A Novel Compact Printed Slot Antenna with Triple Bands for WiMAX/WLAN Applications Using Remodeling Technology

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Abstract ─ A novel compact triple-band Printed Slot Antenna (PSA) fed by CPW is presented in this paper. By attaching a crescent-shaped strip to the extremity of the CPW fed-line of a conventional CPW-fed circle slot antenna, a lower resonant mode is excited. Then, with an annular strip located between the circle slot and the crescent-shaped strip, an additional resonant mode and better impedance matching is achieved. Besides, a rectangular shorting stub is loaded at the appropriate position of the annular strip to obtain more resonant modes. By adopting such remodeling technology, the aperture utilization efficiency is greatly improved, and thus, multi-functional integration in a compact size can be realized. The designed PSA, featuring of a small size of 23×30 mm, operates over the frequency ranges 2.33-2.7 GHz, 3.3-3.8 GHz and 4.83-6.26 GHz, with good omni-directional radiation patterns and rather stable antenna gains, is suitable for both WLAN and WiMAX applications.

Index Terms ─ Compact, PSA, remodeling technology, triple-band and WLAN/WiMAX applications.

I. INTRODUCTION

With the rapid development of personal portable wireless communications, the demand for the design of an antenna with triple or multiband operation has increased; since such an antenna is vital for integrating more than one communication standards in a single compact system [1-10]. However, there are many challenges in designing a multiband antenna and the main one is how to create multi-resonating paths in a limited antenna aperture. Therefore, many efforts have been made and many multiband techniques are emerged. Generally, cutting slots on the metal radiator of antenna and loading parasitic strips are the two most typically used methods to create multi-resonating paths [11-13]. Certainly, multi-band characteristics are obtained in those works above. Nevertheless, all of them are suffering lower aperture utilization efficiency since each resonant mode requires for an unshareable slot or strip.

In addition, the PSA in merit of wider bandwidth, superior impedance matching, lower radiation loss and lower dispersion compared with the normal microstrip patch antenna, has become a rather promising candidate for kinds of multi-band applications. Particularly, the CPW-fed PSA even exhibits simpler structure and easier integration with active devices and MMIC devices [14-15].

In this paper, a novel compact CPW-fed PSA with triple bands using remodeling technology is presented. For a conventional CPW-fed circle slot antenna, there is only a single fundamental mode near 7 GHz. By attaching a crescent-shaped strip to the extremity of the CPW fed-line and adding an annular strip in the circle slot, two resonating paths (3.45/5.15 GHz) are created. Furthermore, two extra resonant modes (2.46/5.8 GHz) are obtained by simply loading a rectangular shorting

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stub at the appropriate position of the annular strip. Accordingly, the size of the PSA is significantly reduced and the aperture utilization efficiency is greatly improved. Details of this antenna are presented and the measured results are given to demonstrate its performances.

II. ANTENNA DESIGN

Figure 1 shows the geometry of the proposed triple bands PSA, which is fabricated on a FR4 substrate of thickness 1.6 mm and permittivity 4.5. The proposed antenna is based on a simple circle slot antenna excited by a 50-Ω CPW fed-line with width w_f=3 mm. By connecting a crescent-shaped strip to the end of the CPW fed-line, the fundamental mode was shifted to a lower band. In order to create anther resonating paths, an annular strip is located between the circle slot and the crescent-shaped strip. Moreover, the rectangular shorting stub at the right side of the annular strip is designed to excite more resonant modes (2.46 GHz, particularly) and achieve better impedance matching across the operating frequency bands, as well as impedance bandwidth. Introducing such remodeling technology, which is an effective way to control the current resonant paths and short the resonant length of need, contributes to a smaller antenna size compared with the traditional one. The optimal antenna dimensions are as follows: L=30 mm, W=23 mm, w_1=3.6 mm, d=5.0 mm, r1=10.8 mm, r2=9 mm, r3=8.6 mm, r4=6 mm, r5=6 mm.

