Progress In Electromagnetics Research Letters, Vol. 83, 51–57, 2019

A Novel Compact Microstrip UWB BPF with Quad Notched Bands Using Quad-Mode Stepped Impedance Resonator

Lihua Wu[1], Pengli Hu[2], Changhao Li[2], Luetao Li[3], and Chengpei Tang[2, *]

Abstract—A novel compact ultra-wideband (UWB) bandpass filter (BPF) with quad-notched bands and wide upper-stopband performance using quad-mode stepped impedance resonator (QMSIR) is proposed in this paper. Firstly, the resonance properties of the proposed QMSIR are studied. The proposed QMSIR is found to have the advantages of introducing quad notched bands and wide upper-stopband performance. Then, the proposed QMSIR is employed to achieve four desired notched bands. To validate the design concept, a novel super compact UWB BPF with quad notched bands respectively centered at frequencies of 5.2 GHz, 5.8 GHz, 7.0 GHz, and 8.0 GHz is designed and measured. The predicted results are compared with measured data, and good agreement is reported.

1. INTRODUCTION

Ultra-wideband (UWB) radio technology has attracted much attention since the U.S. Federal Communications Commission (FCC) allocated a frequency range with a bandwidth of 7.5 GHz (3.1–10.6 GHz) for unlicensed radio applications. Many applications have been developed based on UWB technology such as short-range broadband communication, radar sensing, and body-area networking [1]. These applications benefit from the unique features of low-power spectral density and consumption associated with UWB systems. UWB bandpass filter (BPF), as one of the essential components of the UWB systems, has gained much attention in recent years. There are many techniques presented to design UWB BPF. For example, multi-mode resonator (MMR) [2, 3], multilayer coupled structure [4, 5], and cascaded low-pass/high-pass filters [6] have been widely used to achieve UWB characteristics.

However, the existing wireless networks such as C-band (3.7 $\sim$ 4.2 GHz) satellite communication systems (CSCS) signals, wireless local area network (WLAN) for IEEE802.11a operating at 5.15 $\sim$ 5.35 GHz/5.725 $\sim$ 5.825 GHz, and X-band (7.25 $\sim$ 8.395 GHz) satellite communication systems (XSCS) signals can easily interfere with UWB users, so a compact UWB BPF with multiple notched bands is emergently required to reject these interfering signals. The overlaps of these bands with the UWB spectrum cause severe inband interference and negatively impact the performance of UWB systems, so a compact UWB BPF with multiple notched bands is emergently required to reject these undesired interfering signals [7–17]. Several structures are studied in [7, 8], but only one notched band is created. A filter with dual notched bands is reported in [9, 10], based on a multi-layer structure that is hardly compatible with the existing microwave-integrated circuit. In [11, 12], a compact microstrip UWB BPF with triple notched bands is proposed; however, the reported design suffers from a large electrical size.

Based on the previous work [13], a novel compact UWB BPF with four narrow notched bands and wide upper-stopband performance based on a quad-mode stepped impedance resonator (QMSIR) is proposed. Firstly, the resonance properties of the proposed QMSIR are studied. The proposed

Received 30 December 2018, Accepted 28 February 2019, Scheduled 28 March 2019
* Corresponding author: Chengpei Tang (elechengpeitang@aliyun.com).
[1] School of Intelligent Robot, Open University of Guangdong, Guangzhou 51009, China. [2] School of Intelligent Systems Engineering, Sun Yat-sen University, Guangzhou 510006, China. [3] School of Information and Communication Engineering, Beijing University of Posts and Telecommunications, Beijing 100876, China.

QMSIR is found to have the advantages of introducing quad notched bands and wide upper-stopband performance. Then, the proposed QMSIR is employed to achieve four desired notched bands. To demonstrate a potential application of the proposed structure, a new super compact UWB BPF with quad notched bands respectively centered at frequencies of 5.2 GHz, 5.8 GHz, 7.0 GHz, and 8.0 GHz is designed and measured. The predicted results on S-parameters are compared with measured ones, and good agreement is achieved. The designed topology and principle is very simple and efficient for filter synthesis. Moreover, the proposed novel UWB BPF with a quad notched bands structure is super compact.

Note that all of the numerical simulations and their optimizations reported in this paper are carried out using the frequency domain ANSYS high-frequency structure simulator (HFSS) based on the finite element method (FEM), version 16.0 [18].

