Progress In Electromagnetics Research Letters, Vol. 34, 177–186, 2012

COMPACT TRIPLE-BAND MONOPOLE ANTENNA FOR 2.4/5.2/5.8 GHz WLAN OPERATIONS

Y.-C. Luan*, F.-S. Zhang, and Y. Xu

National Laboratory of Antennas and Microwave Technology, Xidian University, Xi'an, Shaanxi 710071, P. R. China

Abstract—A novel compact monopole antenna with triple-band operation is proposed in this paper. The proposed antenna, fed by a 50-Ω microstrip line, consists of an inverted-L-shaped microstrip feed line loaded with a parasitic strip and a protrudent mirrored quasi-F-shaped strip on the ground plane, with a compact overall size of $20 \times 25\,\text{mm}^2$. The protrudent mirrored quasi-F-shaped strip is aimed to excite a resonant mode at 2.4 GHz. Meanwhile, with the introduction of the parasitic strip to the inverted-L shaped strip, two adjacent resonant frequencies at 5.2/5.8 GHz are obtained. The numerical and experimental results exhibit the designed antenna operates over triple frequency ranges, satisfying the standards of wireless local area networks (WLAN) both in IEEE 802.11 b/a/g at 2.4-GHz, 5.2-GHz, and 5.8-GHz. Besides, the antenna is fabricated and measured, and the simulation and measurement results of the return loss, radiation patterns and peak antenna gains are studied showing that the presented antenna is in good performance.

1. INTRODUCTION

Recently, wireless communication for wireless local area network (WLAN) has experienced tremendous growth, such as the 2.4-GHz band (2400 MHz–2484 MHz) for IEEE 802.11b/g standards, the 5.2-GHz band (5150 MHz–5350 MHz) and 5.8-GHz band (5725 MHz–5825 MHz) for IEEE 802.11a standard. Hence, for wireless device applications in the WLAN, dual- or triple-band planar antennas become the competitive candidates covering these operating frequencies due to the virtues of compact size, low profile, simple

Received 29 July 2012, Accepted 3 September 2012, Scheduled 12 September 2012
* Corresponding author: Yu-Chen Luan (yuchen_luan@yahoo.com.cn).

fabrication and easy integration with other microwave components. To meet these requirements, various types of antenna designs have been studied and reported. Monopole and dipole planar antennas are investigated to fulfill dual- or triple-band operation, such as an antenna with three back-to-back pairs of dipole [1], a monopole antenna with C-shaped and S-shaped branches [2], a CPW-fed ring antenna with two L-shaped arms [3], a four-element printed dipole array with bidirectional high gain performance [4]. Dual or triple current paths are provided by the different shaped strips of the above citations to produce resonant frequencies at multi-bands. Some antennas with slots of different shapes and positions, including inverted E- and C-shaped slots [5], crossed double T-shaped slots [6], and inverted-L and mixing slots [7], are presented, of which the structures of slot either cut, shift or couple with the current path to excite multi-operations. And planar inverted-F antennas (PIFA) are also showing a good performance at the desired dual or triple bands with candidates of a PIFA consisting of three separate short-circuited patches with a triple feed integrated [8], a PIFA with two shorted branches [9], a meander patch PIFA structured by two shorting pins [10]. Furthermore, some hybrid antennas composed of a simple monopole and parasitic elements in [11, 12], with the technology of defected ground plane in [13, 14] or with band-rejected designs of the printed wideband antenna in [15] are reported. The aforementioned designs introduce additional resonance modes or suppress the dispensable bands for accurate expected narrow bands mitigating the interference. The above presented antennas realize dual- or triple-band operations, but disadvantages of either large size, complicated fabrication structure, not adequate low profile or not very stable omni-directional radiation somewhat exist.

In this paper, a novel compact microstrip-fed monopole antenna design with triple-band operation is proposed for 2.4/5.2/5.8 GHz WLAN applications. In the proposed design, the antenna consists of an inverted-L strip with similar shaped parasitic element to separate the 5 GHz band into two 5.2/5.8 GHz bands for accurately covering IEEE 802.11a standard of WLAN and a quasi-F-shaped protrudent arm on the ground plane exciting the lower band for IEEE 802.11 b/g of WLAN at 2.4 GHz. These design skills are adopted to realize accurate triple band operations for WLAN standard mitigating the unwanted interference. The proposed antenna is designed and simulated by Ansoft HFSS simulator, and implemented with prototype. Details of the antenna design are described in the following sections, and both simulated and measured results are presented reaching a reasonable agreement with good impedance bandwidths, stable radiation characteristics and proper peak antenna gains.

