Novel Ultra-Wideband Bandpass Filter With Notched Band Using Stubs Loaded Multi-Mode Ring Resonator

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***Abstract*—A novel compact microstrip ultra-wideband (UWB) bandpass filter (BPF) with narrow notched band using stepped-impedance open stub and short stub loaded multi-mode ring resonator (MMR) is proposed in this letter. By tuning the length and width of open stub, short stub and ring resonator, the center frequency and bandwidth of the UWB passband can be easily adjusted to the desired value. The narrow notched band was introduced by using a new technique which involves embedding stepped-impedance open stub have wide and narrow parts, which are placed on the symmetrical plane to perturb the ring resonator. The center frequency of the notched band can be controlled by tuning the stepped-impedance open stub. A prototype of UWB with 3 dB fractional bandwidth (FBW) of passband is (2.8-11.05 GHz) about 119%, notched band at 5.4 GHz with the FBW is 4.6% is designed and fabricated for demonstration, indicating good agreement with the theoretical expectation.**

Index Terms— Ultra-wideband bandpass filter, stepped-impedance open stub and short stub loaded multi-mode ring resonator.

I. Introduction

In recent years, the ultra-wideband (UWB) bandpass filter (BPF) with high performance are essential component in wireless communication systems, especially after the permission of the unlicensed operation band from 3.1 to 10.6 GHz by the Federal Communications Commission (FCC) in 2002 [1]. Microstrip UWB BPFs have been receiving much attention due to the advantages such as small size, low cost, easy fabrication, and several schemes have been developed in [2]-[4]. In [2], a novel UWB bandpass filter employing ring resonator was reported. By forming a multiple-mode resonator (MMR) and introducing quarter-wavelength paralle-coupled lines, a UWB passband with five transmission poles is achieved [3]. In [4], a microstrip UWB BPF with cascaded broadband bandpass and bandstop filters has been presented. However, existing undesired narrow band radio signals, such as wireless local-area network (WLAN), may interfere with the UWB range defined by the FCC, a notched (rejection) band is necessary to reject these signals. In order to overcome these drawbacks, various UWB BPFs with notched band using different structures are proposed [5]-[8]. In [5], [6] ultra-wideband BPF with a notched band using slot defected ground structure (DGS) were designed and analyzed. However, the use of the slots and DGSs etched in the ground plane might destroy the signal integrity issues for packaging. In [7], UWB ring resonator BPFs with a notched band is designed. Based on the asymmetric coupling strip, a compact UWB BPF with multiple notched bands has been presented in [8]. However, all of them are used parallel coupled lines with high impedance and strong coupling to achieve larger fractional bandwidth, due to the limitation of the fabrication precision, it is very difficult to realize the coupled lines of high impedance and a tight coupling gap. A number of UWB bandpass filters with single/multi-notched bands are investigated and discussed in [9]-[15]. However, little research has described the application of the ring resonator in the ultra-wideband filters with single/multi-notched bands based on transversal signal-interference concept.

In this work, a novel compact microstrip UWB BPF with a notched band using stepped-impedance open stub and short stub loaded multi-mode ring resonator is proposed. The narrow notched band was introduced by using a new technique which involves embedding stepped-impedance open stub have wide and narrow parts, the center frequency of the notched band can be controlled by tuning the stepped-impedance open stub. The theoretical design, simulation and experimental results are given and discussed.

II. Analysis and Design of Proposed Filter

A. Analysis and design of proposed UWB filter

The layout of the proposed ultra-wideband bandpass filter is shown in Figure 1(a). From port 1 to port 2, two transmission paths with characteristic impedance Z_1 and electrical length $2\theta_1$ are introduced, a shorted stub with characteristic impedance Z_2 and electrical length θ_2 and an open stub with characteristics impedance Z_3 and electrical length θ_3 are shuntly connected in the center of the first transmission path. Two microstrip lines with characteristic

