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Miniaturized UWB Monopole-Like Slot Antenna with Low Un-Roundness of *H*-Plane Radiation Patterns at High-Frequency Band

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Abstract—A miniaturized monopole-like slot antenna with improved un-roundness of H-plane radiation patterns at higher frequency response for ultra-wideband application is presented and discussed. With the monopole-like slot antenna structure, wide working band (3.21–16.3 GHz) is obtained within a limited physical size ($21 \times 21.5 \times 1.6\,\mathrm{mm}^3$). By modifying the structure of the proposed antenna, such as etching a quarter of a circular slot at the corner of the ground plane and a trapezoidal slot in the radiating patch, the un-roundness of H-plane radiation patterns is reduced by 5 dB in high-frequency band. Measured results show that it has a bandwidth from 3.2 GHz to 17.52 GHz, which are in good agreement with simulations.

1. INTRODUCTION

With the advantage of low power consumption, high-speed data rate and large data capacity, ultra-wideband (UWB) technology is an ideal candidate for application in short range, broadband indoor wireless communication systems, peer-to-peer ultra-fast communications, etc. Since UWB antenna is the key component of a UWB system with the operating band between 3.1 to 10.6 GHz, it has become a hot topic for academic and industrial research [1–5].

The monopole-like slot antenna with the ground vertically extended toward two sides of the radiation patch having the merits of more easily achieving a wide range of impedance bandwidth, realizing miniaturization and reaching unidirectional radiation patterns is favored by researchers when designing UWB antennas. Hence, various types of monopole-like slot antennas have been investigated in recent years [5–9]. The UWB characteristic is obtained by an M-shaped radiation patch together with a rectangular slot ground plane in [5]. With a stepped stairs extended ground stub around the hexagonal monopole antenna, a relative bandwidth of 133% is accomplished in [6]. By the cooperative use of a fork-like radiator and a ground plane with an L-shaped stub, the CPW-fed monopole-like slot antenna achieves a wide working band between 2.7 to 12.4 GHz in [7]. Various techniques used for the design of miniature antennas are proposed in [10–15]. Some of these techniques use genetic algorithms optimization [10–12], slots [13, 14], coupling and shorting [15], etc. The proposed antenna with trapezoidal slots has more compact physical size than the antennas presented in [5, 7–9] seen from Table 1. Nevertheless, the omnidirectional radiation performance of the antennas in [5–9] in the high frequency band is deteriorated. Since omnidirectional radiation characteristics are required in the UWB wireless system. It is necessary to reduce antenna size while maintaining stable omnidirectional radiation performance.

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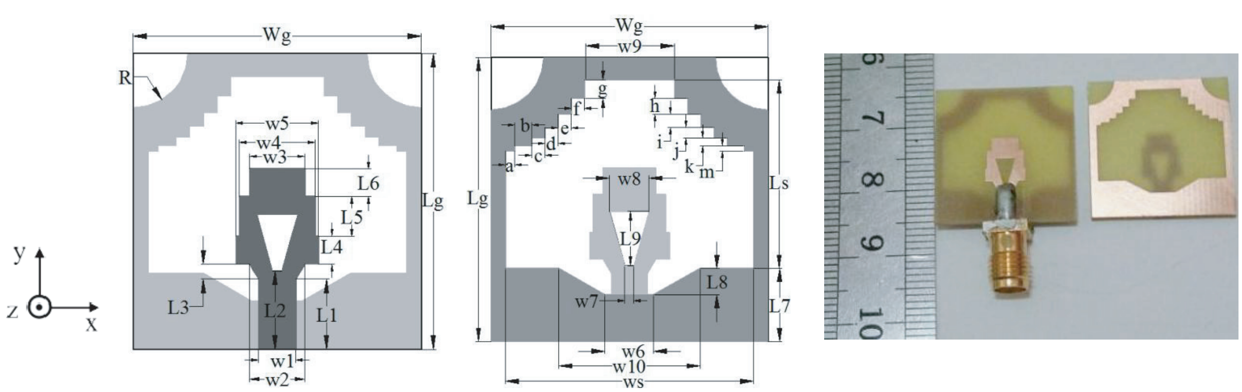
Table 1. The physical size of the proposed antenna and that presented in [5, 7–9].