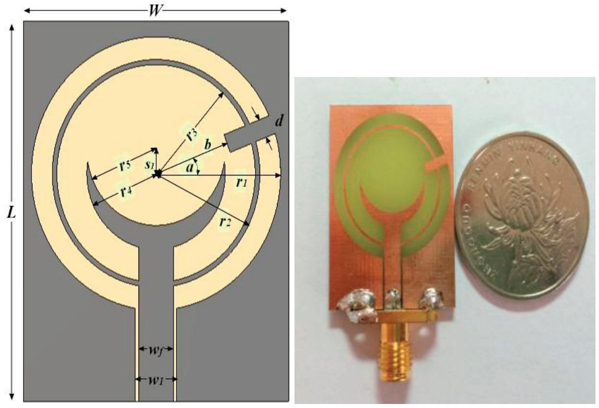


Fig. 1. Geometry of the proposed triple-band PSA.

III. RESULATS AND DISCUSSION

In order to investigate the operation mechanism of the proposed antenna, crescent-shaped strip, annular strip and rectangular shorting stub are successively employed to a conventional CPW-fed circle slot antenna (antenna *a*), while preserving the same parameters and named antenna *b*, *c* and *d*, correspondingly. The simulated reflection coefficients of these antennas are shown in Fig. 2. Obliviously, the single fundamental mode of antenna *a* is decreased from 7 GHz to 3.1 GHz when it comes to the antenna b, since the equivalent electric length is greatly lengthened by the crescent-shaped strip. An extra resonant frequency at 5.1 GHz is observed for antenna *c* because of the annular strip introduced. Moreover, it can be seen that the original operating band of antenna *b* centered at 3.1 GHz is shifted to the exactly 3.5 GHz WiMAX band, while bettering the impedance matching across the band. With the help of the rectangular shorting stub, the antenna *d* even exhibits two more resonant modes at 2.46 GHz and 5.8 GHz, compared with antenna *c*. Specially, among these resonances the highest two resonant modes (5.15 GHz/5.8 GHz) are close enough to fuse together, and thus, result in a very wide impedance bandwidth (4.83-6.16 GHz, 24.2%).

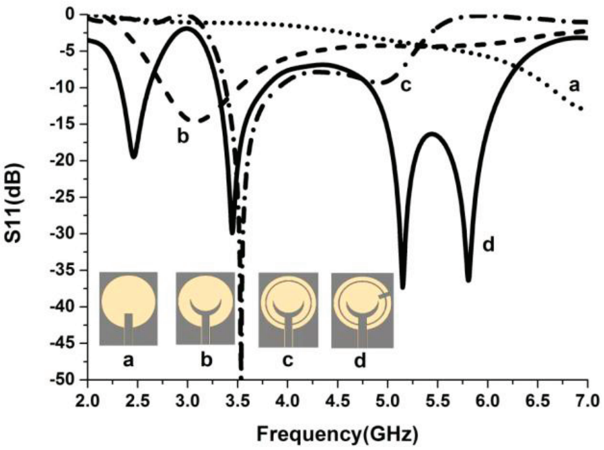
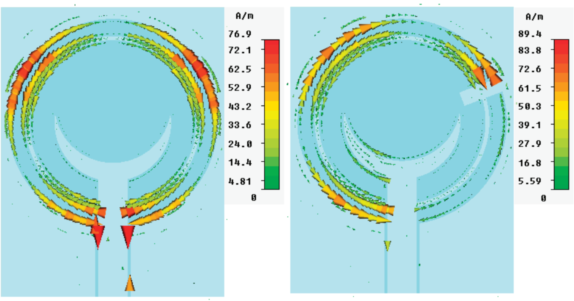


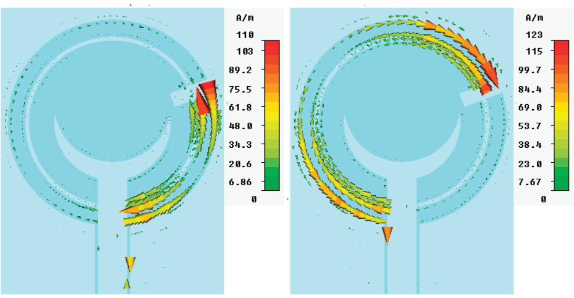
Fig. 2. The S11 curves for relevant antennas.

