Progress In Electromagnetics Research Letters, Vol. 7, 149–159, 2009

COMPACT OPEN-LOOP UWB FILTER WITH NOTCHED BAND

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Abstract—A bandpass filter (BPF) is presented for ultra-wideband (UWB) applications with a notched band to reject the unwanted signals from the wireless local area network (WLAN) systems. The proposed UWB BPF consists of two pairs of open-loop resonators on the top layer and one coupled resonator on the bottom layer. The rejection band is introduced by adding an asymmetric open-loop resonator to two outer arms of open-loop resonators. The bandpass filter is designed to be operated within full bandwidth of 3.1 to 10.6 GHz and to eliminate the WLAN signals of 5.8 GHz. The suppression at 5.8 GHz is larger than 15 dB. The proposed configuration is proved to be both simple and compact.

1. INTRODUCTION

In 2002 the U.S. Federal Communications Commission (FCC) approved the unlicensed use of ultra-wideband (UWB) (range of 3.1–10.6 GHz) for commercial purposes [1, 2]. The most common interference in UWB systems is the strong narrow band signal from the wireless systems using IEEE 802.11a standards such as the wireless local area networks (WLANs) [3]. Hence, it is desired to implement UWB systems with the suppression of the strong narrow-band signals from WLAN systems.

Notch filters are important noise reduction circuits commonly used in cable televisions, mobile phones, and other communication applications. Embedded notch filters can achieve the suppression of WLAN signals within UWB systems. There were several UWB bandpass filters (BPFs) designed by using compact defected ground

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structures (DGSs) for providing an embedded notch band. A third-order suspended stripline filter was added to achieve the band rejection [4]. To reject the undesired signals, UWB filter which consists of five short-circuit stubs along with embedded open-circuit stubs in the first and the last connecting lines was presented [5]. Unfortunately, most configurations occupy large sizes. On the other hand, notch implementation using embedded open-circuit stub in UWB filters is both simple and flexible [6]. However, the size was also not small enough. Also, the interferences between the lower band (3–5 GHz) and the upper band (6–10 GHz) can not be suppressed effectively. Although a small size can be obtained by using the modified multi-mode resonator with stepped-impedance stubs, the measured results of the notch band is not suppressed enough to reject the unwanted signals [7]. Hence, it is desired for circuit designers to obtain both an UWB BPF with a small size and a large suppression of WLAN band.

2. PROPOSED UWB BANDPASS FILTER

Fig. 1 shows the configuration of the proposed UWB BPF with notch band. The presented filter consists of two pairs of open-loop resonators on the top layer and one coupled resonator on the bottom layer. The structure can be illustrated by analyzing two different circuit performances separately. One is the UWB BPF and the other is the notch band characteristics.

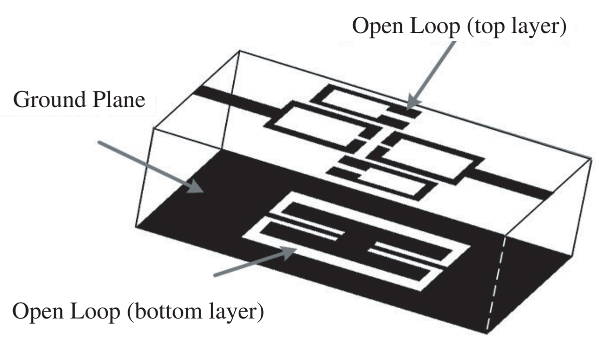


Figure 1. Proposed UWB filter with notch band.

Figs. 2(a) and (b) show the patterns of the top layer and the bottom layer of the UWB filter, respectively. The UWB BPF is constructed by two symmetrical open-loop square-ring resonators on the top layer and two symmetrical open-loop DGSs on the bottom layer. An FR4 substrate with thickness of 0.8 mm and permittivity of