2. INITIAL UWB BANDPASS FILTER DESIGN

Figure 1 shows the layout of the proposed initial UWB BPF. The initial UWB BPF is composed of a square ring structure and an inserted quarter-wavelength short-circuited stub, i.e., square ring quad-mode resonator (SRQMR). To illustrate the design concept, the proposed UWB BPF is fabricated using Rogers 4350B with a thickness of 0.508 mm, relative dielectric constant of 3.48, and loss tangent of 0.009. The simulated scattering parameters are recorded in Fig. 2. It can be seen that the proposed UWB BPF has an insertion loss better than 0.5 dB from 2.52 to 10.54 GHz. The return loss is under −20 dB over most part of the passband. In addition, four poles are located in the passband, i.e., quad-mode resonator. All the dimensions are selected as follows: $l_0 = 4.7$ mm, $l_1 = 6.6$ mm, $l_2 = 7.6$ mm, $l_3 = 4.0$ mm, $l_4 = 2.2$ mm, $l_5 = 2.0$ mm, $l_6 = 3.0$ mm, $l_7 = 2.3$ mm, $l_8 = 1.6$ mm, $w_0 = 1.1$ mm, $w_1 = 0.7$ mm, $w_2 = 0.7$ mm, $w_3 = 0.1$ mm, $w_4 = 0.7$ mm, $r_0 = 0.3$ mm. The size of the whole circuit is only 16.6 mm × 11.8 mm.

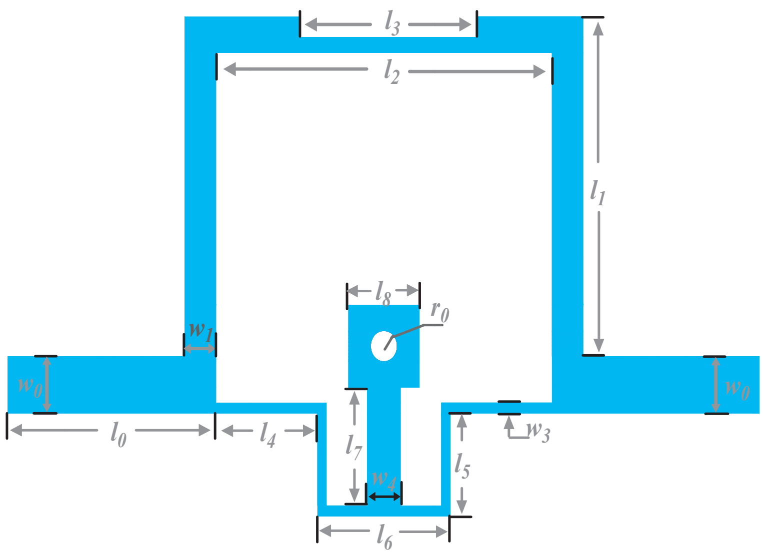

Figure 1. Schematic of the proposed initial UWB BPF.

3. QUAD-MODE STEPPED IMPEDANCE RESONATOR ANALYSIS

Figure 3 shows the geometry of the proposed quad-mode stepped impedance resonator (QMSIR). It consists of two half-wavelength square ring multiple-mode resonators and one short-circuited stub on its center plane.

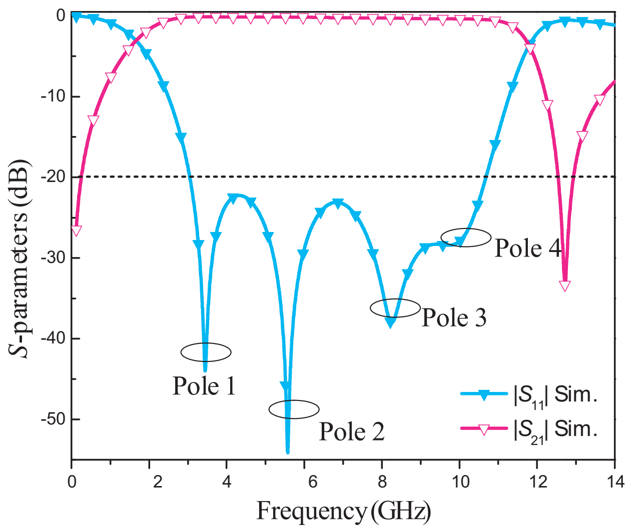

Figure 2. Simulated performance of the proposed initial UWB BPF.