From the above, we can find that the rectangular shorting stub has played a rather important role in designing the proposed triple-band antenna; thus, further study is carried out base on the current distribution. For the case of the optimal design without the rectangular shorting stub, the current distributes along almost the whole annular slot corresponding to 1.5 wavelengths of the 5.1 GHz, as shown in Fig. 3 (a); which is bad to the miniaturization of antenna. Considering the fact that the design with shorting pin can reduce the antenna size effectively, the rectangular shorting stub is loaded at the right (or left) side of the annular strip, where the strongest current distribution exists and shorted to the ground plane. As a result, the original resonance path is divided into two and the left one is shorted by 1/3, while resonating at the same frequency, as shown in Fig. 3 (b). Moreover, in Fig. 4 (a), we can find that the right one also excites another half wavelength resonance at 5.8 GHz. In addition, it is worthy to see from Fig. 4 (b), that not only one wavelength resonance of 5.15 GHz is generated, but also the 1/2 wavelength resonance at 2.46 GHz is obtained by the left part of the annular slot. Accordingly, by adopting such remodeling technology, the aperture utilization efficiency is greatly improved, and thus, the overall antenna size is miniaturized. In Fig. 4 (c), current is mainly concentrated along the bottom edge of the crescent-shaped strip and the inner side of the annular strip, the total resonance length of the created path is 1/2 wavelength; which means the second working band is mostly determined by the two parts mentioned above.

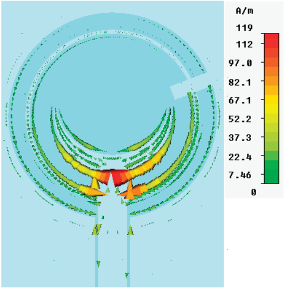


(a) At 5.1 GHz (b) At 5.15 GHz

Fig. 3. The current distribution without and with the rectangular shorting stub: (a) at 5.1 GHz and (b) at 5.15 GHz.



(a) At 5.8 GHz (b) At 2.46 GHz



(c) At 3.45 GHz

Fig. 4. The current distribution at different frequencies: (a) at 5.8 GHz, (b) at 2.46 GHz and (c) at 3.45 GHz.

From the analysis of the current distribution at each resonant frequency, the parameter sweep is adopted to further investigate the influences of the relevant geometry to the corresponding resonant frequency bands.

Figure 5 demonstrates the effects of the rectangular shorting stub to the impedance matching condition. With the angle a (the angle between the center axis of the stub and the positive direction of the x-axis) increasing from 15 degrees, 21 degrees to 25 degrees gradually, the current path of the left (right) annular slot is shorted (lengthened); which results in the first and third resonant frequency shift right, while the fourth one shift left. At the same time, the second band almost stands still.

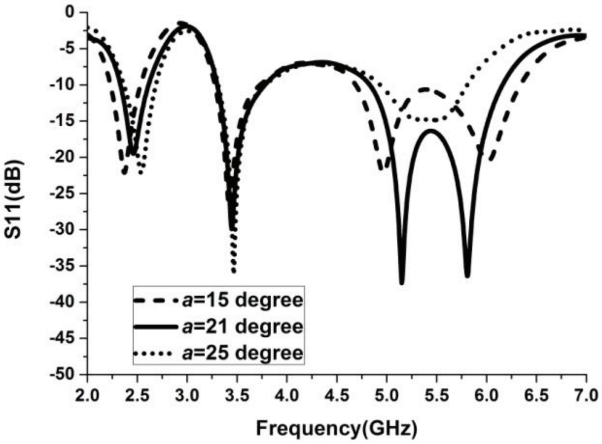


Fig. 5. Simulated S11 for various angle *a*.

Moreover, the -10 dB reflection coefficient for various outer radius of the annular strip r_2 are also plotted in Fig. 6. It can be noted that the parameter

r_2 has great impact on the first and third working bands. With r_2 decreasing from 9.2 mm to 8.8 mm, the centre frequency of the first operating band varies from 2.34 GHz to 2.6 GHz, correspondingly; since the related resonant current path is shorted. Similarly, the third operating band shifts right. Particularly, the electromagnetic coupling effect between the annular slots is sensitive to the width of the annular slot. The wider of the width, the weaker the coupling strength is, which results in the worse impedance matching. However, the annular slot width should not be too narrow, since the over coupling will deteriorate the performances of the working band as well. Finally, the optimized value for r_2 is chosen to be 9 mm considering the fabrication accuracy.

