Progress In Electromagnetics Research Letters, Vol. 38, 161–170, 2013

MINIATURIZED UWB BANDPASS FILTER WITH DUAL NOTCH BANDS AND WIDE UPPER STOPBAND

Pankaj Sarkar[1, *], Manimala Pal[2], Rowdra Ghatak[3], and Dipak R. Poddar[4]

[1]Electronics and Communication Engineering Department, School of Technology, North-Eastern Hill University, Shillong, Meghalaya 793022, India

[2]Department of Electronics and Communication Engineering, NFET, NSHM Knowledge Campus Durgapur, Durgapur, West Bengal 713212, India

[3]Microwave and Antenna Research Laboratory, Electronics and Communication Engineering Department, National Institute of Technology Durgapur, Durgapur, West Bengal 713209, India

[4]Electronics and Telecommunication Engineering Department, Jadavpur University, Kolkata, West Bengal 700032, India

Abstract—In this paper, a miniature ultrawideband (UWB) bandpass filter with dual notch bands and wide upper stopband is presented. The ultrawide passband characteristic is achieved using a microstrip to slot line transition, and a wide upper stop band is realized using an elliptical lowpass filter. The dual band notches at 5.46 GHz and 8.04 GHz are obtained by incorporating defected microstrip structure in the input and output sections. A prototype of the proposed UWB bandpass filter is fabricated and measured. The equivalent circuit of the proposed filter is also presented. A good agreement between the measured, EM simulated and circuit simulated responses is obtained.

1. INTRODUCTION

Since Federal Communication Commission (FCC) announced an unlicensed UWB band (3.1 GHz–10.6 GHz), research to develop UWB systems for the application in medical imaging systems, pulse communication, surveillance systems and ground penetration radar

---

Received 28 January 2013, Accepted 15 March 2013, Scheduled 19 March 2013

[*] Corresponding author: Pankaj Sarkar (pankajsarkar111@gmail.com).

has initiated tremendous interest among microwave researchers. One of the indispensable components in the UWB system is a band pass filter [2, 3]. A wide variety of UWB band pass filters with various design topologies are reported in [4–14]. A novel fork shaped resonator is presented to realize UWB bandpass filter [4]. In [5, 6] UWB BPF is proposed using multiple mode resonator (MMR). However, MMR-based technique has the main disadvantage of narrow upper stopband performance due to higher order harmonics which arise just after the first pass band. A compact UWB BPF with quarter wave length short circuited stub is reported in [7]. In [8], a novel MMR structure is presented to achieve UWB response. Using stub loaded MMR structure a UWB BPF with wide upper stopband is realized in [9]. The designs presented above basically cover the entire UWB range but do not prevent the interference with existing WLAN signals and 8.0 GHz satellite communication system signals. In order to avoid the undesired WLAN signal UWB BPF with notch band using different structures is reported in [10–13]. Embedding open circuited stub, a single notch is implemented in [10] where UWB filter is designed using conventional MMR. Meander shaped defected ground structure is etched in MMR for notch insertion which is reported in [12]. Apart from this UWB BPF with dual notch bands is presented in [14–16]. In [15], two different quarter wavelength shorted lines are realized for dual notch insertion, and surface coupled structure is proposed for UWB BPF design. In [16], the dual notches are implemented using open stub, and the UWB BPF is realized using modified distributed highpass filter and slots on the ground plane in the shape of stepped impedance resonator (SIR).

In this paper, a novel UWB bandpass filter is proposed using a microstrip to slotline transition combined with an elliptical lowpass filter. The dual notches in UWB passband are implemented using two embedded open circuited stubs as defected microstrip structure. The proposed UWB filter is realized using Taconic substrate of dielectric constant 2.2 and height 0.787 mm. Rest of the paper contains the filter design procedure in Section 2 followed by results and discussion in Section 3.

