Compact Microstrip UWB Dual-band Band-pass Filter with Tunable Rejection Band

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Abstract

In this paper coupled open stub circuits are applied for providing band notch in filter design. Even- and odd-mode excitations for a coupled line can be represented as the equivalent capacitance networks. The rejection bandwidth of the designed filter can be controlled by the mutual capacitance C_m. An ultra-wideband (UWB) bandpass filter with 5 GHz to 6 GHz rejection band is proposed. To inhibit the signals ranged from 5 to 6GHz, two pairs of stepped-impedance coupled open stubs are implemented on the multiple-mode resonator (MMR) The designed UWB filter has two transmission bands. The first passband from 2.8 GHz to 5 GHz has less than 0.8 dB magnitude of insertion loss and greater than -15 dB return loss. The second passband within 6 GHz and 10.6 GHz has less than 1.5 dB magnitude of insertion loss and greater than 15 dB return loss. The rejection at 5.5 GHz is better than 50 dB. This filter can be integrated in UWB radio systems and efficiently enhance the interference immunity from WLAN.

1.INTRODUCTION

Applications of ultra-wideband (UWB) have the characteristics of low cost, bulky data transmission rate and very low power consumption that make it attractive in local area networks, position location and tracking, and radar system, etc. Both surface-mountable planar bandpass filters and antennas with wide bandwidth are highly suitable for integration of UWB front-ends. Several types of planar bandpass filter structure have been proposed in the diverse literatures [1]-[10]. Wide bandwidth, multi-transmission poles, compact size and good electrical performances are emphasized. However, some services include IEEE 802.11a compliant data devices that could be commonly used in a local area network, which also works in conjunction with the UWB radio, collocated within the same devices. When considering interference from WLAN, the desired operating band between 3.1 GHz and 5 GHz is a better choice. Under such consideration, it is required to provide an effective with WLAN Notch had proposed [11], it has narrow notch bandwidth but the low-band performance is not good and needs multilayer fabrication. In 2008, a UWB filter with notch band using DGS was proposed [12], however, it needs etching several defect ground structure (DGS) units on the backside ground plane. Therefore, if narrow bandwidth rejection and reduction of fabrication complexity are concerned, the open-circuited stub is a good solution to achieve. In this letter, the simple structure, good performance and compact UWB dual-band filter based on stepped-impedance open stub (SIOS) and multiple mode resonator is demonstrated.

2.DESIGN METHODOLOGY

Coupled open stub circuits shown in Figure 1 are of importance for design of RF/microwave rejection filters. To demonstrate their diversity in microwave filter design, coupling mechanisms are required to be further investigated. Starting with the introduction of a transitional quarter- wavelength open stub indicated in Figure 2, the input impedance of an open stub transmission line is

$$Z_{in}=-jZ_{0n}\cot\theta_n \tag{1}$$

where $\theta_n = \pi/2$ for $\omega = \omega_0$ and Z_{0n} is the characteristic impedance of the open stub. Then consider the two-section open-circuited stub. The stepped-impedance technology is used to reduce the electric length of the open stubs. Based on transmission line theory, the equivalent circuit for a small electrical length and large characteristic impedance transmission line is equal to an inductor, while equivalent circuit for a small electrical length and small characteristic impedance transmission line is equal to a capacitor. In Figure 2, a traditional stepped-impedance quarter-wavelength open stub can be approximated as a series LC resonator when the length θ_n is near 90°. The characteristic impedances of the two-section line are defined as Z_1 and Z_2 with electrical length θ_1 and θ_2. The relationship between electrical θ_1 and resonator length θ_T can be calculated as follows [17]; the impedance ratio of the stepped-impedance line is defined at first