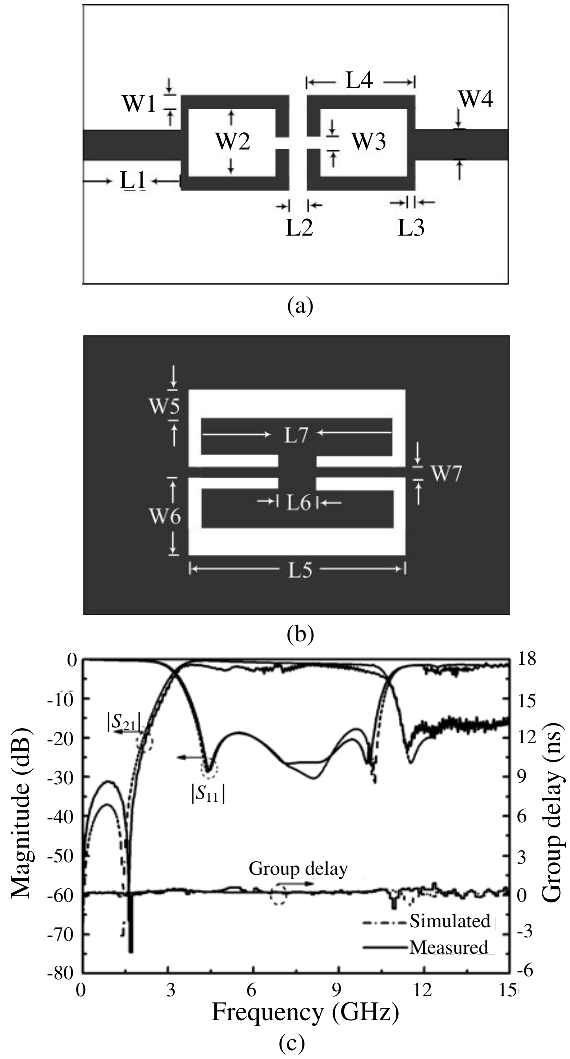


Figure 2. (a) Schematic top view of ultra-wideband filter. (b) Schematic bottom view of ultra-wideband filter. (c) Simulated and measured results of ultra-wideband filter.

4.4 is used to implement the presented UWB BPF. Figs. 2(a) and (b) show the patterns of the top layer and the bottom layer of the proposed UWB filter, respectively. The parameters for the symmetrical UWB filter are $L1 = 4.8$, $L2 = 0.7$, $L3 = 0.4$, $L4 = 5.45$, $L5 = 10.8$, $L6 = 1.9$, $L7 = 9.6$, $W1 = 3.4$, $W2 = 3.4$, $W3 = 0.5$, $W4 = 1.47$, $W5 =$

1.4, $W6 = 3.9$, $W7 = 0.5$. All dimensions are with the units of mm. The input/output 50 Ω impedances of the microstrip lines are taped to the open-loop structure resonators which are coupled to the top layer. The last resonator as the SIR-DGS is coupled to the bottom layer. Fig. 2(c) shows both the simulated and the measured results of the UWB filter with DGS. The fabricated UWB filter has a wide passband from 3.1 GHz to 10.6 GHz at the transmission loss of 3 dB. The group delay is measured to be less than 0.2 ns at the center frequency of each passband. Excellent agreement between the simulated and the measured results was achieved where an UWB bandpass performance is exhibited with fractional bandwidth (FBW) of about 110%.

There are two transmission skirts. The maximum attenuation rate (MAR) is defined as

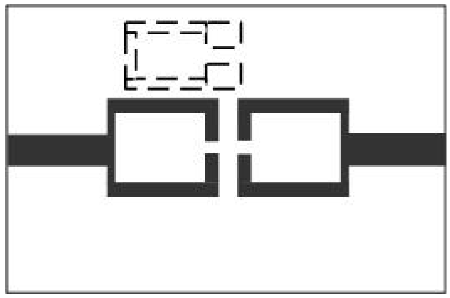
$$\mathrm{MAR} = \frac{S_{21(fz)} - S_{21(fd)}}{f_z - f_d} \tag{1}$$

MAR of the first transmission skirt is 38.48 dB/GHz which calculated from 1.61 GHz with −66.5 dB to 3.26 GHz with −3 dB. Also, MAR of the other transmission skirt is 22.56 dB/GHz calculated from 10.5 GHz with −3 dB to 11.4 GHz with −23.3 dB.

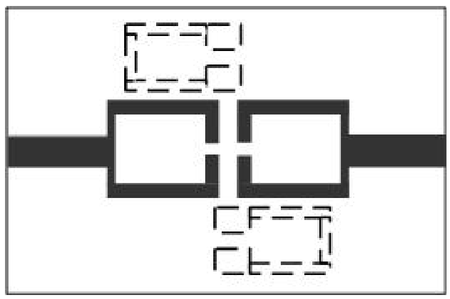
3. CHARACTERIZATION OF NOTCH BAND

To reject the undesired WLAN signals, asymmetric open-loop stepped-impedance resonators (SIRs) are added on the top layer besides UWB open-loop resonators Three structures with different numbers of open-loop SIRs which introduces the same notch band at 5.8 GHz are investigated. The proposed UWB BPF with embedded notch band is shown in Fig. 3. Figs. 3(a), (b), and (c) illustrate the schematics of one open-loop SIR, two open-loop SIRs, and four open-loop SIRs, respectively.