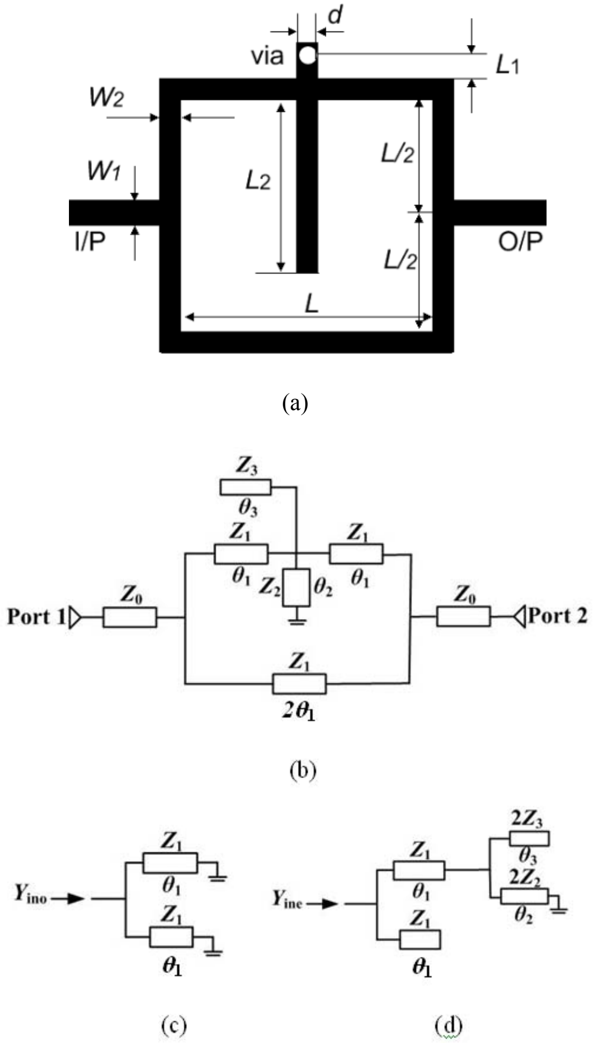


Figure 1. (a) Layout of the proposed UWB filter, (b) Equivalent circuit, (c) Odd-mode equivalent circuit, and (d) Even-mode equivalent.

impedance Z_0 = 50 Ω are connected to ports 1 and 2. The simple equivalent circuit is shown in Figure 1(b), while the odd- and even-mode equivalent circuits are shown in Figures 1(c), (d), respectively. As analyzed [16], due to the symmetry of the square ring resonator, the resonance frequencies can be calculated when Y_{in} = 0 from the one end of the even- and odd-mode circuit, respectively, which are expressed by

$$Y_{ine} = j\frac{\tan\theta_1}{Z_1} + j\frac{\tan\theta_1 - (Z_1\cot\theta_2)/Z_2}{Z_1 + (Z_1^2\tan\theta_1\cot\theta_2)/2Z_2}$$

$$\frac{+(Z_1\tan\theta_3)/2Z_3}{-(Z_1^2\tan\theta_1\tan\theta_3)/2Z_3} = 0$$

for even mode (1)

$$Z_1\tan 2\theta_1 = 0$$ for odd mode (2)

To obtain wider bandwidth than previous work [16], the characteristic impedance and length of the ring resonator are changed. Based on above analysis, the resonant frequencies of the filter can be adjusted easily by changing the characteristic impedance of the two transmission paths. After simulation and optimization accomplished by HFSS, the design parameters are determined as follows: W_1 = 1.5 mm, W_2 = 0.9 mm, L = 5 mm, L_1 = 0.6 mm, L_2 = 3.6mm. ($Z_1 = Z_2 = Z_3$ = 67 Ω, θ_1 = 44°, θ_3 = 53.4°, θ_2 = 9°). The filter is fabricated on the substrate with a relative permittivity of 4.4 and thickness of 0.8 mm.

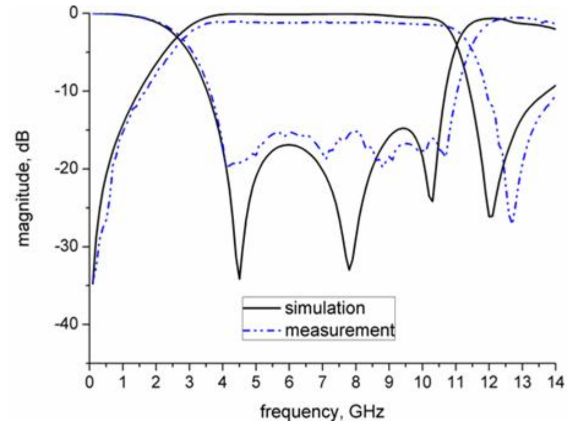


Figure 2. Simulated and measured responses of UWB filter.

Figure 2 shows the simulated and measured results of this filter. The measured 3 dB fractional bandwidth is about 117.7% (2.9-11.2 GHz), while the measured insertion loss for the filter is less than 1.1 dB, and the return loss is over 14.5 dB, in most of the passband.

B. Design of UWB filter with a notched band

Figure 3 shows the layout of the proposed UWB filter with a notched band. To realize the notched band, the stepped-impedance open stub has wide and narrow parts, which are placed on the symmetrical plane. As analyzed in [17], the characteristic impedance of the shunt stub can be adjusted to realize a transmission zero, and a notched band can be introduced by the transmission zero in the proposed UWB filter. Moreover, the center frequency and bandwidth of the notched band can be controlled by tuning the impedance ratio of the stepped-impedance open-stub, and the length of the short stub.