2. FILTER DESIGN

Layout of the proposed UWB band pass filter is shown in Fig. 1. A microstrip to slotline transition is designed with a range of 3.1–14 GHz. To stop the propagation of higher order modes and achieve upper cut-off frequency of 10.6 GHz, an elliptical lowpass filter is implemented with cutoff frequency 10.6 GHz. Furthermore, two notch bands are

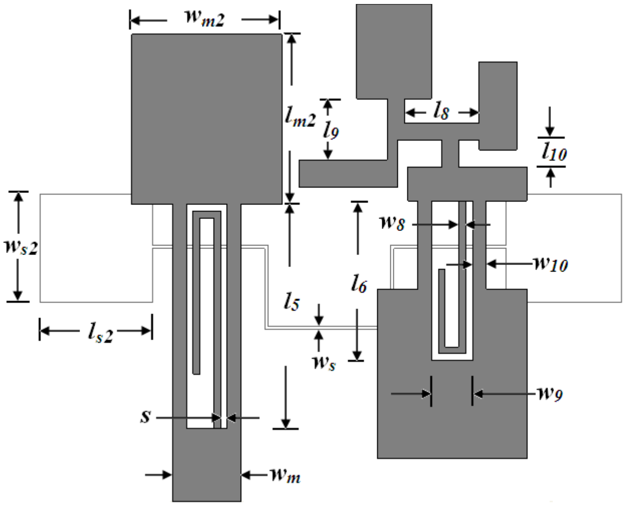
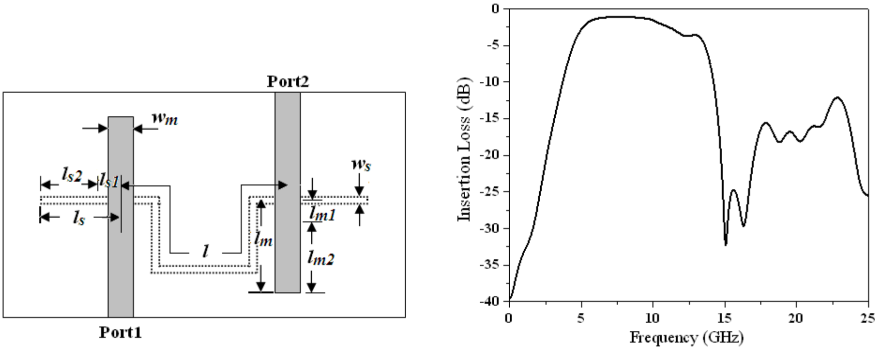


Figure 1. Layout of proposed UWB band pass filter with $l_{m2} = 5$, $l_5 = 6.6$, $l_6 = 4.7$, $l_{s2} = 3.4$, $l_8 = 2.2$, $l_9 = 1.8$, $l_{10} = 0.8$, $w_m = 2.2$, $w_s = 0.1$, $w_{m2} = 4.4$, $w_{s2} = 3.2$, $w_8 = 0.2$, $w_9 = 1.2$, $w_{10} = 0.4$, $s = 0.2$ (all dimensions are in mm.).

inserted using two open stubs to perturb WLAN and satellite signal interference. For the purpose of electromagnetic (EM) simulation CST Microwave Studio$^{\text{TM}}$ is used, and for equivalent circuit analysis ANSOFT Designer$^{\text{TM}}$ is employed. Detailed design process of each individual section of the filter is described as follows.

2.1. Design of Microstrip to Slotline Transition Section

The basic transition structure is shown in Fig. 2(a). The transition is designed at the centre frequency 8.5 GHz to make the structure more compact. For the design of transition, the microstrip line must be short circuited and the slot line open circuited at the junction of the transition. The microstrip short circuit is realized virtually by quarter wavelength long open circuited stub $l_m = 6.2$ mm. The stub is designed at the centre frequency of the transition pass band which is 8.5 GHz. The slotline is terminated with straight stub $l_S = 6.2$ mm which is around quarter wavelength long at 8.5 GHz to make it open circuit. Characteristic impedance of microstrip line and slotline are 50 Ω. To avoid complexity in fabrication, the minimum width of slotline is taken as 0.1 mm which is equivalent to slotline impedance of 91 Ω. The slotline length l is 12.8 mm which is nearly equal to the half wavelength long at 8.5 GHz. The structure is simulated in CST microwave studio, and frequency response is shown in Fig. 2(b). It can be seen that the