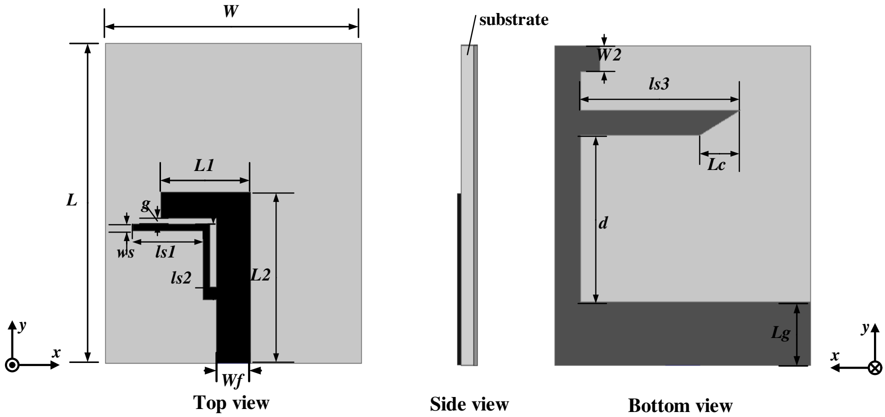


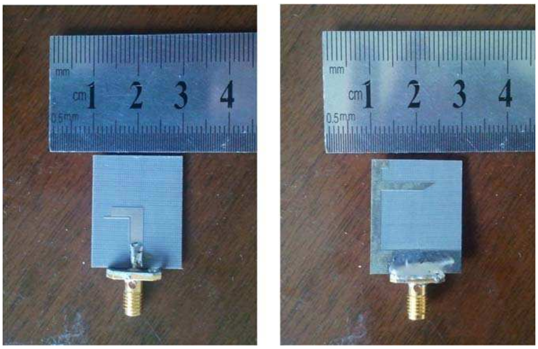
Figure 1. Geometry and dimensions of the proposed antenna.

2. ANTENNA DESIGN

Figure 1 illustrates the configuration of the proposed triple-band monopole antenna, which is designed and fabricated on Arlon AD255A (tm) substrate with relative dielectric constant (ε_r) of 2.55, thickness of 1.0 mm and small size of $20 \times 25\,\text{mm}^2$. In the antenna design, the proposed antenna is composed of an inverted-L-shaped 50-Ω microstrip feed line with fixed width of 2.7 mm, a similar shaped parasitic strip by the side of the feed line, and a defected ground plane with a protrudent mirrored quasi-F-shaped strip with width of 2 mm. The protrudent strip on the ground plane excites the lower frequency mode of 2.4-GHz for IEEE 802.11 b/g WLAN operation, with the longer horizontal strip of length $ls3$ controlling this resonant band and a trigonal end at the longer horizontal strip as to improve the impedance matching condition. In order to introduce the excitation of another two resonant modes at 5.2/5.8-GHz for IEEE 802.11a WLAN operation, the inverted-L feed line is printed on the top side of the substrate with a parasitic strip aside the feed line, which is to separate the 5-GHz band into two 5.2/5.8 GHz bands for precisely containing the IEEE 802.11a standard of WLAN without frequency disturbance. Changing the length $L1$ of the inverted-L feed line and the length $ls1$ of the parasitic element can adjust the resonant band of the IEEE 802.11a standard. The electromagnetic simulator Ansoft HFSS based on the finite element method is applied for the required numerical analysis and to obtain the optimal geometrical parameters which are listed in Table 1.

Table 1. The optimal parameters of the proposed antenna (unit: mm).

W	L	Wf	$L1$	$L2$	ws	g	$ls1$	$ls2$	$W2$	$ls3$	Lc	d	Lg
20	25	2.7	7	13.4	0.3	0.2	5.5	5.2	2	12.5	3.15	13	5



(a) (b)

Figure 2. Photograph of the fabricated printed triple-band monopole antenna with optimal dimensions. (a) Top view. (b) Bottom view.