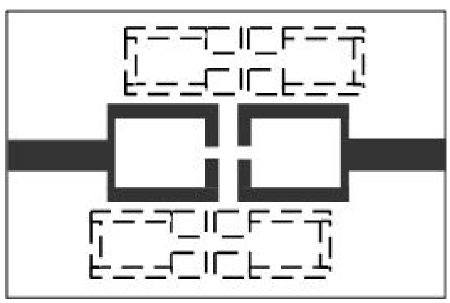
Figure 4(a) depicts the full-wave EM simulation of the insertion loss $|S21|$. A specific notched band can be obtained by adjusting the stubs of the open-loop resonators. The return loss $|S11|$ as shown in Fig. 4(b) demonstrates the input signal reflection of the notched band. The proposed schematic makes it possible to realize a narrow notched band with extremely high impedances by employing conventional open-loop resonators. The resonant bandwidths excited by one, two, and four resonators are 158 MHz, 341 MHz, and 840 MHz, respectively. With the addition of open-loop resonators, the rejection bandwidth from 158 MHz to 840 MHz is provided with the suppression larger than 15 dB.



(a)



(b)



(c)

Figure 3. (a) One open loop resonator, (b) Two open loop resonators, (c) Four open loop resonators.

As seen from Fig. 4(b), the notch band attenuation rate of the structure with one open-loop SIR is not good enough because there is no transmission zero existed in the response of return loss. On the other hand, adding four open-loop SIRs provides a good attenuation for the response of return loss. However, the bandwidth of the BPF with four open-loop SIRs can not meet the FCC specifications. Hence,

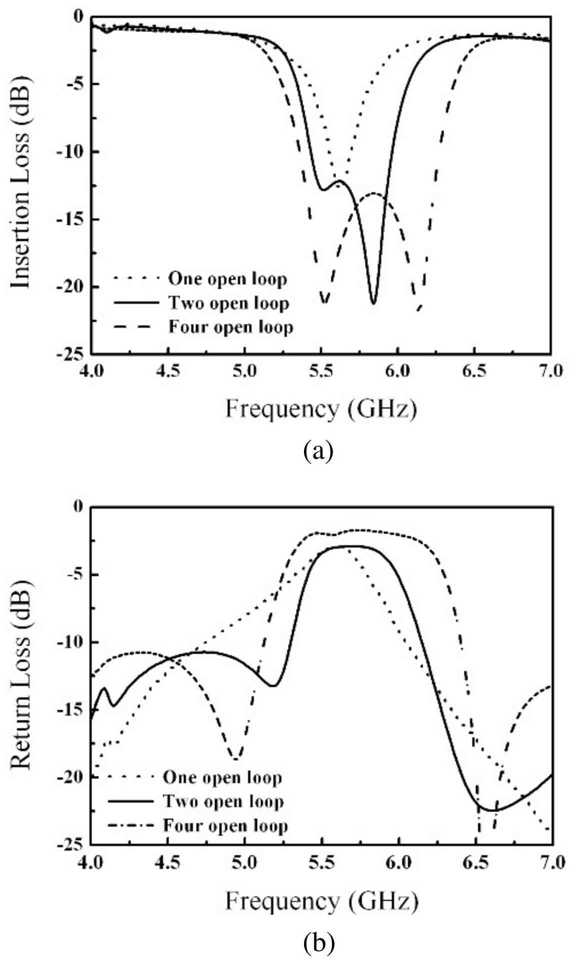


Figure 4. Full-wave EM simulation with adding open loop resonator of (a) $|S11|$ and (b) $|S21|$.

two open-loop SIRs shown in Fig. 3(b) are the better design for the desired UWB BPF with WLAN notch band.