Reference#	Size (mm × mm)	Area (mm^2)	Bandwidth (GHz)
[5]	36 × 36	1296	2.38–12.4
[7]	26 × 29	754	2.7–12.4
[8]	25 × 25	625	2.6–13.04
[9]	28 × 30	840	2.91–12.0
Proposed antenna	21×21.5	451.5	3.21–16.3

In this work, a miniaturized monopole-like UWB slot antenna with reduced un-roundness of H-plane radiation pattern in high-frequency band is proposed. The large space around the radiation patch is effectively used in the design process. Thus, a compact antenna with a limited physical size of $21 \times 21.5 \times 1.6\,\text{mm}^3$ operating at a wide band (3.21–16.3 GHz) is accomplished. Moreover, a quarter of a circular slot is etched at the corner of the ground plane, and a trapezoidal slot is embedded in the radiation patch to enhance the omnidirectional radiation performance of H-plane in the high-frequency band of the proposed antenna. Apparently, the un-roundness of H-plane of the proposed antenna is reduced by about 5.6 dB and 4.6 dB compared to the antenna presented in [7] at 7 GHz and 10 GHz, respectively. Meanwhile, the proposed antenna obtains a physical size reduction of 40.12% compared to that presented in [7]. Details of the proposed antenna are discussed and studied in the following sections.

2. ANTENNA DESIGN

Figures 1(a) and 1(b) show the geometry of the proposed monopole-like UWB slot antenna. It is observed that similar to many wide slot antennas, the antenna is fed at the lowest operation frequency which implies that the size of antenna is reduced. Thus, it may be concluded that the trapezoidal slot structure is useful for both antenna size reduction and broadband operation. The antenna is designed using High Frequency Structure Simulator and fabricated on an FR-4 substrate with relative permittivity $\varepsilon_r = 4.6$. The overall size of the proposed antenna is $21 \times 21.5 \times 1.6\,\text{mm}^3$. The detailed dimensions of the proposed antenna are listed in Table 2.



(a) (b) (c)

Figure 1. Structure of the antenna: (a) Top view; (b) Bottom view; (c) Fabricated antenna.

2.1. Miniaturized Design Process of the Proposed UWB Antenna

The design is started from "Ant. a" shown in Figure 2. The ground plane is modified by cutting rectangular slots. Thus, it works as a radiator which resonates at lower band of UWB. The tapered slot

Table 2. Design parameters (mm) of the proposed antenna.

Lg	$L1$	$L2$	$L3$	$L4$	$L5$	$L6$	$L7$	$L8$	$L9$	Ls	R
21.5	5.1	5.7	1.1	2.4	2.9	2	5.5	2	4.1	14.3	4
Wg	$w1$	$w2$	$w3$	$w4$	$w5$	$w6$	$w7$	$w8$	$w9$	$w10$	ws
21	2.7	4	4	5.5	6	3.7	0.7	3	6.8	10.7	18.8
a	b	c	d	e	f	g	h	i	j	k	m
0.7	1.3	1	1	1	1	1.4	1.2	1	0.8	0.6	0.4

etched under feeding line in "Ant. b" is beneficial for impedance matching at high frequency band. The larger ground loop ensures proper radiation of the signal at low-frequency band. Meanwhile, the ground loop together with the rectangular feeding patch mainly controls radiation at high-frequency band. The height of the ground is reduced, and a 45° cutting corner is introduced on the ground plane at corner for miniaturization in "Ant. c". Thus, "Ant. c" achieves a physical size reduction of 16% with realized good impedance matching over 3.18 to 16.3 GHz band. By modifying the outline of the radiation patch and ground plane with a similar stepped stairs structure, the return loss around frequency A and B of "Ant. d" optimizes nearly 5 dB compared to "Ant. c" illustrated in Figure 3(a).

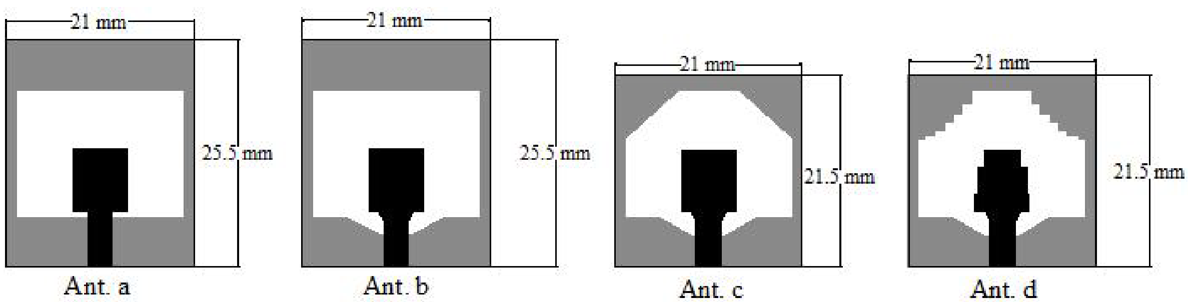


Figure 2. Miniaturized design process of the proposed antenna.