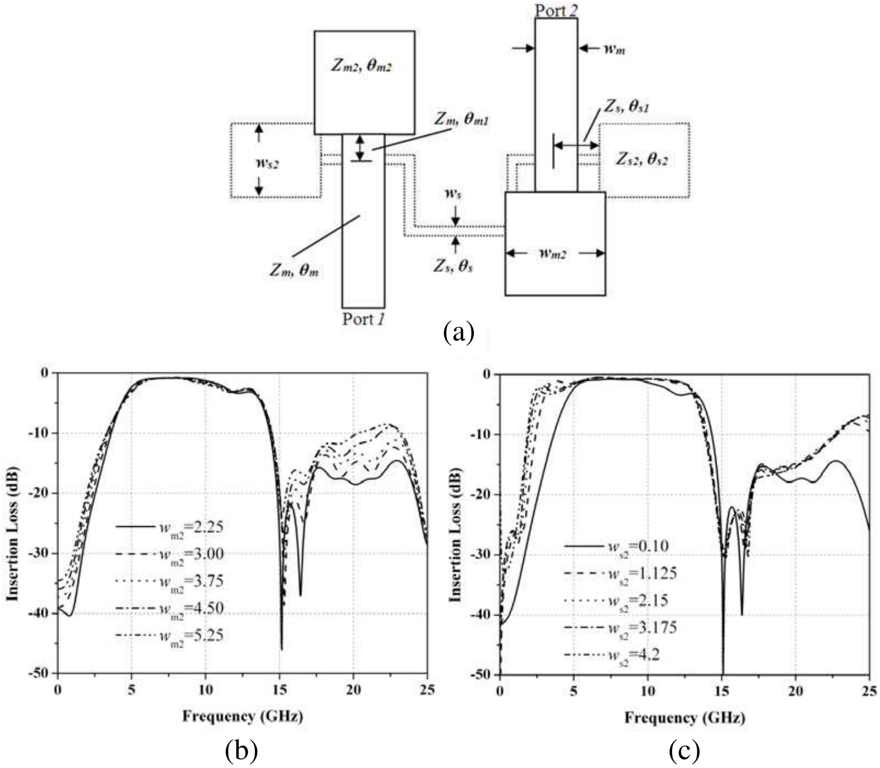
(a) (b)

Figure 2. (a) Basic microstrip to slotline transition structure. (b) S-parameter of the transition.

lower cutoff is obtained at 5.35 GHz, and the flatness in the pass band is very poor. So the structure is not suitable for UWB band pass filter design.

To improve the pass band flatness, the width w_{m2} of microstrip line section l_{m2} and width w_{s2} of slot section l_{s2} are parametrically studied. Keeping the slot line width fixed at 0.1 mm, which is similar to the original transition design, the width of the microstrip line section w_{m2} is varied. Similarly, the slotline width w_{s2} is varied for fixed microstrip line width of 2.2 mm which is that for a 50 Ω input/output (I/O) line. The extracted S-parameter is shown in Fig. 3. It is seen that the lower passband edge flatness improves with increasing w_{m2}. However, the upper band edge is sharp. Parametric variation of the slot line section reveals that the lower band edge sharpness improves with increasing w_{s2}. So the selectivity of upper band edge is contributed by both the microstrip line and slot line width. The lower band edge selectivity improves due to a larger slot line width. Eventually, to obtain the flatness and selectivity, both w_{m2} and w_{s2} are finely tuned to 4.4 mm and 3.2 mm, respectively. However, for further increase in stub width, substantial increase in bandwidth is not noticeable.