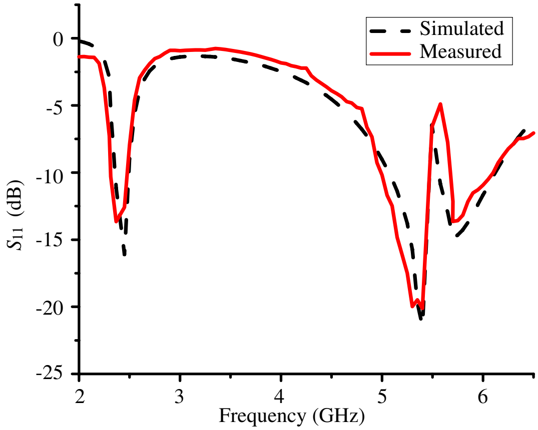
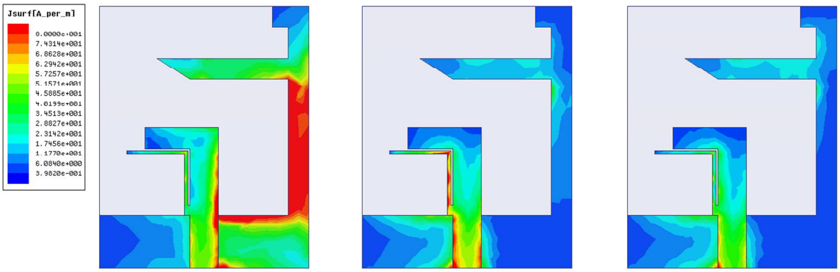


Figure 3. Simulated and measured S_{11} curves of the triple-band monopole antenna.

3. RESULTS AND DISCUSSIONS

The fabricated prototype of the proposed antenna fed by a 50-Ω SMA connector shown in Figure 2 has been constructed and experimentally



(a) (b) (c)

Figure 4. Simulated surface current distributions at different frequencies. (a) 2.425 GHz. (b) 5.35 GHz. (c) 5.75 GHz.

studied, with a WILTRON 37269A vector network analyzer. The simulated and measured return losses (S_{11}) of the proposed triple-band antenna are plotted in Figure 3, with reasonable agreements between the simulation and measurement results. Slight discrepancies between them may be attributed to measurement errors, fabrication inaccuracies, the ununiformity of the substrate permittivity and the impact of the 50-Ω SMA connector. As the results indicate, triple resonant modes are excited at 2.4, 5.2, and 5.8-GHz, which perfectly cover the required WLAN bands. The bandwidth for $S_{11} \leq -10$ dB in the lower band reaches 0.10 GHz (2.39–2.49 GHz), which meets the demands for 2.4-GHz WLAN applications. For the upper bands, the impedance bandwidths of 0.36 GHz (5.06–5.42 GHz) and of 0.62 GHz (5.49-6.11 GHz) at 5 GHz, which are sufficient to cover the 5.2/5.8-GHz WLAN bands, are obtained.

For better understanding the excitation behavior of the proposed antenna, the simulated surface current distributions at different resonant frequencies (2.4, 5.2, and 5.8-GHz) are displayed in Figure 4. For the 2.4-GHz excitation, larger surface current distribution is observed along the longer path of the protrudent strip on the ground plane, which implies that this protrudent strip is the major radiating element at the 2.4-GHz band. For the upper bands at 5.2-GHz and 5.8-GHz, the strong surface current densities are distributed on the parasitic strip and the inverted-L feed line, respectively, meaning that this structure controls the higher resonant bands.

The S_{11} curves for three extra cases of antennas, with and without the protrudent strip on the ground plane, with and without the parasitic element, added for comparison are presented in Figure 5. Case 1 is the final design of the proposed antenna. For case 3 without protrudent strip on the ground plane, the resonant mode at 2.4-GHz doesn't exist, while for case 2 without the parasitic element, the 5-GHz

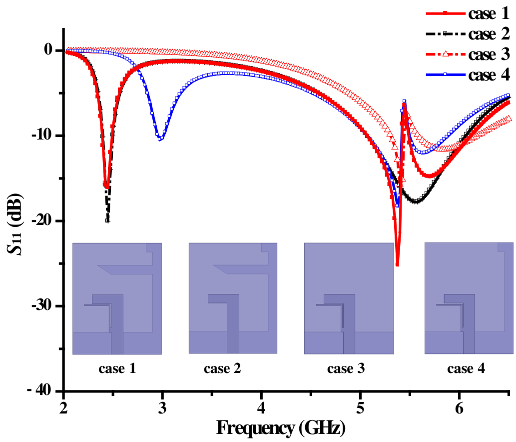


Figure 5. S_{11} curves of the proposed antenna in the different cases.

