TABLE 2 Dimensions of the Final Prototype Filter with Dumbbell DGS Etched

Parameter	Length (mm)	Parameter	Length (mm)
w_t	2.54	l_t	8.382
d_1	2.807	d_2	2.743
a_1	5.69	a_2	4.978
a_s	7.214	l_1	2.54
L	3.556	g	1.32
h	0.508	w	0.254

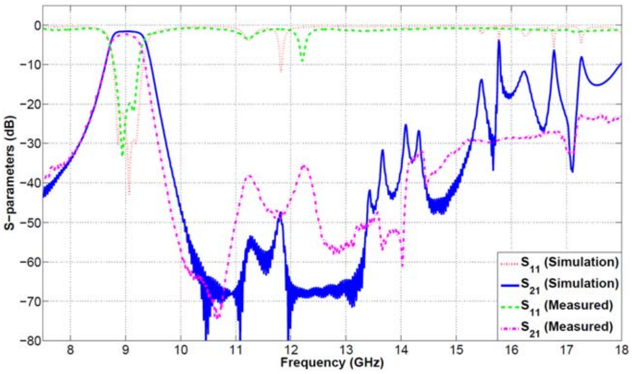

Figure 7 Simulated and measured *S*-parameter results for the final third-order prototype filter with DSS depicted in Figure 6. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

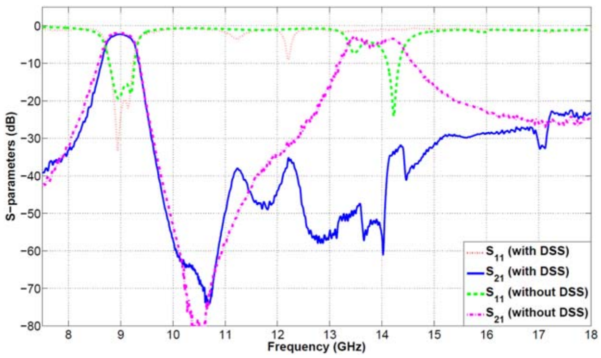

Figure 8 Measured harmonic performance of the third-order prototype filters with and without DSS. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

4. CONCLUSION

A novel SIW-based interdigital BPF is presented. In addition to the interdigital SIW resonators, two additional control mechanisms, namely narrowing the width of the SIW at the middle of filter and use of additional vias at its input and output sides, are introduced to achieve the desired response. The proposed structure is verified with a fabricated prototype which exhibits good filtering properties and good harmonic suppression due to the DSS etched to the ground side of the microstrip line feeding section at both ends of the filter.

REFERENCES

1. G.L. Matthaei, Combline band-pass filters of narrow or moderate bandwidth, Microwave J 6 (1963), 82–91.
2. G. Matthaei, E.M.T. Jones, and L. Young, Microwave filters, impedance-matching networks, and coupling structures, Artech House, Norwood, MA, 1980.
3. M. Bozzi, A. Georgiadis, and K. Wu, Review of substrate-integrated waveguide circuits and antennas, IET Microwave Antennas Propag 5 (2011), 909–920.
4. J.E. Rayas-Sanchez, An improved em-based design procedure for single layer substrate integrated waveguide interconnects with microstrip transitions, In: IEEE MTT-S International Microwave Workshop Series on Signal Integrity and High Speed Interconnects, Guadalajara, Mexico, February 2009.
5. X.-P. Chen and K. Wu, Substrate integrated waveguide cross-coupled filter with negative coupling structure, IEEE Trans Microwave Theory Tech 56 (2008), 142–149.
6. B. Potelon, J.-F. Favennec, C. Quendo, E. Rius, C. Person, and J.-C. Bohorquez, Design of a substrate integrated waveguide (SIW) filter using a novel topology of coupling, IEEE Microwave Wireless Comp Lett 18 (2008), 596–598.
7. T.-S. Yun, H. Nam, K.-B. Kim, and J.-C. Lee, Iris waveguide bandpass filter using substrate integrated waveguide (siw) for satellite communication, In: Asia-Pacific Microwave Conference Proceedings, Suzhou, China, 2005.
8. Y.D. Dong, T. Yang, and T. Itoh, Substrate integrated waveguide loaded by complementary split-ring resonators and its applications to miniaturized waveguide filters, IEEE Trans Microwave Theory Tech 57 (2009), 2211–2223.
9. Y.L. Zhang, W. Hong, K. Wu, J.X. Chen, and H.J. Tang, Novel substrate integrated waveguide cavity filter with defected ground structure, IEEE Trans Microwave Theory Tech 53 (2005), 1280–1287.
10. K. Deng, Z. Guo, C. Li, and W. Che, A compact planar bandpass filter with wide out-of-band rejection implemented by substrate-integrated waveguide and complementary split-ring resonator, Microwave Opt Technol Lett 53 (2011), 1483–1487.
11. J.C. Bohórquez, B. Potelon, C. Person, E. Rius, C. Quendo, G. Tanńe, and E. Fourn, Reconfigurable planar SIW cavity resonator and filter, In: IEEE MTT-S International Microwave Symposium Digest 2006, San Francisco CA, pp. 947–950.
12. J.D. Martinez, M. Taroncher, and V.E. Boria, Capacitively loaded resonator for compact substrate integrated waveguide filters, In: Proceedings of 40th European Microwave Conference, Paris, France, 2010, pp. 192–195.
13. J.D. Martinez, S. Sirci, and V.E. Boria, Compact cpw-fed combline filter in substrate integrated waveguide technology, IEEE Microwave Wireless Comp Lett 22 (2012), 7–9.
14. D. Kajfez, Q-factor, Oxford, MS, Vector Forum, 1994.