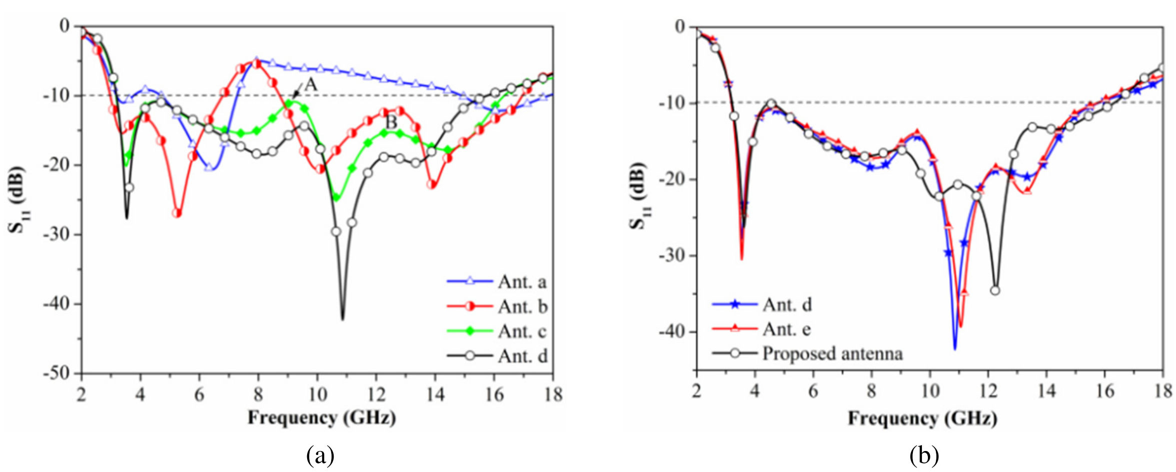


Figure 3. Simulated return loss results of antenna: (a) a to d; (b) d to e and the proposed antenna.

2.2. Un-Roundness Optimization Design Process of H-Plane at High — Frequency Band

The evolution of the proposed antenna structure in the un-roundness optimization process is presented in Figure 4. The bandwidth of the presented antenna is almost constant in the optimization process seen from Figure 3(b). Obviously, etching a quarter of a circular slot at the corner of the ground plane is the most effective way to improve the omnidirectional radiation performance of the proposed antenna especially at upper frequency seen from Table 3. With the introduction of a quarter of a circular slot and the trapezoidal slot, the value of the surface current concentrates on the stepped radiation patch with the smaller wave path-difference increased a lot. Besides, the distribution of the surface current becomes more orderly and uniform around the top corner of the ground plane. Thus, lower un-roundness is accomplished. The proposed antenna has better omnidirectional radiation characteristics than the antenna presented in [6, 7, 9] at 7 GHz, 8 GHz, 9 GHz and 10 GHz seen from Table 4.

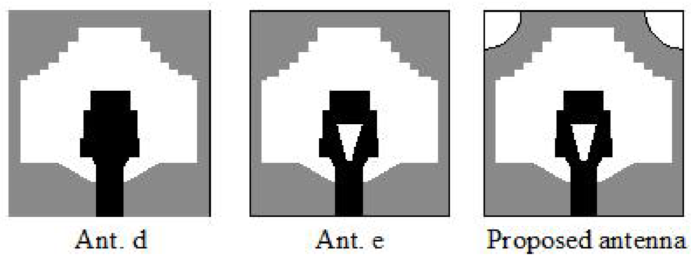


Figure 4. Evolution of the antenna structure in the un-roundness optimization design process.

Table 3. The un-roundness of H-plane among antennas d to e and the proposed antenna in the optimization process.