$$k=Z_2/Z_1=\tan\theta_1\tan\theta_2 \tag{2}$$

Then

$$\theta_T=\theta_1+\theta_2=\theta_1+\tan^{-1}(k/\tan\theta_1) \tag{3}$$

Consider the two equal series LC resonators are shunted at both sides of a transmission line section shown in Figure 1, the value of $(LC)^{-1/2}$ equals the angular resonant frequency of uncoupled resonators. The coupling can be obtained if the open sides of two pairs of quarter-wavelength open stubs are proximately placed. The mutual capacitance C_m between two LC resonators is required to be involved for circuit modeling. Since the two open stubs are parallel to each other, the transverse electric field patterns between them are decomposed into the even and odd modes. Even- and odd- mode excitations for a coupled line can be represented as the equivalent capacitance networks. For the odd mode analysis, the symmetry plane is replaced by an electric wall, the resultant circuit has a resonant frequency of $1/2\pi\sqrt{L(C+C_m)}$. This resonant frequency is lower than that of an uncoupled single resonator. Similarly, for the even mode analysis, the symmetry plane is replaced by a magnetic wall (or an open circuit), the resultant circuit has a resonant frequency of $1/2\pi\sqrt{L(C-C_m)}$. This resonant frequency is higher than that of an uncoupled single resonator. Both resonant frequencies result in resonance mode splitting phenomenon. The rejection bandwidth can be controlled by the mutual capacitance C_m.
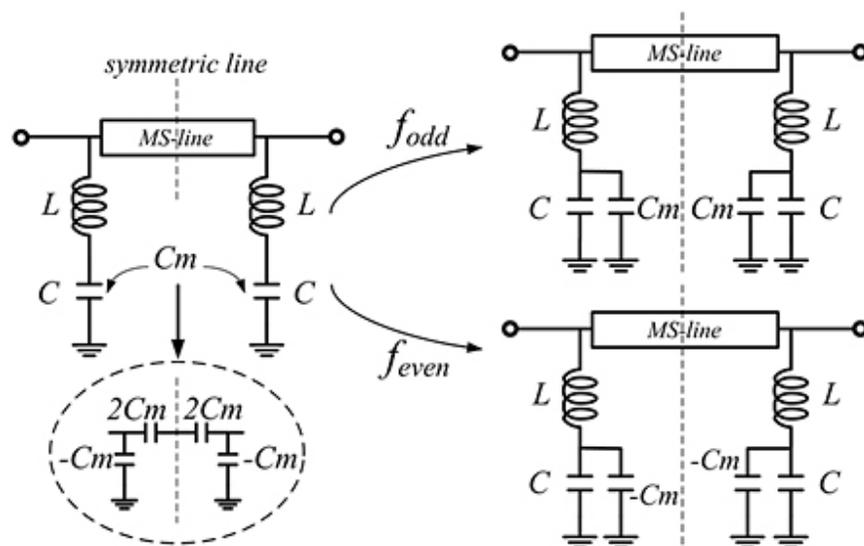
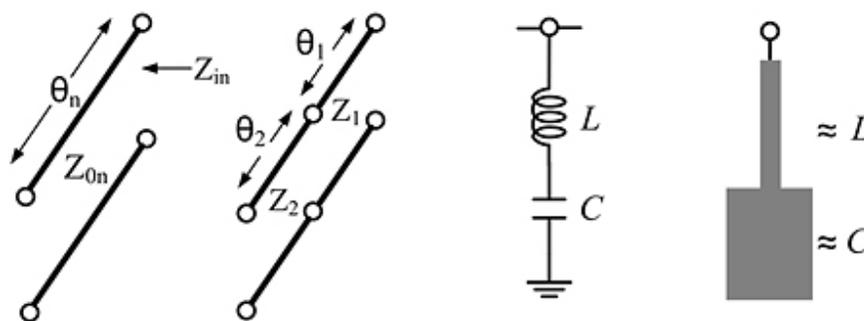Figure 1. The equivalent circuit model of the open-circuited stub

Figure 2. The equivalent circuit model of the open-circuited stub
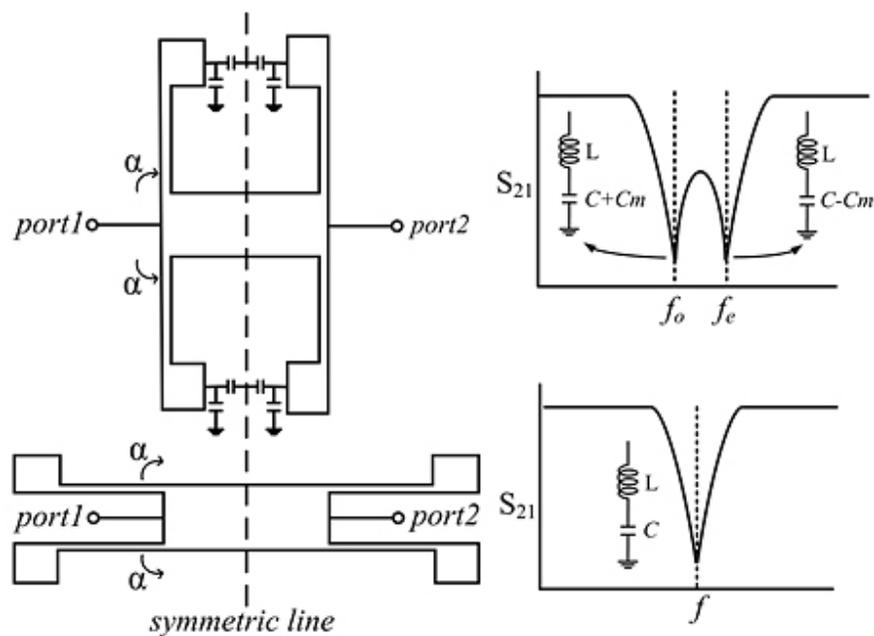