A COMPACT MODIFIED TRIANGULAR CPW-FED ANTENNA WITH MULTIOCTAVE BANDWIDTH

Amir Siahcheshm,[1] Javad Nourinia,[1] Yashar Zehforoosh,[2] and Bahman Mohammadi[1]
[1] Department of Electrical Engineering, Urmia University, Urmia, Iran; Corresponding author: b.mohammadi@urmia.ac.ir
[2] Department of Electrical Engineering, Urmia Branch, Islamic Azad University, Urmia, Iran

Received 9 June 2014

ABSTRACT: *This article presents the results of a compact modified triangular CPW-fed antenna that exhibits multioctave performance. This modification significantly improves the antenna's impedance bandwidth by 198% over an ultra-wideband (UWB) frequency range from 3.06 to 35 GHz. The return-loss (S_{11}) performance over this frequency range is designed to be better than −10 dB. These characteristics make the proposed antenna an excellent candidate for numerous UWB applications and next generation communication systems. The key physical parameters affecting the antenna's frequency characteristics have also been*

investigated to determine optimum antenna performance. The antenna's measured return loss and E-plane and H-plane radiation patterns show a very good correlation with the requirements of UWB applications.
 Microwave Opt Technol Lett 57:69–72, 2015; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.28780

Key words: *multioctave bandwidth; small antenna; triangular CPW-fed antenna; ultra wideband antenna*

1. INTRODUCTION

Ultra-wideband (UWB) technology has undergone many significant developments in recent years. However, there still remain many challenges in making this technology live up to its full potential. The work in this area has gained impetus with the Federal Communication Commission (FCC), permitting the marketing and operation of UWB products within the band 3.1–10.6 GHz. This technology uses short duration pulses that result in very large or wideband transmission bandwidths. With appropriate technical standards, UWB devices can be operated using spectrum, occupied by existing radio services without causing interference, thereby permitting scarce spectrum resources to be used more efficiently. However, this wireless communication technology still needs to be improved further to satisfy the insatiable demand for higher resolution and higher data rate requirements. One key component, necessary to fulfill these requirements in UWB system, is a planar antenna that is capable of providing a wide impedance bandwidth. The antenna needs to operate over the UWB, as it is defined by the FCC. In addition, it needs to provide omnidirectional radiation coverage over the entire UWB frequency range. Other aesthetic features sought from the antenna include being light weighted, small in size, and having a low profile [1–14].

Several monopole configurations have been investigated for wideband applications thus far, which include the various structures [1–14]. Among the proposed wideband antennas include the printed planar monopole antenna, which is a promising candidate for future applications, due to its remarkably compact size, stable radiation characteristics, and ease of construction. The triangular monopole antenna mounted above a ground plane was first proposed in [7], and its impedance bandwidth is found to be dependent on the feeding gap and the antenna's flare angle. Some variants of this type of antenna in an effort to increase its bandwidth have been studied, that is, the tap monopole antenna by a capacitive coupling feed with double band notch function [9], and the staircase bow-tie monopole antenna [11]. In [3], a multiresonance CPW-fed slot antenna, for UWB applications, is proposed. The proposed antenna, consisting of a modified fan-shaped radiating stub and a sprocket-shaped ground plane, provides a wide usable fractional bandwidth of more than 155% (2.39–24.53 GHz). In [4], a CPW-fed antenna is presented for UWB applications. The antenna mainly comprises a simple circular patch and a modified ground plane. The proposed antenna has a compact size of 20 × 20 × 1.6 mm^3 and covers the wide frequency band of 3–23.5 GHz (154%). In [8], a modified monopole compact planar antenna is proposed, which exhibits wide bandwidth performance and completely satisfies the requirements for UWB applications. The proposed antenna exhibits an impedance bandwidth of 160% over a very wide frequency range from 3 to 27 GHz with return loss better than −10 dB. In [11], a printed star-triangular fractal microstrip-fed monopole antenna with semielliptical ground plane is presented for super-wideband applications. The antenna operates over the frequency band between 1 and 30 GHz.