Un-roundness (dB) / Antenna / Freq.	d	e	proposed antenna	Difference between Ant. d and proposed antenna
7 GHz	5.12	5.57	4.4	0.72
8 GHz	6.52	6.57	5.6	0.92
9 GHz	10.36	9.73	7.2	3.12
10.6 GHz	16.26	16.26	11.2	5.06

Table 4. The un-roundness of the proposed antenna and that presented in [6, 7, 9] of H-plane radiation pattern at high-frequency band.

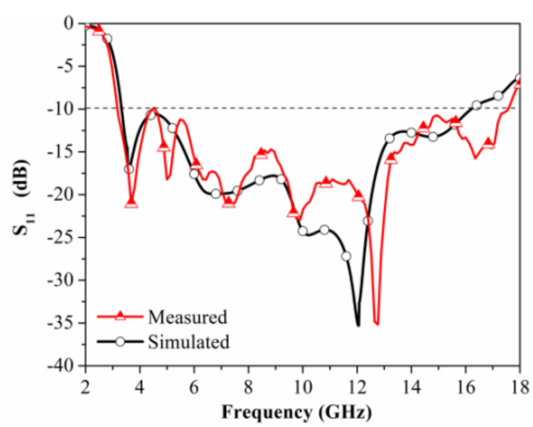
Un-roundness (dB) / Freq.	in [6]	in [7]	in [9]	Proposed Antenna	Reduced by
7 GHz		10		4.4	5.6
8 GHz	10.6			5.6	5
9 GHz			11	7.2	3.8
10 GHz		15		10.4	4.6

3. EXPERIMENTAL RESULTS AND DISCUSSION

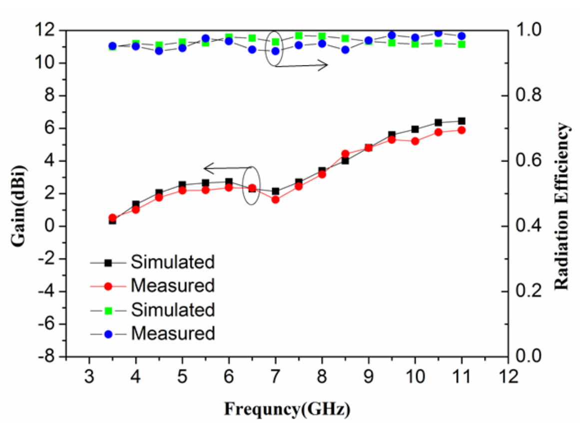
The antenna prototype, fabricated and measured to validate the simulation results, is shown in Figure 1(c). The electrical performance of the proposed antenna is measured by an Agilent E8363B vector network analyzer. As shown in Figure 5(a), the simulated and measured return losses are in good agreement. The designed antenna has an ultra-wide band performance of 3.2 to 17.52 GHz.

The simulated and measured values of peak gain are depicted in Figure 5(b). The antenna shows a steady gain over the entire UWB band. As presented in Figure 5(b), the radiation efficiency of the proposed antenna is all above 90% over the entire UWB band. The simulated and measured gains and radiation efficiencies are in good agreement. The simulated and measured values of group delay are depicted in Figure 5(c). The simulated and measured group delays of the proposed antenna are almost constant (remain nearly 1.25 ns) under the condition that the transceiver antenna pair facing to each other is 30 cm apart. This confirms that the proposed antenna is suitable for UWB communications.

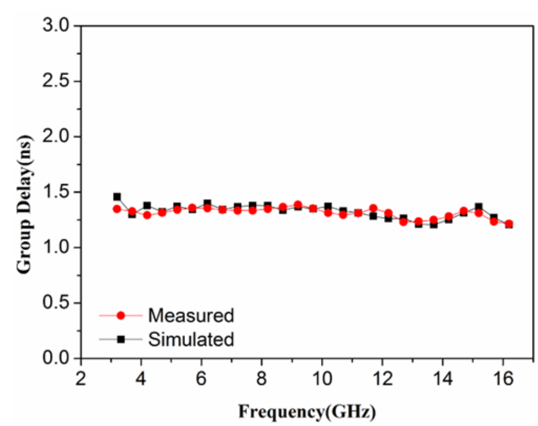
The simulated and measured normalized radiation pattern results of the proposed antenna obtained at selected frequencies (4 GHz, 7 GHz, 10 GHz) are shown in Figure 6. A good agreement is presented between the simulated and measured results. The radiation pattern in the E-plane (yz-plane) and the "8"-figured pattern hare kept perfectly almost over the whole operating band except at high-frequency band where the radiation pattern begins to split a little. The radiation pattern in the H-plane (xz-plane) is nearly omnidirectional, which is favorable for wireless device application.