To analyse the structure further, the equivalent transmission line model is developed and illustrated in Fig. 4. The microstrip line is modelled with three transmission lines, θ_m, θ_{m1} having same impedance of Z_m and θ_{m2} with line impedance Z_{m2}. The values of electrical length are $\theta_m = 90°$, $\theta_{m1} = 19°$, $\theta_{m2} = 70°$, and the impedances Z_m and Z_{m2} are 50 Ω and 30 Ω, respectively. The slotline is also modelled using equivalent transmission line with electrical length $\theta_s = 180°$, $\theta_{s1} = 34°$ and $\theta_{s2} = 51°$. Slotline impedances are $Z_s = 91\,\Omega$ and $Z_{s2} = 350\,\Omega$. The magnitude of coupling between the microstrip to



(a)

(b) (c)

Figure 3. (a) Transition structure with increased w_{m2} and w_{s2}. (b) Insertion loss by varying w_{m2} for fixed w_{s2}. (c) Insertion loss for different w_{s2} with fixed w_{m2}.

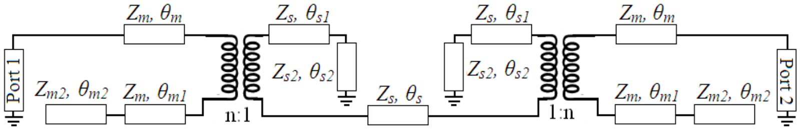


Figure 4. Equivalent transmission line model of the proposed wideband microstrip to slotline transition.

slotline is described by $n = 1$, which is the turns ratio of transformer [1].

2.2. Design of Elliptical Lowpass Filter Section

It can be seen from Fig. 5 that to realize wide upper stopband characteristic, higher order harmonic suppression is required, which arises after 17 GHz. To implement a wide upper stopband response and also to accomplish upper cutoff frequency 10.6 GHz, an elliptical

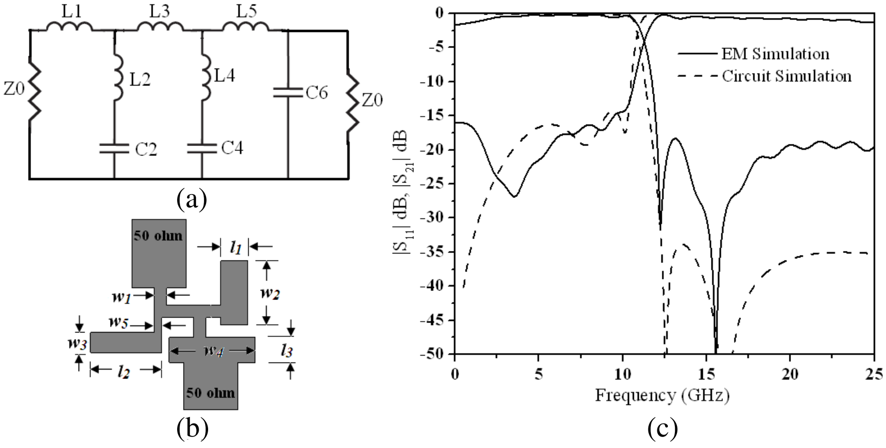


Figure 5. (a) Equivalent circuit of elliptical lowpass filter. (b) Layout of the filter with $l_1 = 1.1$, $l_2 = 2.9$, $l_3 = 1$, $w_1 = 0.5$, $w_2 = 2.6$, $w_3 = 0.8$, $w_4 = 3.5$, $w_5 = 0.6$ (all dimensions are in mm.) (c) Comparison in frequency response between EM simulation and circuit simulation of elliptical lowpass filter.

lowpass filter is designed with cutoff frequency 10.6 GHz. The equivalent circuit diagram of the elliptical lowpass filter is shown in Fig. 5(a). Elliptical lowpass filter has the characteristics to insert two transmission zeroes at finite frequencies. The two transmission zeroes are inserted at the frequencies

$$f_1 = \frac{1}{2\pi\sqrt{L_4 C_4}} = 12.56\,\text{GHz} \quad \text{and} \quad f_2 = \frac{1}{2\pi\sqrt{L_2 C_2}} = 16.12\,\text{GHz}.$$