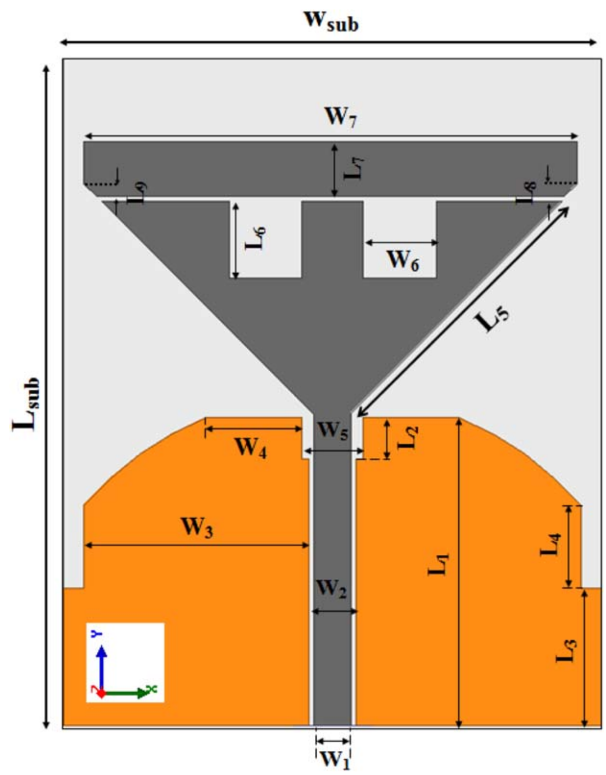

Figure 1 Configuration and parameters defining of the proposed CPW-fed antenna. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

In this article, we present a planar triangular CPW-fed monopole antenna that exhibits multioctave performance. The triangular CPW-fed monopole antenna includes notches above which is located a parasitic element in the form of a narrow rectangular-shaped patch. The antenna's ground plane is truncated and includes slits on the sides. This designed antenna operates over 3.06–35 GHz with $S_{11} < -10$ dB. The proposed CPW-fed antenna displays a good omnidirectional radiation pattern even at higher frequencies and has a smaller size than other reported antennas [3,8]. The simulation results are carried out using Ansoft High Frequency Structure Simulator [15]. The antenna has been fabricated and tested. Good similarity is obtained between the simulated and measured results, which show the validity of the proposed structure.

2. ANTENNA DESIGN

Figure 1 shows the configuration of the proposed multioctave CPW-fed monopole antenna which consists of an inverted triangular structure whose base includes two rectangular-shaped notches, and positioned above triangular base is a parasitic rectangular resonant patch. The ground plane is truncated, as shown in Figure 1, and envelops the feed line to the radiating triangular patch. The ground- lane includes symmetrically slits notch at its center and sides. The proposed CPW-fed antenna is constructed from FR4 substrate with thickness of 1.6 mm and relative dielectric constant of 4.4. The width W_1 of the microstrip feed line is fixed at 2 mm. The antenna's dimensions are 32 mm × 26 mm ($L_{\text{sub}} \times W_{\text{sub}}$). The parameters L_1 and $g = w_2 - w_1$ represent the gap between the edges of the feed line and the ground plane. The dimensions of the slits embedded in the ground plane are important parameters in determining the sensitivity of the antenna's impedance match.