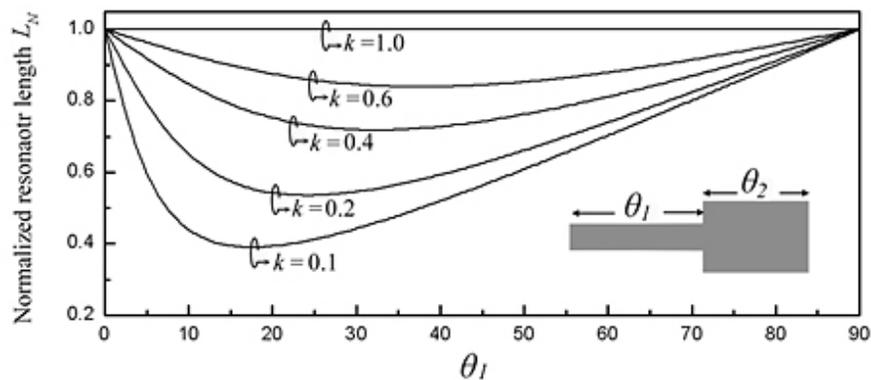Figure 3. Simulated responses of the perpendicular and horizontal λ/4 resonator.
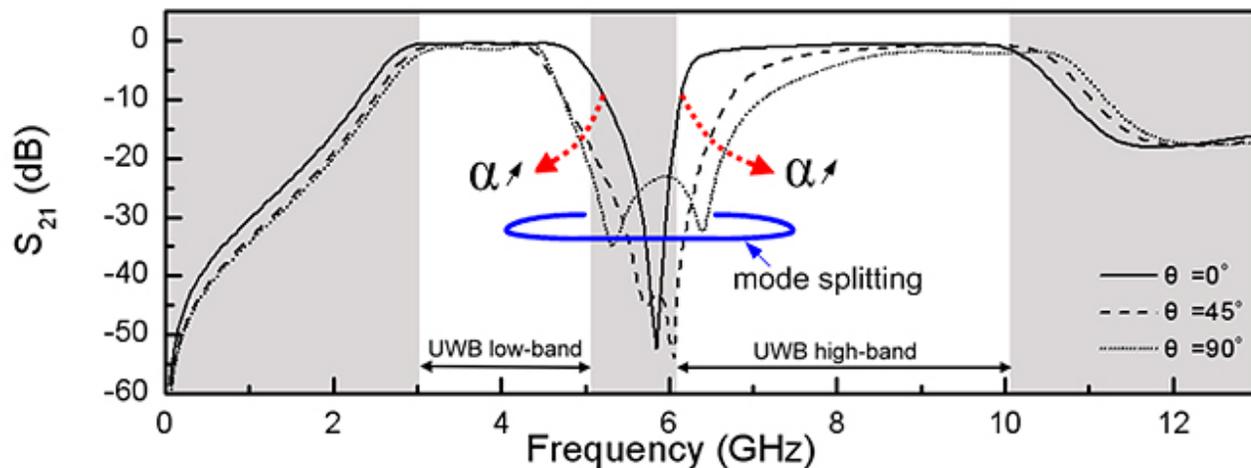
Figure 4. Resonance condition of the SIOS.