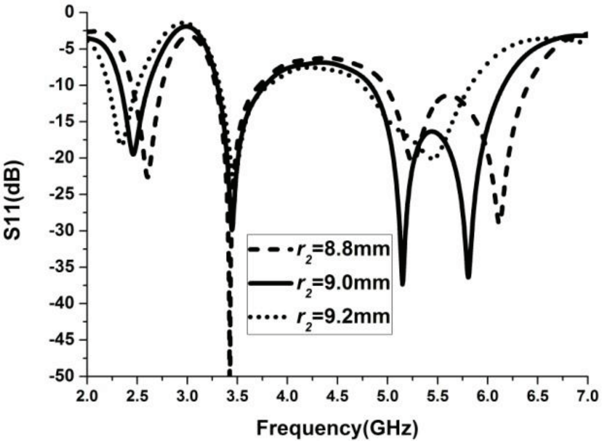


Fig. 6. Simulated S11 for various length r_2.

Figure 7 shows the reflection coefficient for different values of r4. It can be found that the second resonant mode shifts from around 3.45 GHz to 3.24 GHz, corresponding to the outer radius r4 of the crescent-shaped strip from 6 to 6.2 mm. That is due to the fact that the resonant length of the second resonant mode is lengthened with the r4 increasing gradually. Similarly, with *b* increasing from 5.9 mm to 6.1 mm, the second operating band shifts left as well, shown in Fig. 8.

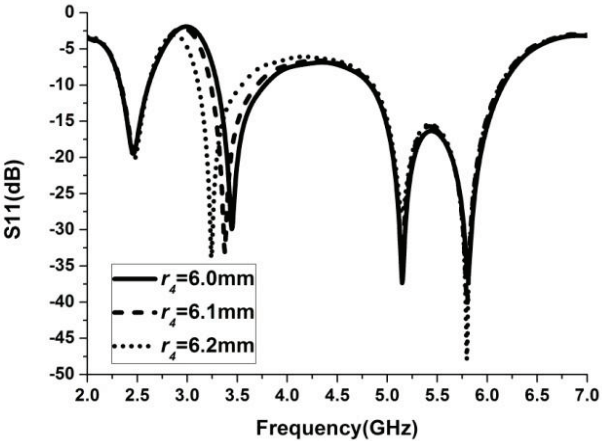


Fig. 7. Simulated S11 for different values of r4.

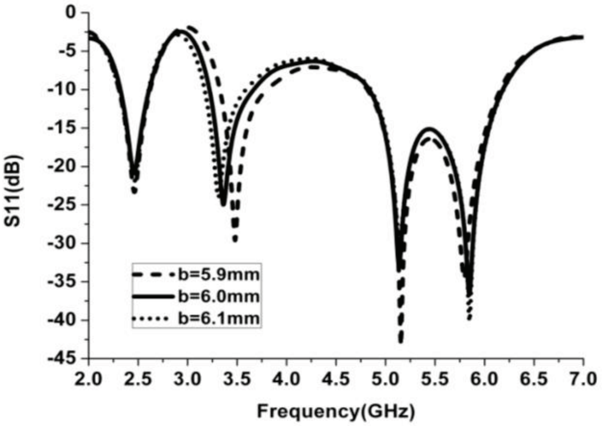


Fig. 8. Simulated S11 for different values of b.

The simulated and measured S11 of the proposed triple-band PSA is shown in Fig. 9; the results of the simulation reveals excellent agreement with that of the measurement. It can be observed that the designed antenna has triple operating bands covering the frequency ranges 2.33-2.7 GHz, 3.3-3.8 GHz and 4.83-6.26 GHz, corresponding to an impedance bandwidth of 14.7%, 14.1% and 25.8%, with respect to the appropriate resonant frequency, respectively. Apparently, the above obtained bandwidths with good impedance characteristic can simultaneously cover both the 2.4/5.2/5.8 GHz WLAN and 2.6/3.5/5.5 GHz WiMAX bands.