(a)



(b)



(c)

Figure 5. (a) Simulated and measured return loss curves of the fabricated antenna; (b) Simulated and measured total gains and radiation efficiencies of the proposed antenna; (c) Simulated and measured group delays for the proposed UWB antenna.

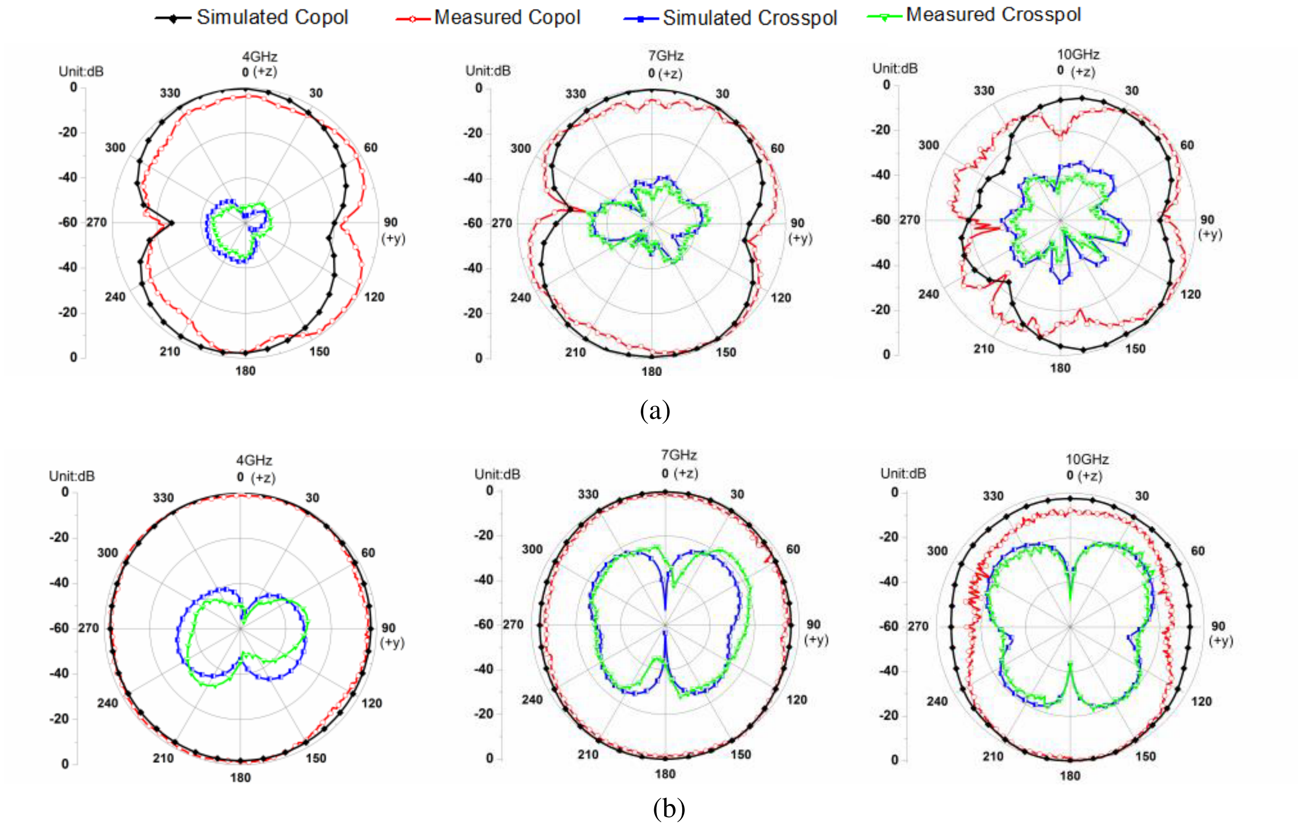


Figure 6. Simulated and measured normalized radiation patterns of the proposed antenna: (a) E-plane (yz-plane); (b) H-plane (xz-plane).

