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Miniaturized Planar Ultra-Wideband Bandpass Filter with Notched Band

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Abstract

This paper presents a planar ultra-wideband (UWB) bandpass filter with sharp out-of-band rejection performance. The filter is formed by a folded multiple-mode resonator to realize high performance in an operation band from 3.3 to 10 GHz with a very compact size of 20 mm × 20 mm × 0.5 mm. An extra notched band centered at 5.8 GHz is further accomplished by etching a Hilbert fractal curve slit on the filter without the necessity of readjusting the geometrical parameters. The simulated and measured results are in good agreement.

Keywords

Ultra-Wideband (UWB), Bandpass Filter, Notched Band, Hilbert Fractal Curve

1. Introduction

Ultra-Wideband (UWB) systems have attracted increasing attention since the Federal Communications Commission released the unlicensed use of the frequency spectrum 3.1 - 10.6 GHz for UWB applications in 2002. With the rapid development of electronic products, high performance and compact size have been import issues in design considerations. The investigation on an UWB bandpass filter, which is one of the main components of UWB systems, has been a subject of interests.

Since 2005, various UWB bandpass filters have been designed and reported, including filters of composite lowpass and highpass structures [1], shorted-circuited stub filters [2] [3], multiple-mode resonator (MMR) structure filters [4], etc. Modification or improvement of MMR filters has also been proposed due to their compact size and high performance [5]-[9]. In [7] [8], the transmission zeros of MMR filters are used to realize sharp out-of-band rejection performance.

Because of the possible interference with the existing wireless local area network or other applications, the

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research on UWB bandpass filters with notched bands has also been conducted in recent years. For example, etching slots on the patch or on the ground plane [10] [11], using asymmetric coupled lines [12], and adding notch resonators [13] [14].

Based on [7], a miniaturized UWB filter formed by a MMR is realized in this paper. The MMR is formed by a stepped-impedance resonator with a stepped-impedance stub. Different from [7], however, the UWB bandpass filter here achieves UWB with a much more compact size of 20 mm × 20 mm by folding the MMR. An extra notched band around 5.8 GHz is further obtained by etching a Hilbert fractal curve slit [15] on the filter without the necessity of readjusting the geometrical parameters. The filter is fabricated on a printed circuit board with a relative permittivity of 2.65 and thickness of 0.5 mm.

The structure of the paper is as follows. In Section 2, the configurations of the proposed filters with or without the notched band are introduced and their resonance characteristics are analyzed. In Section 3, the experiment results of the above UWB filters are presented and compared with the simulated ones. Finally, conclusions are given in Section 4.

2. Filter Structure and Design

2.1. Configuration and Design

The configuration of the proposed UWB bandpass filter without a notched band is shown in **Figure 1**, which consists of a folded MMR formed by a stepped-impedance resonator with widths of W_i and lengths of L_i (i = 1, 2, 3, 4). It is fed by a microstrip line with width W and parallel-coupled structure with width of W_s and lengths of L_s. This MMR structure is used to create five resonance frequencies in the passband to achieve UWB operation bandwidth by adjusting the parameters of the MMR. In addition, the stepped-impedance stub with widths of W_3 and W_4 and lengths of L_3 and L_4 can also introduce two transmission zeros, sharp rejection can then be realized by changing the locations of these transmission zeros to the edges of the passband.

Figure 2(a) shows the MMR structure. Y_i and θ_i (i = 1, 2, 3, 4) are the characteristic admittances and electronic lengths, respectively. Since the MMR is symmetrical in structure, the even- and odd-mode methods can be used for its characterization. **Figure 2(b)** and **Figure 2(c)** are its even- and odd-mode equivalent circuits, respectively. The symmetrical planes are open-circuited for even-mode excitation and short-circuited for odd-mode excitation. The input admittances Y_{in}^e and Y_{in}^o for the even- and odd-mode excitations can be respectively given bellow

$$Y_{in}^e = Y_1\left(Y_1^e + \mathrm{j}Y_1\tan\theta_1\right)\Big/\left(Y_1 + \mathrm{j}Y_1^e\tan\theta_1\right), \tag{1}$$

$$Y_{in}^o = jY_1\left(Y_1\tan\theta_1 - jY_2\cot\theta_2\right)\Big/\left(Y_1 + Y_2\tan\theta_1\cot\theta_2\right), \tag{2}$$

where

$$Y_1^e = Y_2\left(Y_2^e + jY_2\tan\theta_2\right)\Big/\left(Y_2 + jY_2^e\tan\theta_2\right), \tag{3}$$

$$Y_2^e = jY_3\left(Y_4\tan\theta_4 + Y_3\tan\theta_3\right)\Big/2\left(Y_3 - Y_4\tan\theta_3\tan\theta_4\right), \tag{4}$$