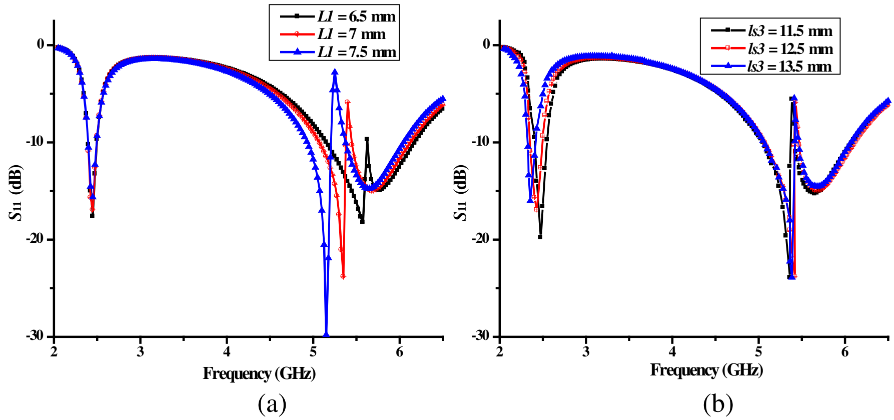


Figure 6. Simulated S_{11} variations for the proposed antenna of different lengths $L1$ and $ls3$. (a) $L1$. (b) $ls3$. (Other parameters are the same as in Table 1).

band isn't separated into two bands accurately suitable for 5.2/5.8-GHz operations. Case 4 shows that absence of the long horizontal strip on the ground plane composing the mirrored F-shaped stub results in the impedance mismatch.

For further investigation on resonant frequency bands, two crucial parameters having effects on the resonant mode are analyzed. According to the simulated S_{11} curves for various values of $L1$ illustrated in Figure 6(a), it is seen from the figure that increasing the horizontal strip length $L1$ from 6.5 mm to 7.5 mm leads to the shift towards the lower frequencies of resonant modes at 5.2/5.8-GHz. Figure 6(b) shows the effect of different length $ls3$ on the S_{11} curves, indicating that the change of the length $ls3$ controls the resonant band for 2.4-GHz, simultaneously has little impact on upper ones at 5.2/5.8-GHz. Thus, from surface current distributions, and the S_{11} characteristic curves of different cases and various vital

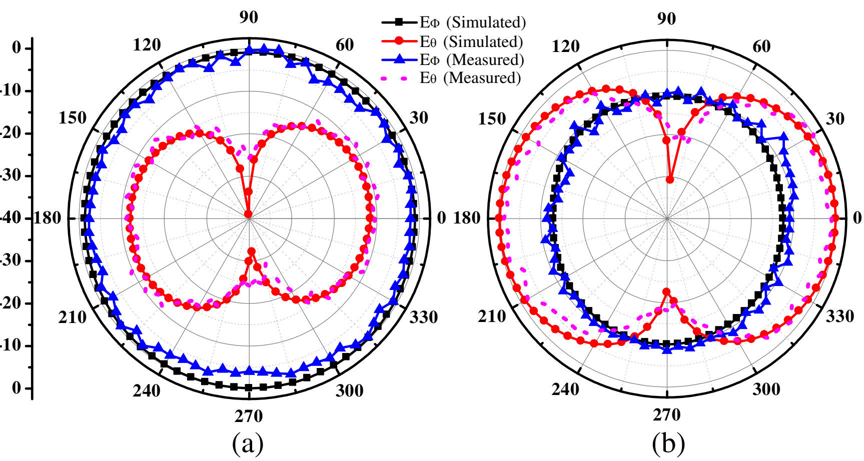


Figure 7. Measured and simulated normalized radiation patterns for the proposed antenna at 2.425 GHz. (a) x-z plane. (b) y-z plane.