The calculated parameters to obtain a cutoff at 10.6 GHz are $L_1 = 0.545\,\text{nH}$, $L_2 = 0.258\,\text{nH}$, $L_3 = 0.788\,\text{nH}$, $L_4 = 0.593\,\text{nH}$, $L_5 = 0.74\,\text{nH}$, $C_2 = 0.378\,\text{pF}$, $C_4 = 0.271\,\text{pF}$, $C_6 = 0.3\,\text{pF}$. The layout of the elliptical lowpass filter is shown in Fig. 5(b). The structure is bended in such a way that it can be accommodated in small area. The comparison of S-parameter between EM simulated and circuit simulated response is shown in Fig. 5(c). An excellent attenuation characteristic is achieved beyond 10.6 GHz.

Finally, the transition structure and elliptical lowpass filter are combined to get UWB pass band response with wide stop band. The proposed structure is analyzed in CST Microwave Studio$^{\text{TM}}$, and the extracted S-parameter is plotted in Fig. 6 along with equivalent circuit response. It can be seen that a good UWB pass band response is obtained with upper stopband extended up to 25 GHz, and the equivalent circuit model simulation matches well with the EM simulated response.

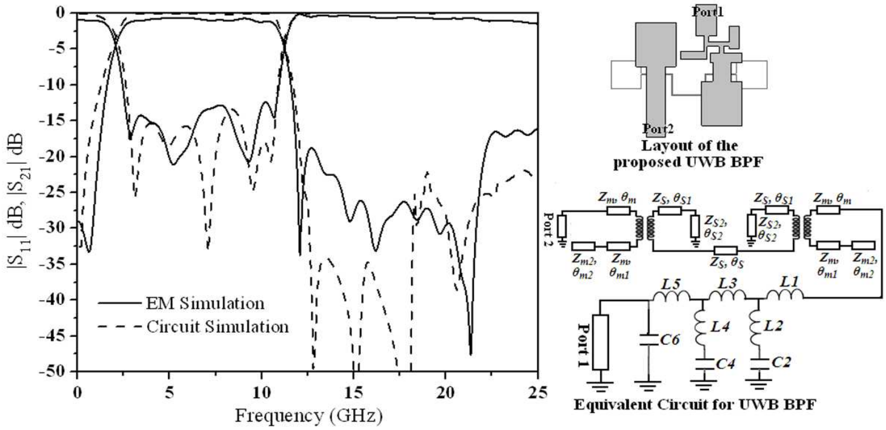


Figure 6. S-parameter of the proposed UWB band pass filter. Also shown along side is the equivalent circuit model of UWB BPF without notch.

2.3. Design of Notch Section

To generate notch bands in the UWB pass band, two embedded open circuited stubs of lengths 11.2 mm and 7.2 mm are realized in input and output microstrip line as defected microstrip structure. The stubs are $\lambda_g/4$ long at the frequencies 5.5 and 8.0 GHz to stop the interference with unwanted WLAN and satellite signals, respectively. Further the stubs are bent to reduce the circuit space requirement. The notch bands can be changed by varying the stub length. Fig. 7 illustrates that the shift of notch frequencies can be easily controlled by varying the lengths l_{s1} and l_{s2}.

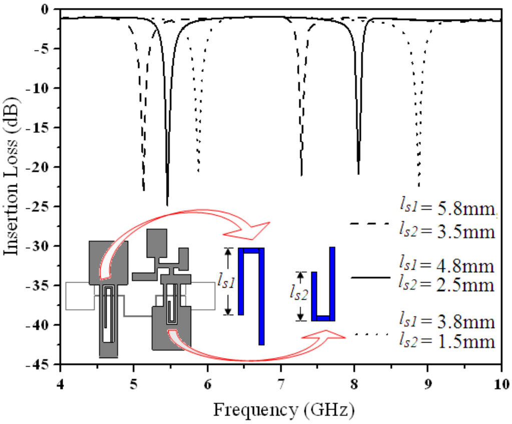


Figure 7. Notch band variations for different length of l_{s1} and l_{s2}.