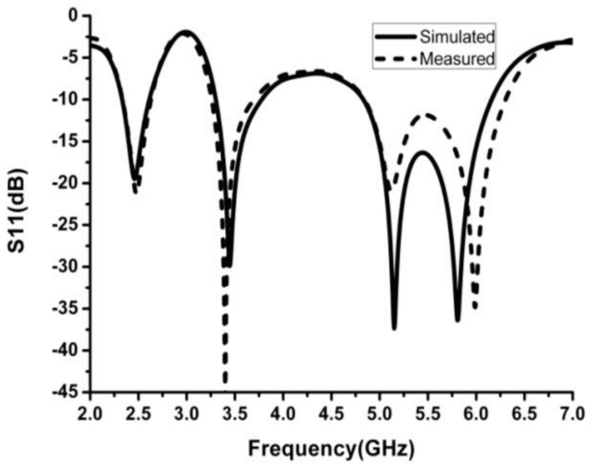
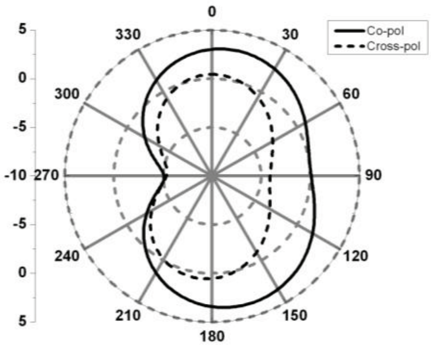
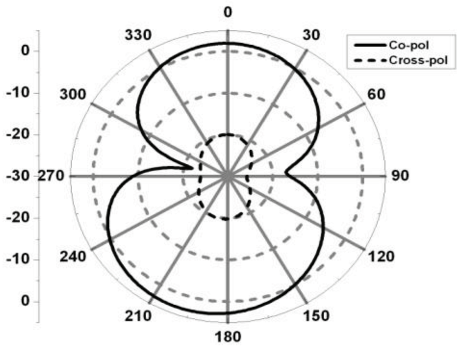


Fig. 9. The measured and simulated S11 of the proposed antenna.

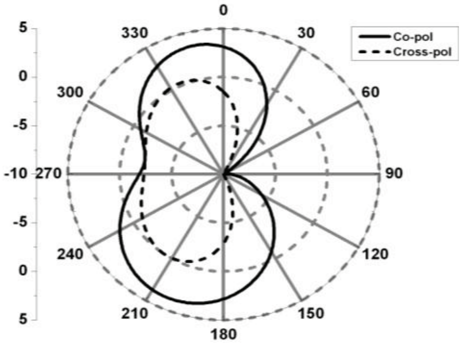
Figure 10 (a) and (b) show the E-plane and H-plane radiation patterns of the proposed antenna at 2.46 GHz, 3.45 GHz and 5.15 GHz, respectively. It can be seen that the proposed antenna exhibits a fairly good omni-directional radiation pattern in the H-plane and a dipole-like radiation pattern in the E-plane. In the lower band (2.46 GHz), the resonant mode is excited by adding the rectangular shorting stub to force the current to mainly distribute along the left part of the annular slot, but considerable current is also excited in the right part of the annular slot. So a more distorted H-plane pattern is observed, compared with the higher bands.