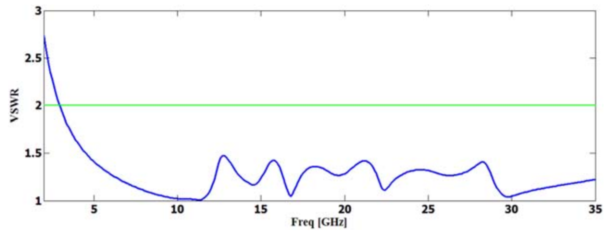

Figure 2 Simulated VSWR characteristic for the proposed CPW-fed antenna. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

The proposed shape of the truncated ground plane acts as an effective impedance matching network to realize a CPW-fed antenna with a very wide impedance bandwidth. This is because the truncation creates capacitive loading that neutralizes the inductive nature of the patch to produce nearly pure resistive impedance present at the CPW-fed antenna's input. The flare angle of the antenna also affects its impedance bandwidth. Here, the flare angle is set to be. The narrow rectangular parasitic patch helps improve the return-loss characteristics ($S_{11} < -10$ dB) at the lower frequency band 3–5 GHz. Also, by introducing slits in the sides of the ground plane and by carefully adjusting their dimensions results in the improvement of the CPW-fed antenna's impedance match over 3–5 GHz and higher frequencies. By properly selecting the parameters of the slit dimensions (L_2 and L_4), an impedance bandwidth of 11.7:1 can be realized. The improvement in impedance match over the multioctave bandwidth is attributed to the phenomenon of defected ground structure with slits that create additional surface current paths in the CPW-fed antenna. Moreover, this ground plane structure changes the inductive and capacitive nature of the input impedance, which in turn leads to change in bandwidth [8–14]. Figure 2 shows the simulated VSWR characteristic of the proposed antenna. The fabricated antenna satisfies the VSWR < 2 requirement from 3.06 to over 35 GHz. The final values of the presented CPW-fed antenna design parameters are specified in Table 1.

The capacitive coupling feed parameters (L_1 and g) are that have a major effect on the antenna's return-loss characteristics. By adjusting L_1 and g, the electromagnetic coupling between the edges of the feed line and the ground plane can be controlled. It can be seen that the lower frequency of the impedance band is reduced by increasing the length gap (L_1) but the impedance match becomes even poorer for larger values of g. As indicated above, the ground plane serves as an impedance matching network, which is a function the electromagnetic coupling between the edges of the feed line and the ground plane (L_1, g). The optimized capacitive coupling feed parameter are $L_1 = 15$ mm and $g = 0.3$ mm.

To enhance the impedance bandwidth characteristic, two pairs of symmetrical located rectangular slits are embedded in

TABLE 1 The Final Dimensions of the Designed CPW-FED Antenna

Param.	(mm)	Param.	(mm)	Param.	(mm)
W_1	2	W_6	3.5	L_4	4
W_2	2.3	W_7	23.6	L_5	14
W_3	10.8	L_1	15	L_6	4.3
W_4	4.6	L_2	2.2	L_7	2
W_5	3	L_3	6.6	L_8	0.8
W_{sub}	26	L_{sub}	32	L_9	0.6

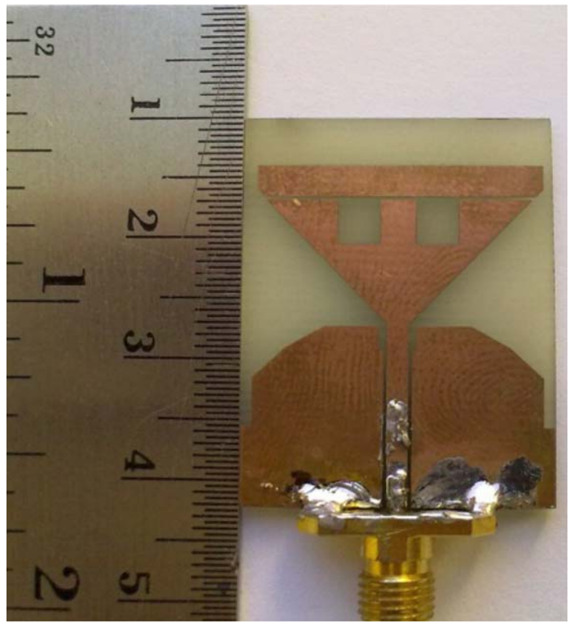

Figure 3 Photograph of the fabricated CPW-fed antenna prototype. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

the ground plane of the proposed antenna; it is found that the impedance bandwidth is greatly dependent on the dimensions of the slits. This phenomenon occurs because the slit acts as current perturbation on the ground plane [9–13]. These parameters are used to fine tune the impedance and determine the impedance bandwidth that can be achieved. From the simulation results, it is found that the lower and upper frequencies are significantly affected by varying the slit lengths L_2 and L_4. It is observed that the impedance match is effectively changed by varying the size of slit widths. As the slit widths are increased or decreased, the lower frequency of the return-loss response is affected. The slit widths are a critical parameter to determine the lower and upper frequency of the impedance bandwidth. The optimum dimensions of the slits are listed in Table 1.