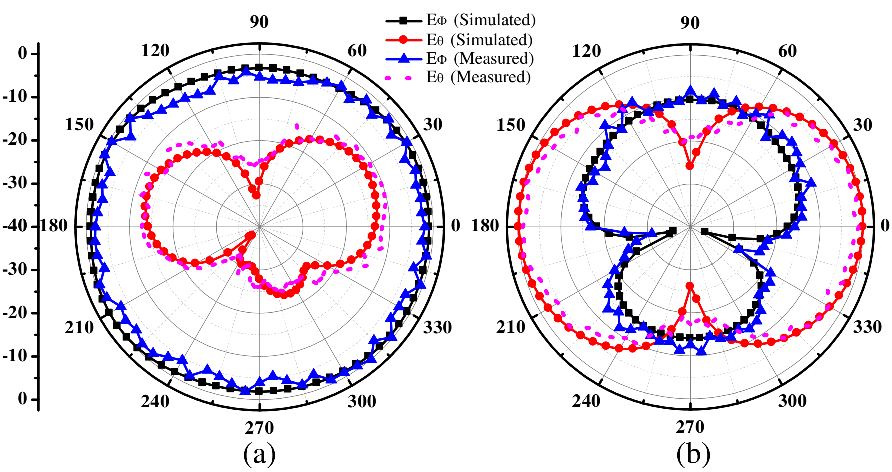


Figure 8. Measured and simulated normalized radiation patterns for the proposed antennas at 5.35 GHz. (a) x-z plane. (b) y-z plane.

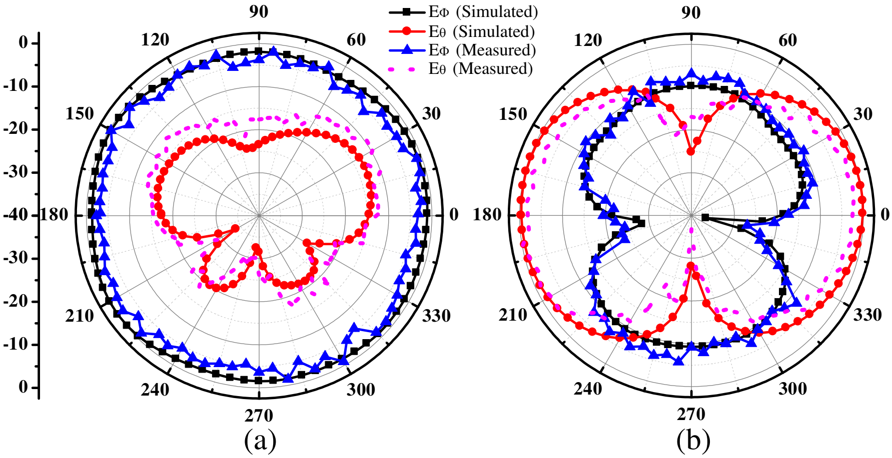


Figure 9. Measured and simulated normalized radiation patterns for the proposed antenna at 5.75 GHz. (a) x-z plane. (b) y-z plane.

parameters of the antenna structure, we can clearly comprehend and gain a relatively deep understanding of the function of the relevant geometrical mechanism on the impedance matching condition of the proposed antenna.

The far-field measured and simulated normalized radiation patterns of the proposed triple-band monopole antenna are also investigated. Figures 7–9 show the measured and simulated radiation patterns including the vertical (E_θ) and the horizontal (E_Φ) polarization patterns of the proposed antenna at 2.425, 5.35 and 5.75 GHz, respectively. It can be obviously noticed that the nearly omni-directional radiation in the H plane (x-z plane) and bidirectional radiation in the E plane (y-z plane) for all the triple operation bands are obtained, which show a monopole-like radiation characteristics. The measured results of the radiation patterns are in accordance with the simulated ones with acceptable discrepancies which may result from the influence of the anechoic chamber environment. That is, stable radiation patterns have been obtained for the proposed antenna.

The measured and simulated peak gains of the proposed antenna for frequencies across the triple operating bands are stable and acceptable, as illustrated in Figure 10. The measured peak antenna gains are about 1.8–2.7 dBi for the 2.4-GHz band, 2.5–3.1 dBi for the 5.2-GHz band and 2.6–2.8 dBi for the 5.8 GHz band. For the 2.4-GHz band, the gain variations are less than 0.9 dBi, while for the 5.2-GHz and 5.8-GHz bands, the gain variations are less than 0.6 dBi, respectively.

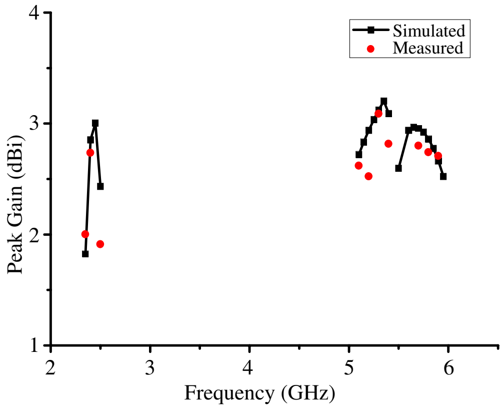


Figure 10. Measured and simulated peak antenna gains of the proposed antenna for the triple bands.