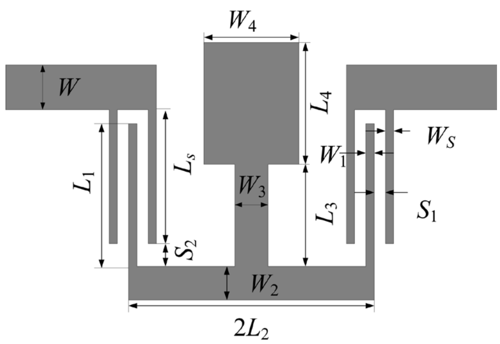


Figure 1. Configuration of the proposed UWB filter without notched band.

From the resonance condition: $Y_{in}^e = 0$ or $Y_{in}^o = 0$, the resonance frequency of the even-mode f_e or that of the odd-mode f_o can be obtained from

$$\frac{k_2 - k_1 k_2 \tan\theta_1 \tan\theta_2}{2\left(\tan\theta_3 \tan\theta_4 - k_3\right)} = \frac{k_1 \tan\theta_1 + \tan\theta_2}{\tan\theta_4 + k_3 \tan\theta_3}, \quad (5)$$

or

$$k_1 \tan\theta_1 \tan\theta_2 = 1, \quad (6)$$

where $k_1 = Y_1/Y_2$, $k_2 = Y_3/Y_2$, and $k_3 = Y_3/Y_4$. The transmission zeros f_z can be produced by $Y_{in}^e = Y_{in}^o$.

Three $f_e\left(f_{e1}, f_{e2}, f_{e3}\right)$, two $f_o\left(f_{o1}, f_{o2}\right)$, and two $f_z\left(f_{z1}, f_{z2}\right)$ can be determined within the passband. To realize sharp rejection, the locations of the transmission zeros f_z can be moved to the edges of the passband by adjusting k_3, L_3, and L_4. The resonance frequencies f_o can be changed by adjusting k_1, L_1, and L_2 and those of f_e by k_1, k_2, and k_3, and L_i (i = 1, 2, 3, 4). **Figure 3** plots the resonance frequencies and transmission zeros of the MMR with varying k_1, k_2, and k_3. It is seen that f_e and f_z can be very close at both lower and upper frequencies, such that sharp rejection can be realized at the band edges.

The parameters W_s and S_1 determine the coupling of the MMR and parallel-coupled structures. **Figure 4** illustrates the $|S_{21}|$ simulated by HFSS with weak and strong coupling. From the weak coupling the resonance frequencies and transmission zeros can be obviously observed. With strong coupling and the MMR characteristics, an UWB bandpass filter with high performance can be realized.

2.2. UWB Filter with Notched Band

Since a Hilbert fractal curve slit can produce a narrow notched band without increasing circuit area [15], it's utilized and etched on the stepped-impedance stub to produce a notched band around 5.8 GHz, while the other structure parameters remain unchanged, as shown in **Figure 5**. **Figure 6** depicts the change of resonant frequencies with different values of x_h, y_h or w_h. By fine-tuning the dimensions of the Hilbert fractal curve slit, the

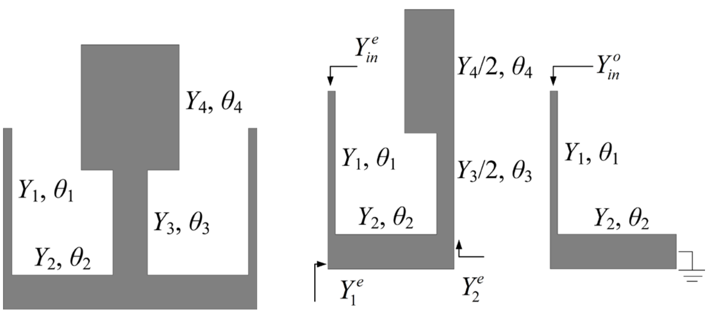


Figure 2. (a) Configuration of MMR; (b) Even-mode equivalent circuit; (c) Odd-mode equivalent circuit.