3. RESULTS AND DISCUSSIONS

The proposed CPW-fed antenna with final design parameters, as shown in Figure 3, was fabricated and tested. Figure 4 shows a good agreement between the simulated and measured results. This discrepancy is mostly due to a number of parameters such as the fabricated antenna dimensions as well as the thickness and dielectric constant of the substrate, on which the antenna is

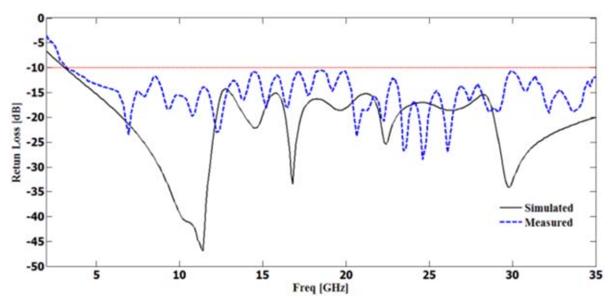

Figure 4 Measured and simulated return loss for the proposed CPW-fed antenna. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

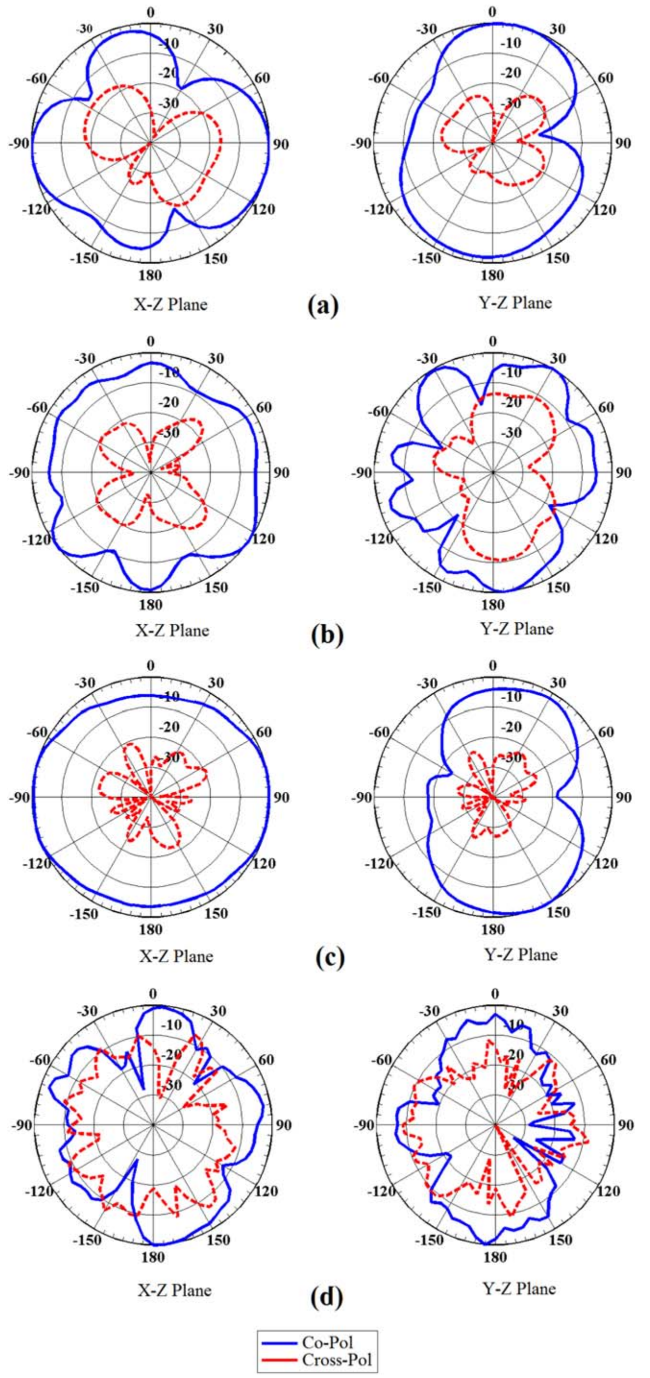

Figure 5 Measured radiation patterns of the proposed CPW-fed antenna, (a) 4 GHz, (b) 7 GHz, (c) 10 GHz, and (d) 13 GHz. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

fabricated, and also the wide range of simulation frequencies. 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 [1–3]. The antenna's measured impedance bandwidth extends from 3.06 to 35 GHz for which its return-loss characteristic is better than −10 dB. This performance exceeds the UWB, as defined by FCC. Figure 5 shows the measured radiation patterns including the copolarization and crosspolarization in the *H*-plane (*x-z* plane) and *E*-plane (*y-z* plane). The main purpose of the radiation patterns is to demonstrate that the antenna actually radiates over a wide frequency band. It can be seen that the radiation patterns in *x-z* plane are nearly omnidirectional for the four frequencies.