3. RESULTS AND DISCUSSION

The proposed filter is fabricated on a Taconic substrate with dielectric constant 2.2 and height 0.787 mm. A photograph of the fabricated prototype is shown in Fig. 8. The overall size of the filter is 19 × 16 mm^2. Measurement of prototype is done using ZVA 40 VNA from Rhode and Schwarz. The frequency responses obtained from circuit simulation, fullwave EM simulation and measurement of the UWB BPF are shown in Fig. 9(a). A good agreement is observed among them. The proposed BPF has a wide passband from 2.75 GHz to 10.58 GHz with insertion loss less than 1.5 dB. The measured S_{11} parameter throughout the band is better than 12 dB. The attenuation is greater than 20 dB at the center of each notch band pertaining to 5.46 GHz and 8.04 GHz. The

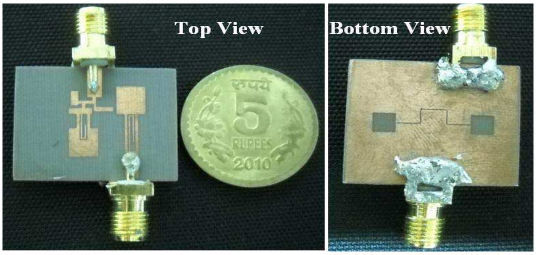
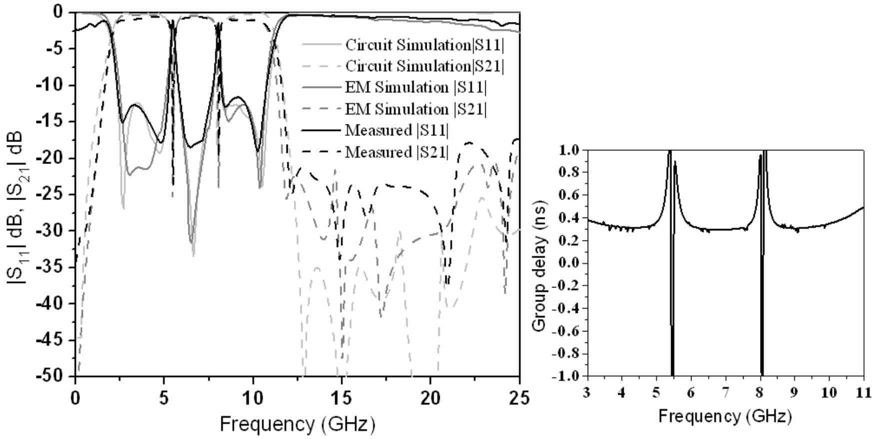


Figure 8. Fabricated prototype of the proposed UWB bandpass filter. I/O connections are realized using SMA 3.5 mm connectors.



(a) (b)

Figure 9. (a) Comparison of circuit simulation, EM simulation and measured S-parameter of the proposed UWB BPF. (b) Group delay of the proposed UWB BPF.

fractional bandwidths (FBW) of the notch bands are about 0.45% at 5.46 GHZ and 0.35% at 8.04 GHz, respectively. The proposed filter also shows a wide upper stop band extending up to 25 GHz with attenuation of around 18 dB. Group delay of the fabricated filter is approximately 0.3 ns with a variation of 0.08 ns throughout the passband as shown in Fig. 9(b).

4. CONCLUSION

In this paper, a miniature UWB band pass filter is presented by incorporating microstrip to slotline transition combined with an elliptical lowpass filter. The dual notch band property is achieved by introducing two embedded open circuited stubs at 5.46 GHz and 8.04 GHz. The prototype of the proposed UWB BPF is fabricated and measured, which agrees well with simulated response. Due to its compact size ($19 \times 16\,\text{mm}^2$) and satisfactory in and out of band performance, the filter can be useful for modern UWB communication technology.