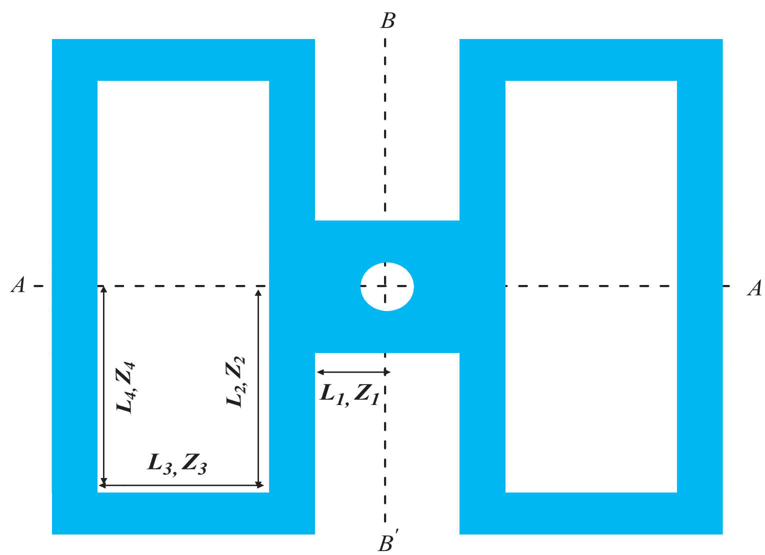

Figure 3. Geometry of the QMSIR.

Since the resonator is symmetrical to the A-A' plane and B-B' plane, the odd-even-mode method is implemented. For odd-mode excitation, the resonant frequency can be deduced as:

$$f_{notch\text{-}ino} = \frac{c}{4L_1\sqrt{\varepsilon_{eff}}} \tag{1}$$

where f_{ino} is the center frequency of the notch band, ε_{eff} the effective dielectric constant, and c the light speed in free space.

For even-mode excitation, The resonant frequencies can be determined as follows:

$$f_{notch\text{-}ine1} = \frac{c}{2(L_1+L_2)\sqrt{\varepsilon_{eff}}} \tag{2}$$

$$f_{notch\text{-}ine2} = \frac{c}{2(L_1+L_2+L_3)\sqrt{\varepsilon_{eff}}} \tag{3}$$

$$f_{notch\text{-}ine2} = \frac{c}{2(L_1+L_2+L_3+L_4)\sqrt{\varepsilon_{eff}}} \tag{4}$$

where $Z_1 = Z_2 = Z_3 = Z_4$ is assumed for simplicity. The resonance frequencies can be determined by the electrical length.

Figure 4 shows the simulated current distribution on the surface of the resonator at four frequencies: 5.2, 5.8, 7.2, and 8.0 GHz. The figure shows that the current is more sparsely distributed as it is near the areas marked in blue, while its distribution grows denser in the red areas. Maximum and minimum values are set equal in order to allow an accurate comparison among Figs. 4(a)–(d).