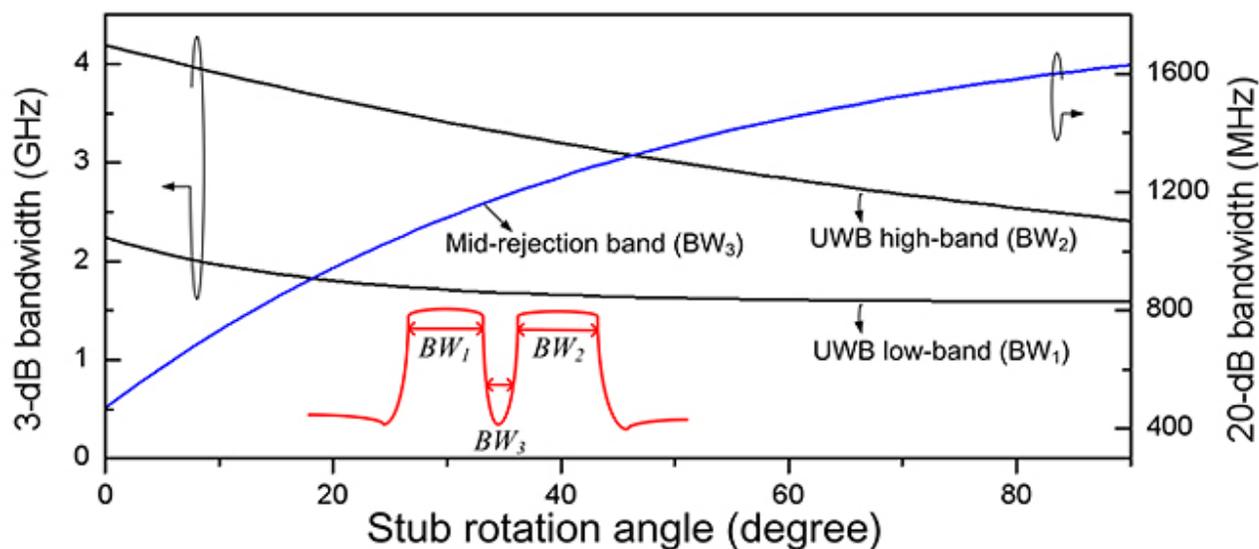Figure 5. The S_{21} simulated results by using different stubs angle.

Figure 6. The bandwidth investigation of sensitivity to stubs angle

3.DESIGN OF UWB 3 GHZ TO 10 GHZ BANDPASS FILTER WITH 5 GHZ TO 6 GHZ REJECTION BAND

To create two transmission bands in ultra-wide band filter, the signals ranged from 5 GHz to 6 GHz need to be reflected back. Two cases are shown in Figure 3, one is MMR with perpendicular open stubs, and the other is MMR with horizontal open stubs. From pre-simulation results, the uncoupled horizontal open stubs tapped on the MMR excite a single resonant mode at resonant frequency f_0. In second case, two pairs of open stubs are

perpendicular to the resonator and cause the resonance mode splits to f_e and f_o. On the consideration of optimization in finding suitable rejection band for dual ultra-wide band filter design, the different tapped angles α between the SIOS to the resonator are further simulated. It is a greatest challenge since the impedance near the resonant frequency is very sensitive. Figure 4 shows the resonant condition of the SIOS. In this case, the impedance ratio k is selected by 0.55 and resonant frequency is design at 5.6 GHz. The simulated frequency responses by using different stubs rotation angles α = 0°, 45° and 90° are shown in Figure 5. When the rotation angle between two stubs is increased, the higher pass-band is affected. With mutual coupling involved, the attenuation no longer centers at frequency ω_0. There is an appreciable increase in the passband attenuation because of the dissipation. The bandwidth investigation of sensitivity to stubs rotation angle is shown in Figure 6. It demonstrates that when the θ increases, the resonant mode in rejection band is being splitted since the coupling between two open stubs has been enhanced. In this case, the rotation angle 0° is applied for this design. An UWB dual-band bandpass filter based on MMR with tapped SIOS is proposed and shown in Figure 7. The electrical coupled line length l is close to 90o and the coupling spacing is 0.3 mm. It has been reported that the three coupled lines structure can provide wider transmission bandwidth and better impedance matching within the passband than that of the two coupled lines structure [18].