Figure 4 (b) shows the even/odd-mode resonator frequencies for the ring resonator with shorted/stepped-impedance open stubs under weak coupling, (C_0 = 0.02 pF), and a transmission zero (f_z) located at 5.4 GHz.

Figure 5 shows the simulated frequency responses of the proposed filter under the different value of W_3. We may note that the center frequency of notched band change from 5.1 to 5.4, 5.75 GHz when W_3 varies from 4.1 to 3.7, 3.3 mm, respectively. Figure 6 shows the simulated frequency responses of the filter in cases of different length L_1. The bandwidth of notched band increases with increasing L_1. In this way, a compact UWB filter with an adjusted notched band can be realized. After optimization using Ansoft

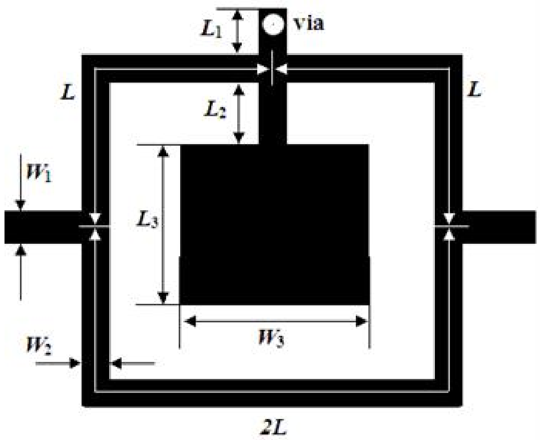
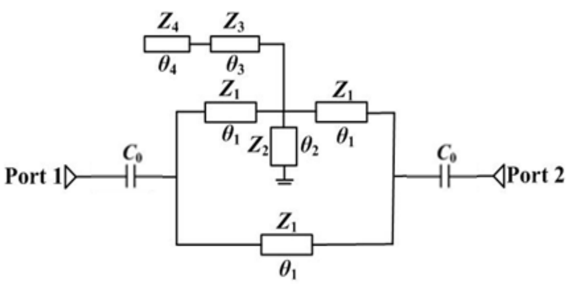
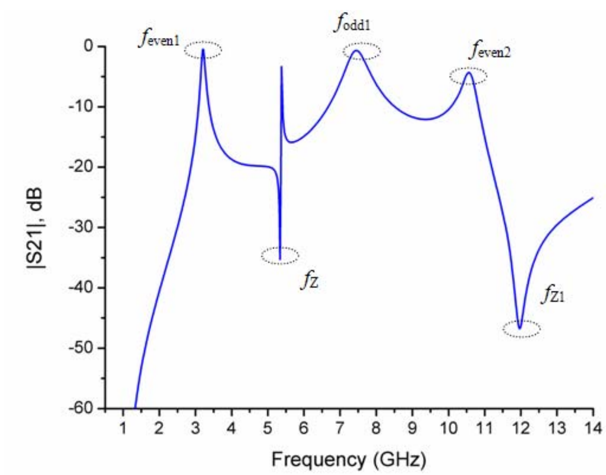


Figure 3. Layout of the proposed UWB filter with a notched band.



(a)



(b)

Figure 4. (a) Equivalent circuit of the ring resonator under weak coupling, (b) Simulation result of $|S_{21}|$ under weak coupling (Z_1 = Z_2 = Z_3 = 67 Ω, Z_4 = 27 Ω, θ_1 = 44°, θ_2 = 9°, θ_3 = 11°, θ_4 = 56°, C_0 = 0.02 pF)

HFSS 10.0, the design parameters are chosen to be W_1 = 1.5mm, W_2 = 0.9mm, W_3 = 3.5mm, L_1 = 1.2mm, L_2 = 0.6, L_3 = 3.6mm, L = 5.9mm, and via diameter is 0.7mm, (Z_1 = Z_2 = Z_3 = 67 Ω, Z_4 = 27 Ω, θ_1 = 44°, θ_2 = 9°, θ_3 = 11°, θ_4 = 57°). The filter is fabricated on the substrate with a relative permittivity of 4.4 and thickness of 0.8 mm.