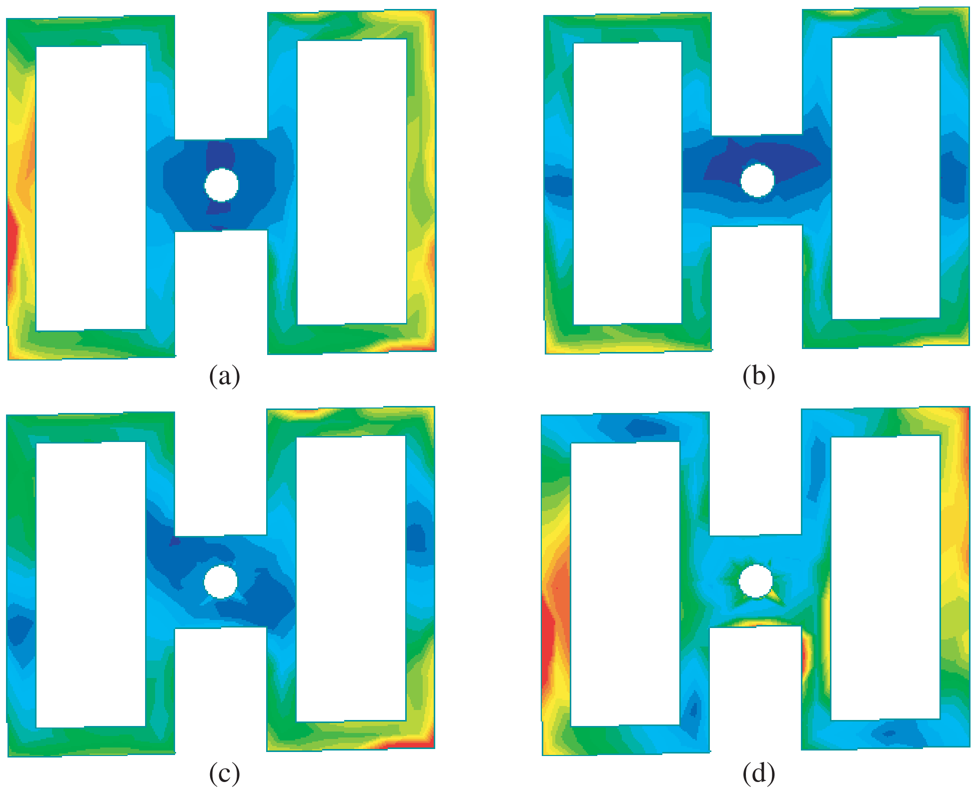

Figure 4. Simulated current distribution of the proposed structure at the four resonant frequencies: (a) 5.2 GHz, (b) 5.8 GHz, (c) 7.0 GHz, (d) 8.0 GHz.

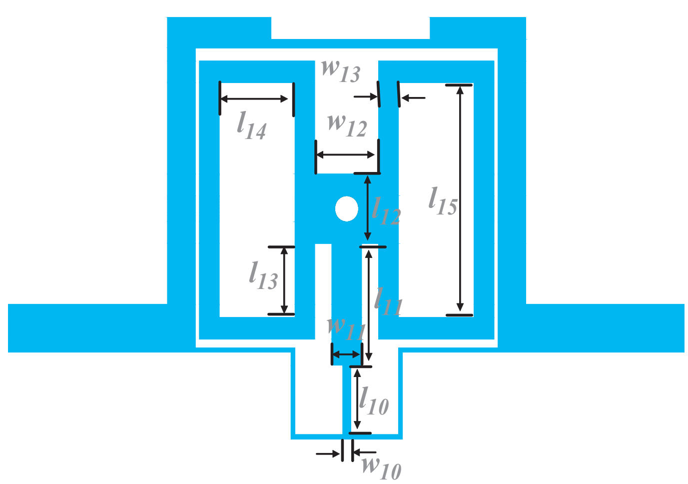

Figure 5. Schematic view of the UWB BPF with quad notched bands.

4. EXPERIMENTAL RESULTS

Finally, the designed UWB BPF is measured with an Agilent N5244A vector network analyzer. Fig. 5 shows the layout of the proposed UWB BPF with quad notched bands. Fig. 6 shows the simulated group delay. Fig. 7 shows the comparison between the simulated and measured results. It can be seen that the designed UWB BPF has a passband from 1.7 GHz to 11.9 GHz. The return loss is under −20 dB over most part of the passband. The four notched bands realizing high selectivity with 3 dB FBW are 5.4%, 4.4%, 3.2% and 3.4%, respectively. The attenuation is better than −10 dB at the center frequencies 5.2 GHz, 5.8 GHz, 7.2 GHz, and 8.0 GHz. The upper stopband is really stretched up to 28.5 GHz, over which an insertion loss or attenuation is higher than 15 dB. The minor discrepancy between simulation and measurement results is mainly due to the reflections from the SMA connectors and the finite substrate. Comparisons with other reported UWB BPFs with notched bands are listed in Table 1, which demonstrates that the proposed filter has good characteristics and a small size.