4. SIMULATION AND MEASUREMENT RESULTS

In this paper, one of MMR UWB filter design examples which used 0 degree stubs rotation angles is designed and fabricated on an RT/Duroid 5880 substrate with a thickness h = 125 mil and a relative dielectric constant ε_r =2.2. The simulation and measurement results of the proposed UWB bandpass filter with 5 GHz to 6 GHz steep notch are shown in Figure 8. The filter has two transmission bands, the first passband from 2.8 GHz to 5 GHz has about 0.8 dB magnitude of insertion loss and greater than -12 dB return loss. The second passband from 6.3 GHz to 10.6 GHz has about 1.8 dB magnitude of insertion loss and the return loss within the passband is about -15 dB. With the addition of four open stubs, the rejection from 5.8 GHz to 6.05 GHz is successfully suppressed to the level lower than -30 dB and the maximum attenuation is 52 dB at 5.98 GHz. For wideband application, the investigation of the flat group delay is important and required. The simulated and measured group delay are shown in Figure 9, it is below 0.4 ns within the lower and higher passband.
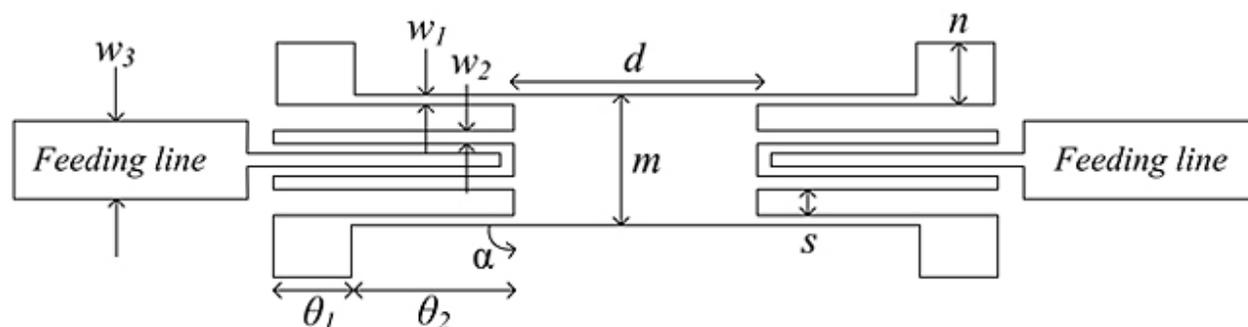

