W_3 and W_6.

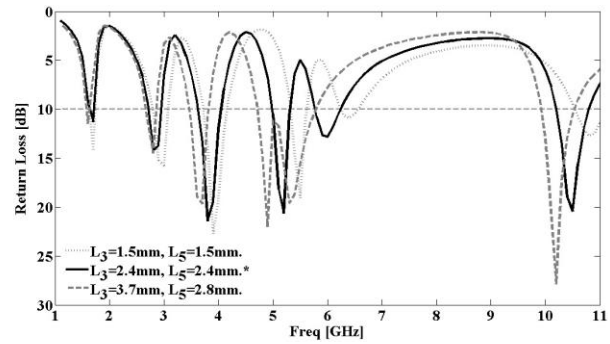

Fig. 5. Simulated return loss characteristics for the antenna with different values of the L_3 and L_5.

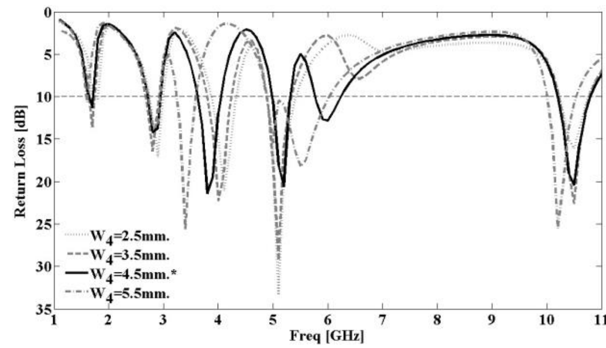

Fig. 6. Simulated return loss characteristics for the antenna with different values of the W_4.

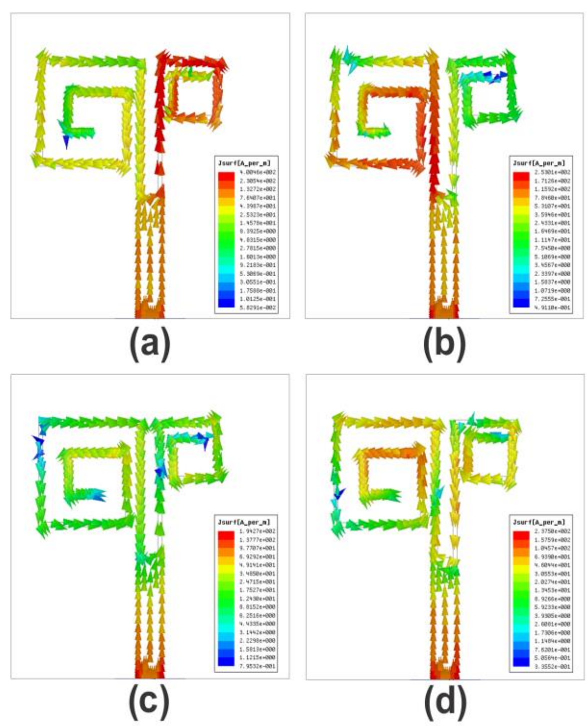

Fig. 7. Simulated surface current distributions on the radiating patch at: (a) 2.7, (b) 3.7, (c) 5.1, and (d) 5.8 GHz.

III. RESULTS AND DISCUSSIONS

The photograph of the manufactured antenna is shown in Fig. 8. Simulated and measured return loss characteristics of the discussed antenna are plotted in Fig. 9. Figure 9 indicates that there is a discrepancy between the simulated and measured results. This discrepancy is commonly due to the a number of parameters, such as the wider range of simulation frequencies, the fabricated antenna dimensions as well as the thickness, and dielectric constant of the substrate, on which the antenna is fabricated. To confirm the accurate return loss characteristics for the designed antenna, it is recommended that the manufacturing and measurement process need to be performed carefully; besides, SMA soldering accuracy and FR4 substrate quality need to be taken into consideration [15].

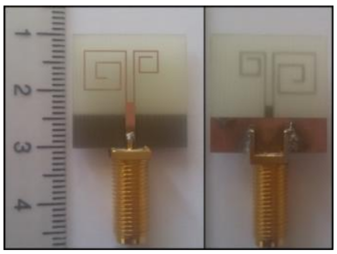

Fig. 8. Photograph of the fabricated antenna prototype with proposed patch.

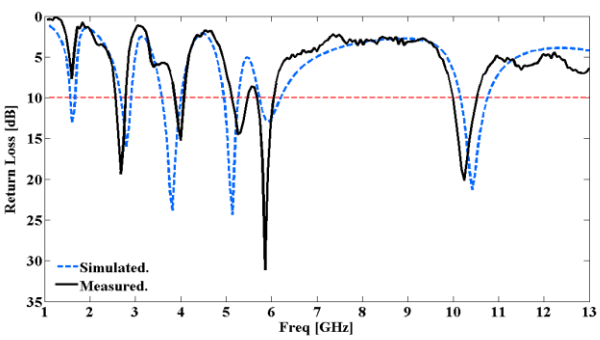

Fig. 9. Measured and simulated return losses of the proposed antenna.