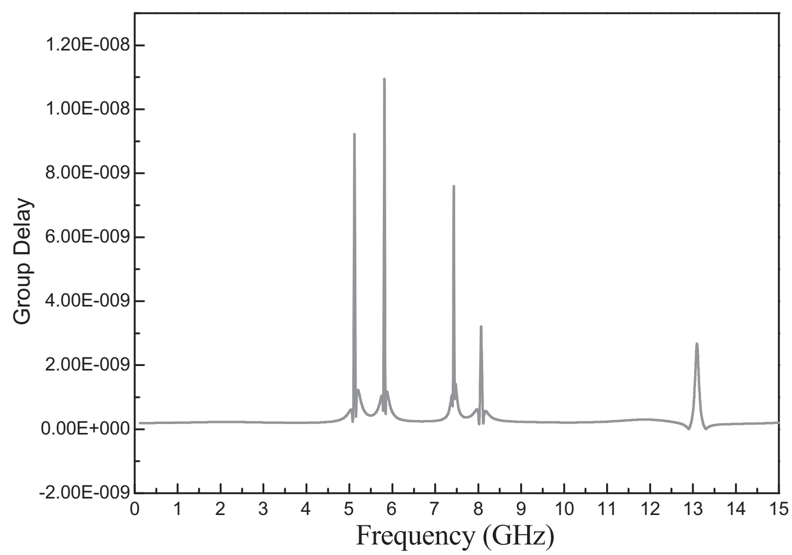

Figure 6. Simulated group delay of the designed UWB BPF.

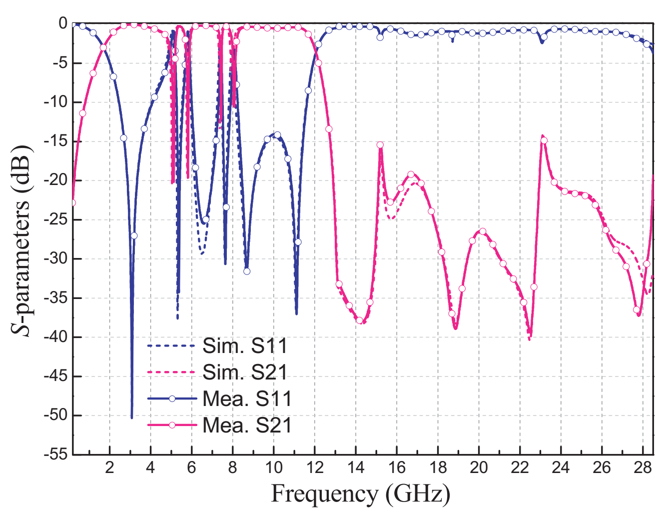

Figure 7. Simulated and measured S-parameters of the designed UWB BPF.

Table 1. Comparisons with other proposed UWB BPF with notched band.

Ref.	Circuit dimension	Pass band (GHz)	fractional bandwidth	Insertion loss (dB)	Notch Frequency (GHz)	Circuit size (λ_g: at 6.85 GHz)
[7]	2-D	$3.7 \sim 11.6$	103%	0.45	7.0	0.46×0.34
[8]	2-D	$3.6 \sim 10.2$	95.7%	0.6	5.6	0.81×0.17
[9]	3-D	$2.6 \sim 10.6$	121%	0.75	6.4/8.0	1.36×0.32
[10]	3-D	$3.1 \sim 14$	127%	1.5	5.5/8.0	0.65×0.55
[11]	2-D	$2.8 \sim 11.0$	119%	1.0	5.2/5.9/8.0	1.16×0.68
[12]	2-D	$3.0 \sim 10.2$	109%	0.7	3.6/5.8/8.0	0.63×0.36
[13]	2-D	$3.2 \sim 10.9$	109%	0.5	5.9/8.0	0.63×0.36
This work	2-D	$1.8 \sim 11.8$	147%	0.4	5.2/5.8/7.0/8.0	0.42×0.33

5. CONCLUSION

A new super compact UWB BPF with quad-notched bands and wide upper-stopband performance has been designed and measured. The proposed QMSIR is studied to achieve quad notched bands and wide upper-stopband performance. Good agreement between simulation and measurement results demonstrates the validity of the method. The proposed filter is very useful for modern UWB wireless communication systems due to its simple topology, compact size, and excellent performance.

ACKNOWLEDGMENT

This work was supported by the Special Fund of Guangdong Frontier and Key Technology Innovation (No. 2016B010108005), Special Fund of Guangdong Applied Science and Technology Research and Development (No. 2016B010125001), Guangdong Science and Technology Plan (No. 2016B090918110, 2015B010135006), Guangdong Natural Science Foundation (2018A030313797), Special Project of Scientific and Technological Innovation and Industrialization in Yuexiu District (2017-GX-005).