4. CONCLUSION

In this article, a compact modified triangular CPW-fed antenna is proposed that exhibits multioctave bandwidth performance and easily satisfies the requirements for UWB applications. The measured results show that the impedance bandwidth of the proposed CPW-fed antenna is significantly improved with the inclusion of rectangular notches on the radiating patch, a narrow rectangular parasitic element located above the patch, and using a truncated ground plane containing slits. The measured results show good radiation patterns within the UWB frequency range.

ACKNOWLEDGMENT

The authors thank the northwest antenna and microwave research laboratory (NAMRL) for their beneficial and professional help.

REFERENCES

1. A. Valizade, C. Ghobadi, J. Nourinia, N. Ojaroudi, and M. Ojaroudi, Band-notch slot antenna with enhanced bandwidth by using Ω-shaped strips protruded inside rectangular slots for UWB applications, Appl Comput Electromagn Soc J 27 (2012), 816–822.
2. A. Valizade, C. Ghobadi, J. Nourinia, and M. Ojaroudi, A novel design of reconfigurable slot antenna with switchable band notch and multi-resonance functions for UWB applications, IEEE Antennas Wireless Propag Lett 11 (2012), 1166–1169.
3. M. Ojaroudi, S. Bashiri, N. Ojaroudi, and M.T. Partovi, Octave-band, multi-resonance CPW-fed small slot antenna for UWB applications, Electron Lett 48 (2012), 980–982.
4. M. Majidzadeh, C. Ghobadi, and J. Nourinia, Compact CPW -fed circular patch antenna for UWB applications, J Commun Eng 2 (2013), 63–72.
5. Q. Wu, R. Jin, J. Geng, and J. Lao, Ultra-wideband rectangular disk monopole antenna with notched ground, Electron Lett 43 (2007), 1100–1101.
6. M. Abdollahvand and G.R. Dadashzadeh, Compact double-fed dual annular ring printed monopole antenna for UWB application, J Electromagn Waves Appl 23 (2009), 1969–1980.
7. G.H. Brown and O.M. Woodward, Experimentally determined radiation characteristics of conical and triangular antennas, RCA Rev 13 (1952), 425–452.
8. A. Siahcheshm and Y. Zehforoosh, A novel modified monopole antenna a 5.5 GHz notch filter, J Telecommun 10 (2011), 14–17.
9. Y. Zehforoosh and A. Siahcheshm, Ultra wideband monopole antenna excited by a capacitive coupling feed with double band notch function, J Commun Eng 1 (2012), 60–68.
10. M.N. Moghadasi, G.R. Dadashzadeh, M. Abdollahvand, Y. Zehforoosh, and B.S. Virdee, Planar triangular monopole antenna with multioctave bandwidth, Microwave Opt Technol Lett 53 (2010), 10–14.
11. V. Waladi, N. Mohammadi, Y. Zehforoosh, A. Habashi, and J. Nourinia, A novel modified star-triangular fractal (MSTF) monopole antenna for super-wideband applications, IEEE Antennas Wireless Propag Lett 12 (2013), 651–654.
12. J.P. Lee, S.O. Park, and S.K. Lee, Bow-tie wideband monopole antenna with the novel impedance-bandwidth technique, Microwave Opt Technol Lett 36 (2002), 448–452.
13. C.C. Lin, H.R. Chuang, and Y.C. Kan, A 3–12 GHz UWB planar triangular monopole antenna with ridged ground-plane, Prog Electromagn Res 83 (2008), 307–321.
14. A. Balalem, A.R. Ali, J. Machac, and A. Omar, Quasi-elliptic microstrip low-pass filters using an interdigital DGS slot, IEEE Microwave Wireless Compon Lett 17 (2007), 586–588.
15. Ansoft High Frequency Structure Simulation (HFSS). Ver. 15, Ansoft Corporation, 2012.