As shown in Fig. 9, multiband operation at 245 MHz (2.498-2.743 GHz), 254 MHz (3.789-4.043 GHz), 365 MHz (5.063-5.428 GHz), 397 MHz (5.601-5.998 GHz), and 580 MHz (9.911-10.491 GHz) can be attained to cover WiMAX frequency bands at 2.5 GHz (2500-2690 MHz), and WLAN frequency bands at 5.2/5.8 GHz (5150-5350 MHz)/(5725-5825 MHz). The simulated and measured peak gains for the proposed antenna for the lower, middle and higher bands are shown in Fig. 10. The normalized co-polarization and cross-polarization radiation patterns of the antenna at 2.56, 3.94, 5.2, and 5.8 GHz are illustrated in Fig. 11. The radiation pattern in x-z plane is approximately omnidirectional.

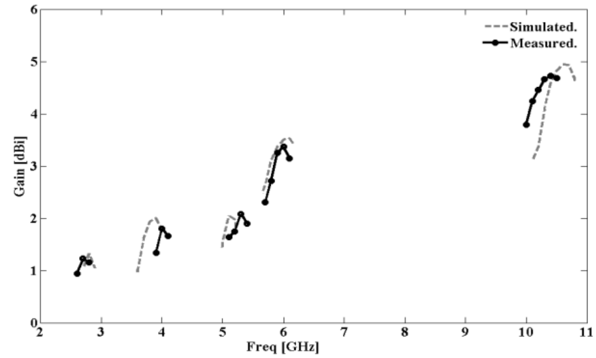

Fig. 10. Measured and simulated gain curves of the proposed antenna.

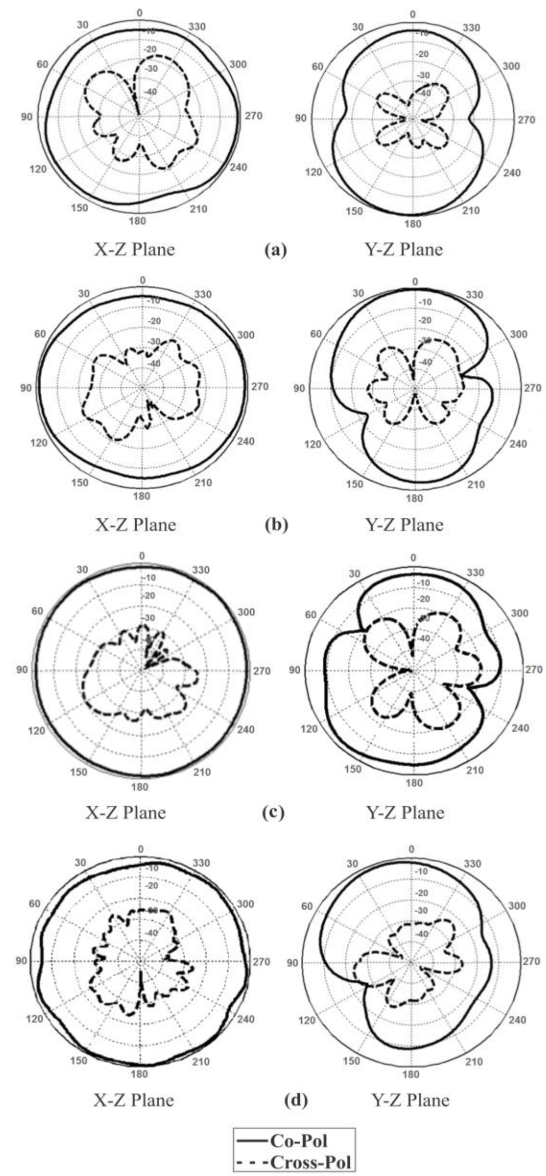

Fig. 11. Normalized radiation patterns of the proposed antenna at: (a) 2.56, (b) 3.94, (c) 5.2, and (d) 5.8 GHz.

IV. CONCLUSION

A novel multiband printed antenna for WiMAX/ WLAN applications has been reported. We showed that by using two square spiral arms as radiating elements and a partial ground plane, five frequency bands at 245 MHz (2.498-2.743 GHz), 254 MHz (3.789-4.043 GHz), 365 MHz (5.063-5.428 GHz), 397 MHz (5.601-5.998 GHz), and 580 MHz (9.911-10.491 GHz) can be obtained, so WiMAX/WLAN standard frequency bands can be covered. Also, the radiation patterns in both H-plane and E-plane are omnidirectional at covered frequency bands. The proposed antenna is attractive and can be practical for various multi frequency systems.

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