Fig. 5 shows the equivalent circuit model of the propsoed filter in Fig. 3(b). The data of the simulation results in Fig. 4 are fit into the circuit model to derive the appropriate element values. Each part of the filter is simulated separately using an Ansoft circuit simulator. The symmetric UWB open-loop resonators on the top layer can be modeled by two LC resonators which include a capacitance C_a, an inductance L_a, and a resistance R in series with a coupling capacitance C_b. Two pairs of the notch band prototypes, L_c and Ce ares shunted to be equivalent to two outer arms of open-loop SIRs on the top layer. The ground produces two pairs of inductances L_b and capacitance C_d associated with the enclosure which creates a grounded capacitor C_c. The component values of the lumped circuit are listed in Table 1.

Table 1. Components of the proposed filter (L:nH, C:pF, R: kΩ).

Element	L_a	L_b	L_c	C_a	C_b	C_c	C_d	C_e	R
Value	0.07	1.2	0.09	1.45	0.8	0.35	0.1	9	100

Fig. 6 shows both the circuit model and the EM simulation results of the proposed UWB with notch band. It is obvious that passband from 3.1 GHz to 10.6 GHz is formed by DGS resonator on the bottom layer. When two open-loop resonators on the top layer is introduced, notch band at 5.8 GHz is excited.

4. MEASUREMENT RESULTS OF UWB BPF WITH NOTCHED BAND

The proposed filter has been fabricated using the printed circuit board (PCB) technology. The patterns are implemented on a microstrip substrate with both a relative dielectric constant of 4.4 and a thickness of 0.8 mm. The total etched size is 21 mm × 12 mm. The input and output microstrip lines are with the length of 1.47 mm as shown in Fig. 7. The respective optimum lengths of the open-loop resonators with the units of mm are $L8 = 5.57$, $L9 = 1.7$, $L10 = 3.38$, $W8 = 0.5$, $W9 = 1.2$, $W10 = 3.2$. The distance between SIRs and UWB open-loop resonators is $D = 0.5$ mm. The filter which fabricated on

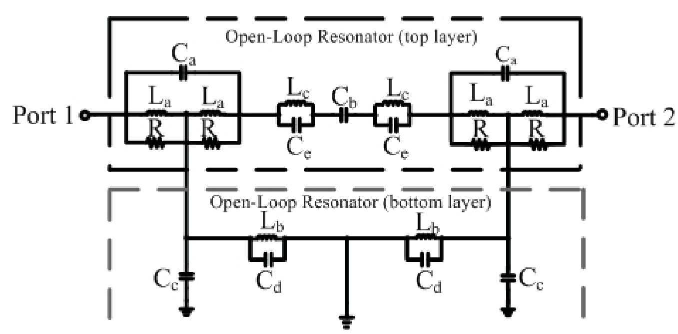


Figure 5. Equivalent circuit of UWB with notch band.

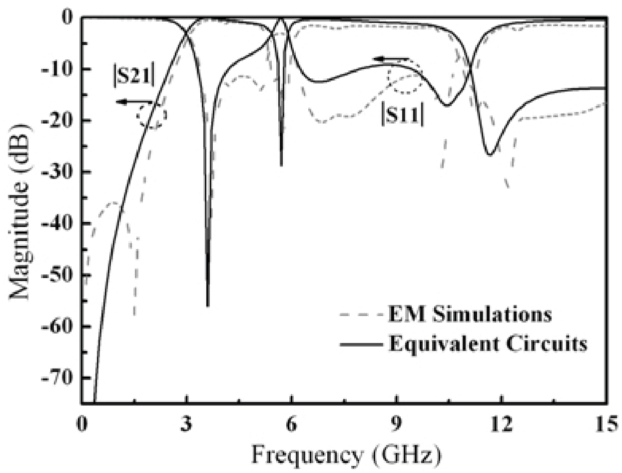


Figure 6. Circuit model simulation and EM simulation results.

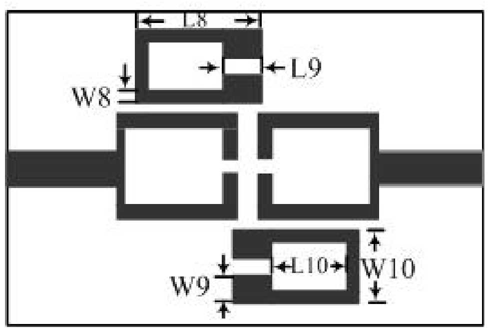
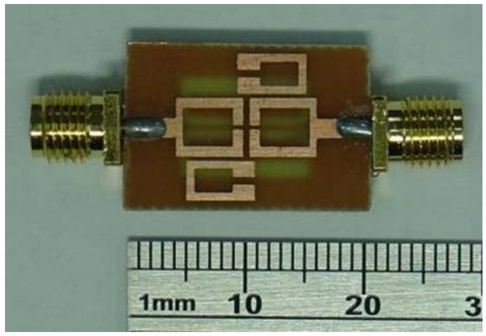