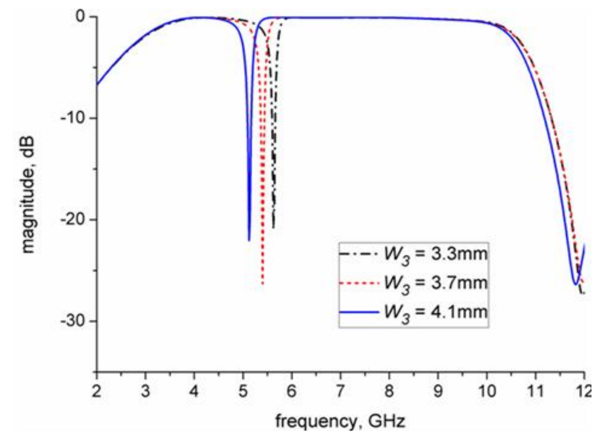


Figure 5. Simulated frequency responses of the UWB filter under the different W_3.

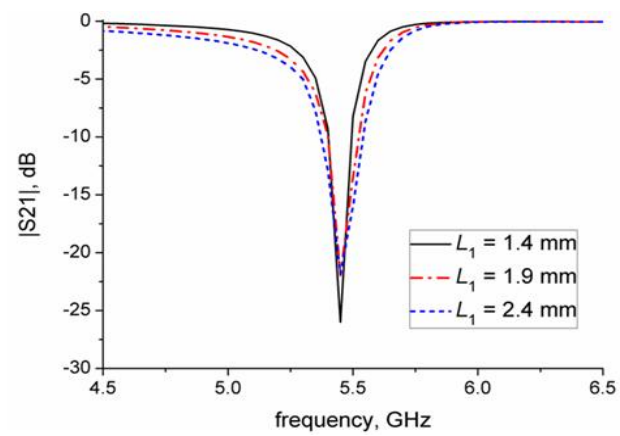


Figure 6 Simulated frequency responses of the UWB filter under the different L_1.

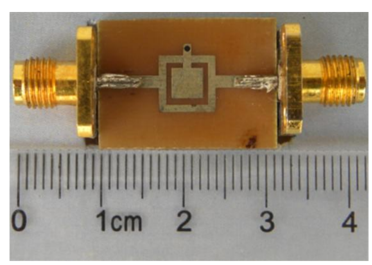


Figure 7 Photograph of the fabricated UWB filter with notched band.

III. MEASURED RESULTS AND DISCUSSIONS

One prototype of the proposed UWB filter with a notched band is designed and fabricated on a substrate with ε_r = 4.4 and h = 0.8 mm. The prototype photograph is shown in Figure 7 the size of the filter is about 8 mm * 6.8 mm ($0.28\lambda_g$ * $0.37\lambda_g$, λ_g is the guided wavelength of 50 Ω microstrip at 6.85 GHz), indicating quite compact design. The measured S-parameters and the group delay are illustrated in Figure 8. The measured 3 dB fractional bandwidth is 119% (2.8 - 11.05 GHz), while the measured insertion loss for the filter is less than 0.85 dB, and the return loss is over 15.5 dB, the group delay is less than 0.35 ns in the whole passband. The insertion loss in notched band is greater than 20 dB and the fractional bandwidth is 4.6% at 5.4 GHz.

The group delay is very flat in the whole band except in the notched band. The slight frequency discrepancy may probably be caused by unexpected fabrication tolerance and measurement error.

IV. CONCLUSION

In this work, a novel UWB bandpass filter with a notched band using stepped-impedance open-stub and short-stub multi-mode ring resonator is presented. The center frequency of the notched band can be obtained by tuning the dimensions of the stepped-impedance stub. The filter shows the advantages of compact size, simple structure. Both measured and simulated results show that the ultra-wideband BPF has a good performance including a low insertion loss, a small group delay variation, and a high out-of-band rejection level, indicating the validity of the proposed design strategies.

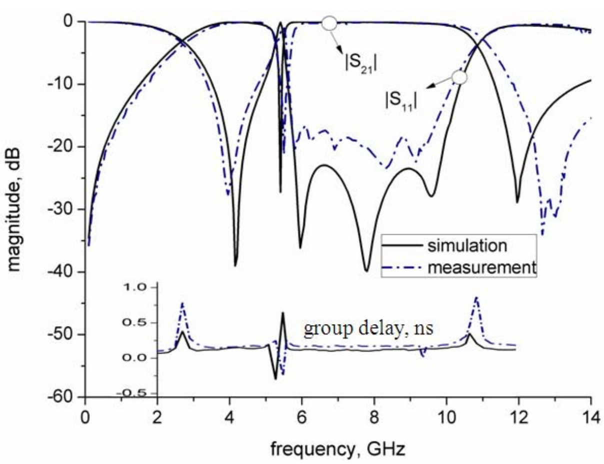


Figure 8 Simulated and measured responses of filter.

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