2.46 GHz

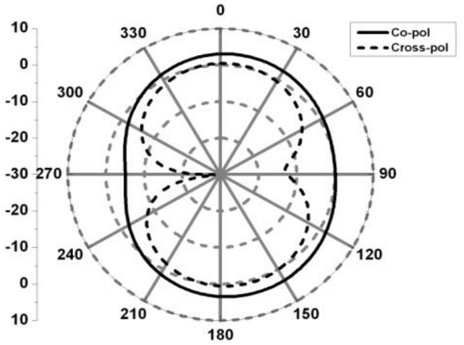


3.45 GHz

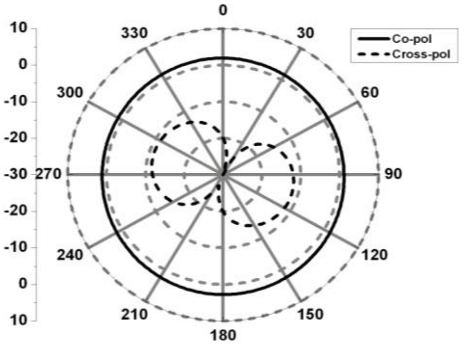


5.15 GHz

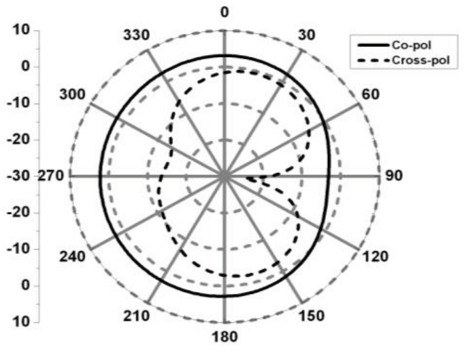
(a) E-plane



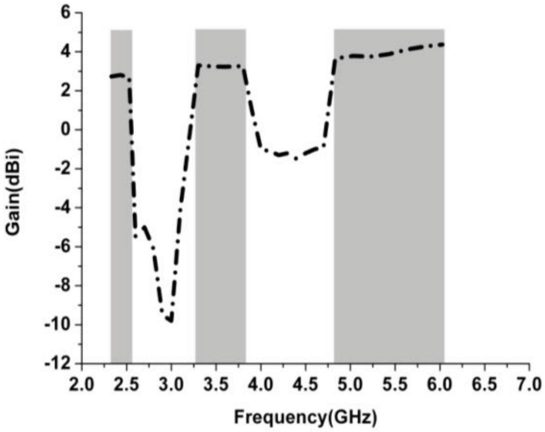
2.46 GHz



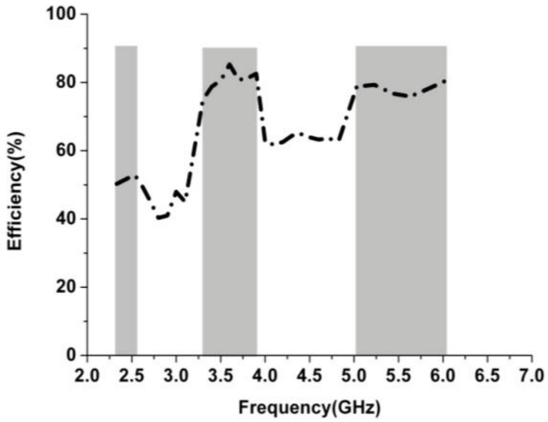
3.45 GHz



5.15GHz
(b) H-plane



(c) Antenna gains



(d) Antenna efficiency

Fig. 10. The radiation patterns and antenna gains of the proposed antenna: (a) E-plane, (b) H-plane, (c) antenna gains and (d) antenna efficiency.

The average antenna gains are about 3.75 dBi, 3.28 dBi and 4 dBi for the triple operating bands, respectively. Particularly, the gains across the entire operating bands keep rather stable, which is critical to designing a well performed personal portable wireless communication system, as shown in Fig. 10 (c). Besides, the antenna efficiency is also discussed in Fig. 10 (d). It can be seen that the antenna efficiency is around 80% in the higher two operation bands. In the lower band, the antenna efficiency is decreased to about 53%, since the antenna size is rather compact for 2.4 GHz band. Finally, a comparison in size and performance with the previous reported designs is also presented, to give a better view of the proposed antenna, shown in Table 1.