4. CONCLUSION

In this paper, a miniaturized monopole-like UWB slot antenna with improved omnidirectional radiation characteristics at high-frequency band has been designed, realized and tested. With the use of a monopole-like antenna structure, a relative bandwidth of more than 130% (3.21–16.3 GHz) is obtained with a physical size reduction of 40.12% compared to that presented in [7]. Furthermore, with the introduction of the structure such as a trapezoidal slot and a quarter of a circular slot in the un-roundness optimization process, the un-roundness of H-plane of the proposed antenna is reduced by about 5.6 dB and 4.6 dB compared to the antenna presented in [7] at 7 GHz and 10 GHz, respectively. Besides, the group delay of the proposed antenna is almost constant over the operating band. Thus, the proposed antenna is very ideal for applying in UWB communication system.

REFERENCES

1. Ellis, M. S., Z. Q. Zhao,, J. W. Wu,, Z. P. Nie,, and Q. H. Liu, "Small planar monopole ultra-wideband antenna with reduced ground plane effect," *IET Microw. Antennas Propag.*, Vol. 9, No. 10, 1028–1034, 2015.
2. Lin, C., "Compact bow-tie quasi-self-complementary antenna for UWB applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 11, 987–989, 2012.
3. Li, P., J. Liang,, and X. Chen,, "Study of printed elliptical/circular slot antennas for ultra wideband applications," *IEEE Trans. Antennas Propag.*, Vol. 54, No. 6, 1670–1675, 2006.
4. Barbarino, S. and F. Consoli,, "UWB circular slot antenna provided with an inverted-L notch filter for the 5 GHz WLAN band," *Progress In Electromagnetics Research*, Vol. 104, No. 4, 1–13, 2010.

5. Shrivastava, M. K., A. K. Gautam,, and B. K. Kanaujia,, "An M-shaped monopole-like slot UWB antenna," *Microw. Opt. Technol. Lett.*, Vol. 56, No. 1, 127–131, 2014.
6. Zhao, D. S., C. X. Yang,, M. Zhu,, and Z. X. Chen,, "Design of WLAN/LTE/UWB antenna with improved pattern uniformity using ground-cooperative radiating structure," *IEEE Trans. Antennas Propag.*, Vol. 64, No. 1, 271–276, 2016.
7. Qing, X. and Z. N. Chen,, "Compact coplanar waveguide-fed ultra-wideband monopole-like slot antenna," *IET Microw. Antennas Propag.*, Vol. 3, No. 5, 889–898, 2009.
8. Gautam, A. K., S. Yadav,, and B. K. Kanaujia,, "A CPW-fed compact UWB microstrip antenna," *IEEE Antennas & Wireless Propagation Letters*, Vol. 12, No. 12, 151–154, 2013.
9. Lui, W. J., C. H. Cheng,, and H. B. Zhu,, "Experimental investigation on novel tapered microstrip slot antenna for ultra-wideband applications," *IET Microwaves Antennas & Propagation*, Vol. 1, No. 2, 480–487, 2007.
10. Jeevani, J. M., W. Jayasinghe, and D. N. Uduwawala, "A novel multiband miniature planar inverted F antenna design for bluetooth and WLAN applications," *International Journal of Antennas and Propagation*, Vol. 2015, Article ID 970152, 6 pages, 2015.
11. Lamsalli, M., A. El Hamichi, M. Boussouis, N. Amar Touhami, and T. Elhamadi, "Genetic algorithm optimization for microstrip patch antenna miniaturization," *Progress In Electromagnetics Research Letters*, Vol. 60, 113–120, 2016.
12. Jayasinghe, J. W. and D. N. Uduwawala, "A novel miniature multi-frequency broadband patch antenna for WLAN applications," *2013 IEEE 8th IEEE International Conference on Industrial and Information Systems*, No. 2013, 361–363, Sri Lanka, Dec. 2013.
13. Meng, F. and S. Sharma, "A single feed dual-band (2.4 GHz/5 GHz) miniaturized patch antenna for wireless local area network (WLAN) communications," *Journal of Electromagnetic Waves and Applications*, Vol. 30, No. 18, 2390–2402, 2016.
14. Tanweer, A., C. Rajashekhar, and A. Biradar, "Miniaturized volkswagen logo UWB antenna with slotted ground structure and metamaterial for GPS, WiMAX and WLAN applications," *Progress In Electromagnetics Research C*, Vol. 72, 29–41, 2017.
15. Liu, H., B. Lu, and L. Li, "Novel miniaturized octaband antenna for LTE smart handset applications," *International Journal of Antennas and Propagation*, Vol. 2015, Article ID 861016, 8 pages, 2015.