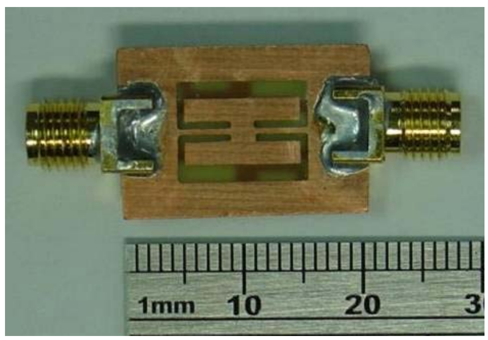
Figure 7. Top view of ultra-wideband filter with notched band.

PCB attaching the input/output SMA connectors is photographed and shown in Fig. 8.

The UWB BPF has the −3 dB bandwidth from 3.1 to 10.6 GHz as shown in Fig. 9. The insertion loss is about 2.3 dB at central frequency 5.8 GHz. Also the insertion loss remains low and flat over the whole band. The groups delay has a small value of 0.2 ns with 18.8 dB insertion loss and 2 dB notched bandwidth of 4.6%. The steepness of the notched band is 23.76 dB/GHz obtained from 5.2 GHz with −14.88 dB to 5.7 GHz with −3 dB. The other steepness is 18.72 dB/GHz obtained from 5.8 GHz with −3 dB to 6.8 GHz with −21.72 dB. Table 2 lists the performance comparison among the fabricated UWB BPFs and other circuits in previous publications. The



(a)



(b)

Figure 8. Realization of the UWB BPF with notched band. (a) Top view, and (b) Bottom view.

Table 2. Comparison of various UWB BPFs.

Parameters\Ref.	[4] 2006	[5] 2007	[6] 2008	[7] 2008	This work
Permittivity	10.2	3.05	10.8	10.8	4.4
Thickness (mm)	0.254	0.508	1.27	0.635	0.8
Loss Tangent	0.002	0.0027	0.0023	0.0023	0.0245
Pass band (GHz)	3.1–10.6	3.1–10.6	2.8–10.8	3.6–10.3	3.1–10.6
Transmission zeros	One	One	Two	None	Two
Etched size (mm^2)	54.1×22.9	22.2×15.1	36×16	10.7×16	20×12
Relative Size	5.16	1.40	2.4	0.71	1

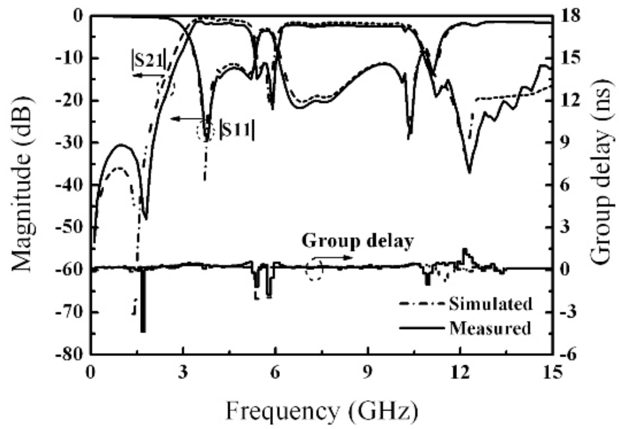


Figure 9. Simulated and measured results of UWB BPF with notched band.

results show that the proposed UWB BPF using a DGS structure has the advantage of miniaturization.

5. CONCLUSIONS

The ultra-wideband bandpass filter with embedded notch band is presented. The proposed configuration is proved to be both simple and compact. The UWB BPF is fabricated by using two open-loop SIRs on the top layer besides UWB open-loop resonators and a pair of coupling DGS open-loop resonators on the bottom layer. Design and fabrication of the proposed UWB BPF with notch band shows the advantages such as fewer number of resonators required, higher rejection level performed, as well as asymmetrical response. Moreover, the location of the transmission zeros can be precisely controlled. The proposed filter is fabricated on the FR4 PCB which can be easily integrated in UWB systems with other IC components and enhance the interference immunity efficiently.

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