Table 1: Antenna performance comparisons

Size (mm)	Bandwidth GHz	Max Gain (dBi)	Antenna
30*23	2.33-2.7, 3.3-3.8, 4.83-6.26	4.36	This paper
48*35	1.77-2.5, 4.87-6.14	4	Reference [11]
50*35	0.86-0.98, 1.7-2.5, 4.72-6.61	3.74	Reference [13]

IV. CONCLUSION

A novel compact CPW-fed PSA for a triple-frequency operation has been presented. The crescent-shaped strip, annular strip and rectangular shorting stub introduced successfully created the multi-resonating paths in a simple circle slot antenna. With the use of remodeling technology, compact antenna size, higher aperture utilization efficiency and the wider impedance bandwidth are achieved. Furthermore, well covering all the WLAN and WiMAX operating bands, the proposed triple bands antenna also shows quite suitable radiation performances and stable antenna gains, which make it a very good candidate for various kinds of personal portable wireless communications applications.

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REFERENCES

[1] S. Chaimool and K. L. Chung, "CPW-fed mirrored-l-monopole antenna with distinct triple bands for WiFi and WiMAX applications," *Electron. Lett*., 45 (18), pp. 928-929, 2009.

[2] A. Foudazi, H. R. Hassani, and S. M. A. Nezhad, "Small UWB planar monopole antenna with added GPS/GSM/WLAN bands," *IEEE Trans. Antennas Propag*., 60 (6), pp. 2987-2992, 2012.

[3] R. K. Gupta, "Printed tri-band monopole antenna structures for wireless applications," *Microw. Opt. Technol. Lett*., 51 (7), pp. 1781-1785, 2009.

[4] P. Nepa, G. Manara, A. A. Serra, and G. Nenna, "Multiband PIFA for WLAN mobile terminals," *IEEE Antennas Wirel. Propag. Lett*., 4 (105), pp. 349-350, 2005.

[5] Y. C Lee and J. S Sun, "Compact printed slot antennas for wireless dual and multi-band operations," *Progress In Electromagnetics Research*, 88, 289-305, 2008.

[6] A. Foudazi, A. Mallahzadeh, etc., "A triple-band WLAN/WiMAX printed monopole antenna for MIMO applications," *Microwave and Optical Technology Letters*, volume 54, issue 5, pages 1321-1325, May 2012.

[7] Z. Yang, S. Xin, etc., "Design of a CPW-fed compact slot antenna for WIMAX/WLAN applications," *2011 International Conference on Computational Problem-Solving (ICCP)*, 2011.

[8] M. Jahanbakht, A. A. L. Neyestanak, etc., "Band notching ultra wideband microstrip antenna with an augmented crescent cut," *Eu CAP 2009*, 2009.

[9] O. M. Haraz, A. Elboushi, etc., "Band rejection capabilities of UWB elliptical slot antenna with half circular and crescent ring shaped radiators," *APSURSI 2010*, 2010.

[10] A. Mallahzadeh, etc., "A small-size pentaband hand-shaped coplanar waveguide-fed monopole antenna," *Microwave and Optical Technology Letters*, volume 53, issue 7, pages 1576-1579, July 2011.

[11] W. C. Liu, M. Ghavami, and W. C. Chung, "Triple-frequency meandered monopole antenna with shorted parasitic strips for wireless application," *IET Microw. Antennas Propagate*., 3 (7), pp. 1110-1117, 2009.

[12] P. Xu, Z. H. Yan, and C. Wang, "Multi-band modified fork-shaped monopole antenna with dual l-shaped parasitic plane," *Electron. Lett*., 47 (6), pp. 1051-1052, 2011.

[13] K. Seol, J. Jung, and J. Choi, "Multi-band monopole antenna with inverted u-shaped parasitic plane," *Electron. Lett*, 42 (15), pp. 844-845, 2006.

[14] J. S. Chen, "Dual-frequency annular-ring slot antennas fed by CPW feed and microstrip line feed," *IEEE Trans. Antennas Propag*., vol. 53, no. 1, pp. 569-573, January 2005.

[15] A. U. Bhobe, C. L. Holloway, M. Piket-May, and R. Hall, "Wide-band slot antennas with CPW feed lines: hybrid and log-periodic designs," *IEEE Trans. Antennas Propag*., vol. 52, no. 10, pp. 2545-2554, October 2004.

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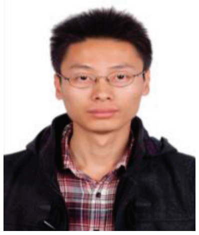

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