Figure 7.   Ultra-wideband bandpass filters with 5 GHz to 6 GHz rejection band. (l = 8 mm, m = 3.2 mm, n = 1.7 mm, w_1 = 0.3 mm, w_2 =0.3 mm, w_3 =3.9 mm, and d = 6.7 mm.)
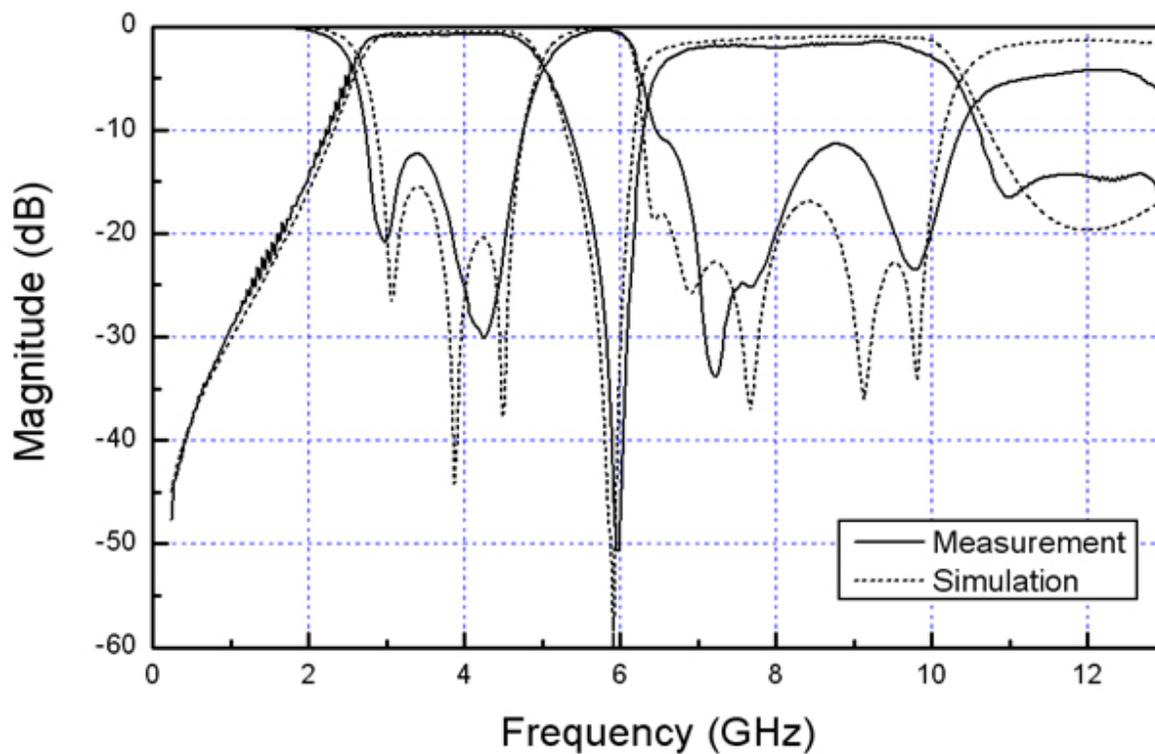
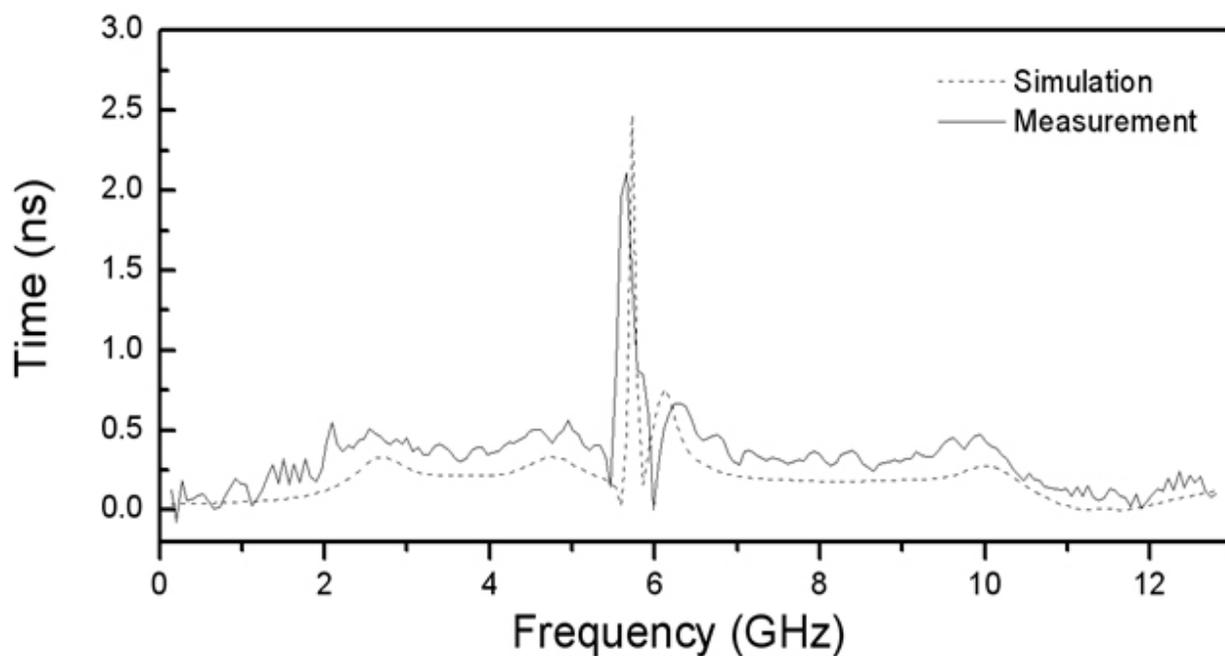Figure 8. Simulation and measurement results of UWB dual-band filter.

Figure 9. Group delay of the proposed dual-band filter

5.CONCLUSION

Band notch filter design using step impedance coupled open stub circuits is demonstrated in this paper. The prediction model based on even- and odd- mode analysis is developed. Both resonance frequencies result in mode splitting phenomenon. The rejection bandwidth can be accurately controlled. The high performance and compact UWB dual-band filter based on coupled open stubs structure and the MMR is presented and fabricated in this letter. The novelty of the proposed UWB dual-band filter with two pairs of coupled open stubs added is emphasized on suppression of 5 GHz to 6 GHz spectrum without degrading the passband performance and increasing the component size. It has been shown that the filter has the advantages of good magnitude of

insertion loss of less than 1 dB in both operating bands. This filter can be integrated in UWB radio systems and efficiently enhance the interference immunity.

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