ACKNOWLEDGMENT

Rowdra Ghatak and Manimala Pal are grateful to Department of Science and Technology, Government of India for supporting their work under DST-FIST grant to ECE Dept., NIT Durgapur vide sanction No. SR/FST/ETI-267/2012(c) Dated June 10, 2011.

REFERENCES

1. Gupta, K. C., R. Garg, and I. J. Bahl, *Microstrip Lines and Slotlines*, Artech House, Norwood, MA, 1979.
2. Sun, S. and L. Zhu, "Multimode resonator based band pass filters," *IEEE Microwave Magazine*, 88–98, Apr. 2009.
3. Hao, Z.-C. and J.-S. Hong, "Ultrawideband filter technologies," *IEEE Microwave Magazine*, 56–68, Jun. 2010.
4. Chen, H. and Y.-X. Zhang, "A novel and compact UWB bandpass filter using microstrip fork-form resonators," *Progress In Electromagnetics Research*, Vol. 77, 273–280, 2007.
5. Zhu, L., S. Sun, and W. Menzel, "Ultra-wideband (UWB) bandpass filters using multiple-mode resonator," *IEEE Microwave and Wireless Components Letters*, Vol. 15, No. 11, 796–798, Nov. 2005.

6. Wang, H., L. Zhu, and W. Menzel, "Ultra-wideband bandpass filter with hybrid microstrip/CPW structure," *IEEE Microwave and Wireless Components Letters*, Vol. 15, No. 12, 844–846, Dec. 2005.
7. Razalli, M. S., A. Ismail, M. A. Mahdi, and M. N. Hamidon, "Novel compact microstrip ultra-wideband filter utilizing short-circuited stubs with less vias," *Progress In Electromagnetics Research*, Vol. 88, 91–104, 2008.
8. Zhang, Z. X. and F. Xiao, "An UWB bandpass filter based on a novel type of multi-mode resonator," *IEEE Microwave and Wireless Components Letters*, Vol. 22, No. 10, 506–508, Oct. 2012.
9. Deng, H.-W., Y.-J. Zhao, X.-S. Zhang, L. Zhang, and S.-P. Gao, "Compact quintuple-mode UWB band pass filter with good out-of-band rejection," *Progress In Electromagnetics Research Letters*, Vol. 14, 111–117, 2010.
10. Yang, G.-M., R. Jin, C. Vittoria, V. G. Harrisand, and N. X. Sun, "Small ultra wideband (UWB) band pass filter with notch band," *IEEE Microwave and Wireless Components Letters*, Vol. 18, No. 3, 176–178, Mar. 2008.
11. Weng, M.-H., C.-T. Liauh, H.-W. Wu, and S. R. Vargas, "An ultra-wideband bandpass filter with an embedded open-circuited stub structure to improve in-band performance," *IEEE Microwave and Wireless Components Letters*, Vol. 19, No. 3, 146–148, Mar. 2009.
12. Ghazali, A. N. and S. Pal, "Analysis of a small UWB filter with notch and improved stopband," *Progress In Electromagnetics Research Letters*, Vol. 34, 147–156, 2012.
13. Kim, C. H. and K. Chang, "Ultra-wideband (UWB) ring resonator bandpass filter with a notched band," *IEEE Microwave and Wireless Components Letters*, Vol. 21, No. 4, 206–208, Apr. 2011.
14. Song, K. J. and Q. Xue, "Compact ultra-wideband (UWB) bandpass filters with multiple notched bands," *IEEE Microwave and Wireless Components Letters*, Vol. 20, No. 8, 447–449, Aug. 2010.
15. Huang, J.-Q., Q.-X. Chu, and C.-Y. Liu, "Compact UWB filter based on surface-coupled structure with dual notched bands," *Progress In Electromagnetics Research*, Vol. 106, 311–319, 2010.
16. Sarkar, P., R. Ghatak, M. Pal, and D. R. Poddar, "Compact UWB bandpass filter with dual notch bands using open circuited stubs," *IEEE Microwave and Wireless Components Letters*, Vol. 22, No. 9, 453–455, Sept. 2012.