REFERENCES

1. FCC, "Revision of Part 15 of the Commission's Rules regarding ultra-wide-band transmission system," *Tech. Rep.*, 98–153, ET-Docket, 2002.
2. Zhu, L., S. Sun, and W. Menzel, "Ultra-wideband (UWB) bandpass filters using quad-mode resonator," *IEEE Microw. Wireless Compon. Lett.*, Vol. 15, No. 11, 796–798, 2005.
3. Qiang, L., Y.-J. Zhao, Q. Sun, W. Zhao, and B. Liu, "A compact UWB HMSIW bandpass filter based on complementary split-ring resonators," *Progress In Electromagnetics Research C*, Vol. 11, 237–243, 2009.
4. Packiaraj, D., K. J. Vinoy, and A. T. Kalghatgi, "Analysis and design of two layered ultra wide band filter," *Journal of Electromagnetic Waves and Applications*, Vol. 23, Nos. 8–9, 1235–1243, 2009.
5. Wang, H., L. Zhu, and W. Menzel, "Ultra-wideband bandpass filter with hybrid microstrip/CPW structure," *IEEE Microwave Wireless Compon. Letters.*, Vol. 15, No. 12, 844–846, 2005.
6. Comez-Garcia, R. and J. I. Alonso, "Systematic method for the exact synthesis of ultra-wideband filtering responses using high-pass and low-pass sections," *IEEE Trans. Microw. Theory Tech.*, Vol. 54, No. 10, 3751–3764, 2006.

7. Pirani. S., J. Nournia, and C. Ghobadi, "Band-notched UWB BPF design using parasitic coupled line," *IEEE Microw. Wirel. Compon. Lett.*, Vol. 20, No. 8, 444–446, 2010.
8. Wong, S. W. and L. Zhu, "Implementation of compact UWB bandpass filter with a notch-band," *IEEE Microw. Wirel. Compon. Lett.*, Vol. 18, No. 1, 10–12, 2008.
9. Hao, Z.-C. and J.-S. Hong, "Compact UWB filter with double notch-bands using multilayer LCP technology," *IEEE Microw. Wireless Compon. Lett.*, Vol. 19, No. 8, 500–502. 2009.
10. Hsiao, P.-Y. and R.-M. Weng, "Compact tri-layer ultra-wideband bandpass filter with dual notch bands," *Progress In Electromagnetics Research*, Vol. 106, 49–60, 2010.
11. Wei, F., Q. Y. Wu, X. W. Shi, and L. Chen, "Compact UWB BPF with triple-notched bands based on stub loaded resonator," *IET Electron. Lett.*, Vol. 49, No. 2, 124–126, 2013.
12. Zhao, J.-D., J.-P. Wang, and J.-L. Li, "Compact UWB bandpass filter with triple notched bands using parallel U-shaped defected microstrip structure," *IET Electron. Lett.*, Vol. 50, No. 2, 89–91, 2014.
13. Zhao, J.-D., J.-P. Wang, and J.-L. Li, "Compact microstrip UWB bandpass filter with dual notched bands using E-shaped resonator," *IEEE Microw. Wireless Compon. Lett.*, Vol. 23, No. 12, 638–640, 2013.
14. Zhu, L., S. Sun, and W. Menzel, "Ultra-Wideband (UWB) bandpass filters using multiple-mode resonator," *IEEE Microw. Wireless Compon. Lett.*, Vol. 15, No. 11, 796–798, Nov. 2005.
15. Hsu, C. L., F. C. Hsu, and J. Kuo, "Microstrip bandpass filters for Ultra-Wideband (UWB) wireless communications," *IEEE MTT-S International Microwave Symposium Digest*, 679–682, Long Beach, CA, 2005.
16. Assimonis, S. D., A. X. Lalas, N. V. Kantartzis, and T. V. Yioultsis, "Reconfigurable bowtie electromagnetic bandgap based microwave filters," *Microw. Opt. Technol. Lett.*, Vol. 53, 2472–2474, 2011.
17. Taibi, A., M. Trabelsi, A. Slimane, M. T. Belaroussi, and J. Raskin, "A novel design method for compact UWB bandpass filters," *IEEE Microw. Wireless Compon. Lett.*, Vol. 25, No. 1, 4–6, 2015.
18. NSYS Corp. ANSYS/ANSOFT, High Frequency Structure Simulator (HFSS), Ver. 13.0, 2012, [Online], Available: http://www.ansoft.com.