4. CONCLUSION

A novel compact monopole antenna with triple-band operation is designed, investigated and fabricated in this paper. By introducing a parasitic element to the monopole feed line and a protrudent mirrored quasi-F-shaped strip on the ground plane, the prototype of the antenna with an area of $20 \times 25\,\text{mm}^2$ has achieved satisfactory multi-band performance for WLAN application, which obtains impedance bandwidths of 2.39–2.49 GHz, 5.06–5.42 GHz and 5.49–6.11 GHz, respectively. The radiating mechanism and the effects of different dimensions on the feature of the proposed antenna have also been discussed. Due to the good radiation pattern performance, stable gains across the triple bands and the above features, the proposed antenna has wide and promising applications for wireless communication systems.

REFERENCES

1. Wu, Y.-J., B.-H. Sun, J.-F. Li, and Q.-Z. Liu, "Triple-band omni-directional antenna for WLAN application," *Progress In Electromagnetics Research*, Vol. 76, 477–484, 2007.
2. Li, F., L.-S. Ren, G. Zhao, and Y.-C. Jiao, "Compact triple-band monopole antenna with C-shaped and S-shaped meander strips for WLAN/WiMAX applications," *Progress In Electromagnetics Research Letters*, Vol. 15, 107–116, 2010.
3. Rezaeieh, S. A., "Compact dual band CPW-fed monopole antenna with L-strips for WLAN/WiMAX applications," *19th Telecommunications Forum (TELFOR)*, 1602–1604, 2011.

4. Li, X., L. Yang, S.-X. Gong, and Y.-J. Yang, "Bidirectional high gain antenna for WLAN applications," *Progress In Electromagnetics Research Letters*, Vol. 6, 99–106, 2009.
5. Zhang, S.-M., F.-S. Zhang, W.-M. Li, W.-Z. Li and H.-Y. Wu, "A multi-band monopole antenna with two different slots for WLAN and WiMAX applications," *Progress In Electromagnetics Research Letters*, Vol. 28, 173–181, 2012.
6. Ren, F.-C., F.-S. Zhang, J.-H. Bao, B. Chen, and Y.-C. Jiao, "Compact triple-frequency slot antenna for WLAN/WiMAX operations," *Progress In Electromagnetics Research Letters*, Vol. 26, 21–30, 2011.
7. Lee, Y.-C. and J.-S. Sun, "Compact printed slot antennas for wireless dual-and multi-band operations," *Progress In Electromagnetics Research*, Vol. 88, 289–305, 2008.
8. Song, C. T. P., P. S. Hall, H. Ghafouri-Shiraz, and D. Wake, "Triple band planar inverted F antennas for handheld devices," *Electron. Lett.*, Vol. 36, No. 2, 112–114, 2000.
9. Hsiao, F.-R. and K.-L. Wong, "Compact planar inverted-F patch antenna for triple-frequency operation," *Microwave Opt. Technol. Lett.*, Vol. 33, No. 6, 459–462, 2002.
10. Dou, W. P. and Y. W. M. Chia, "Novel meandered planar inverted-F antenna for triple-frequency operation," *Microwave Opt. Technol. Lett.*, Vol. 27, No. 1, 58–60, Oct. 5, 2000; Dig., 112–115.
11. Abaga Abessolo, M. A., A. El Moussaoui, and N. Aknin, "Dual-band monopole antenna with omega particles for wireless applications," *Progress In Electromagnetics Research Letters*, Vol. 24, 27–34, 2011.
12. Jan, J.-Y. and L.-C. Tseng, "Small planar monopole antenna with a shorted parasitic inverted-L wire for wireless communications in the 2.4-, 5.2-, and 5.8-GHz bands," *IEEE Trans. Antennas Propag.*, Vol. 52, No. 7, 1903–1905, 2004.
13. Antoniades, M. A. and G. V. Eleftheriades, "A compact multiband monopole antenna with a defected ground plane," *IEEE Antennas Wireless Propagat. Lett.*, Vol. 7, 652–655, 2008.
14. Li, R.-H., X.-W. Shi, N. Zhang, Y.-F. Wang, and Y.-J. Wang, "A novel compact dual-band antenna for WLAN applications," *Microwave Opt. Technol. Lett.*, Vol. 54, No. 6, 1476–1479, 2012.
15. Chen, W.-S. and K.-Y. Ku, "Band-rejected design of the printed open slot antenna for WLAN/WiMAX operation," *IEEE Trans. Antennas Propag.*, Vol. 56, No. 4, 1163–1169, 2008.