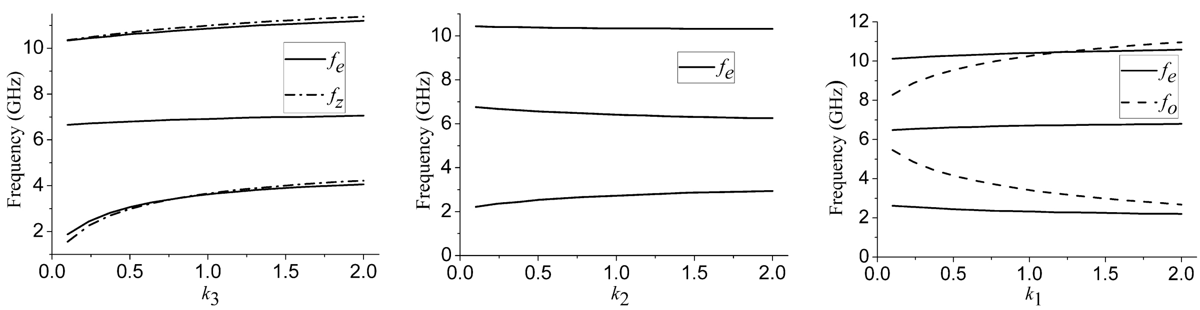


Figure 3. Resonance characteristics of MMR. (a) With varying k_3. k_1 = 1, k_2 = 0.2; (b) With varying k_2. k_1 = 1, k_3 = 0.2; (c) With varying k_1. k_2 = 0.2, k_3 = 0.2. L_1 = 8 mm, L_2 = 7 mm, L_3 = 10 mm, and L_4 = 4 mm.

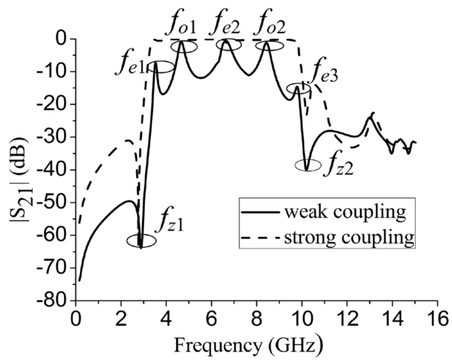


Figure 4. Simulated $|S_{21}|$ with weak and strong coupling.

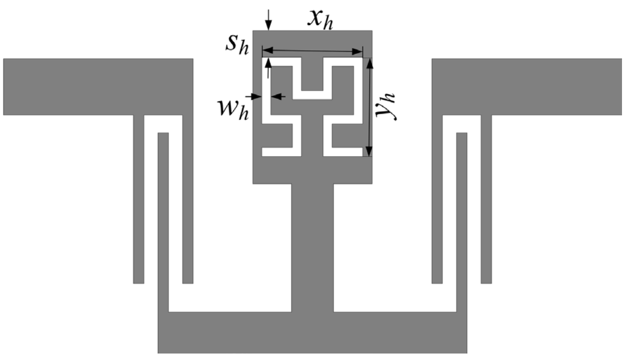


Figure 5. Configuration of the filter with notched band.

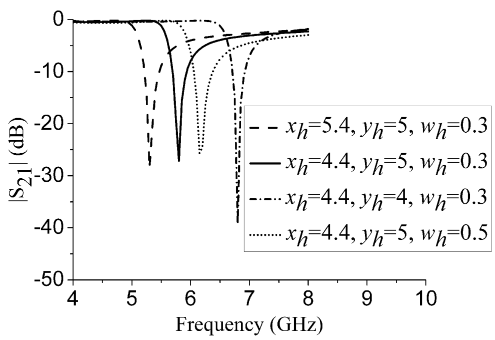


Figure 6. Simulated $|S_{21}|$ of the notched band.

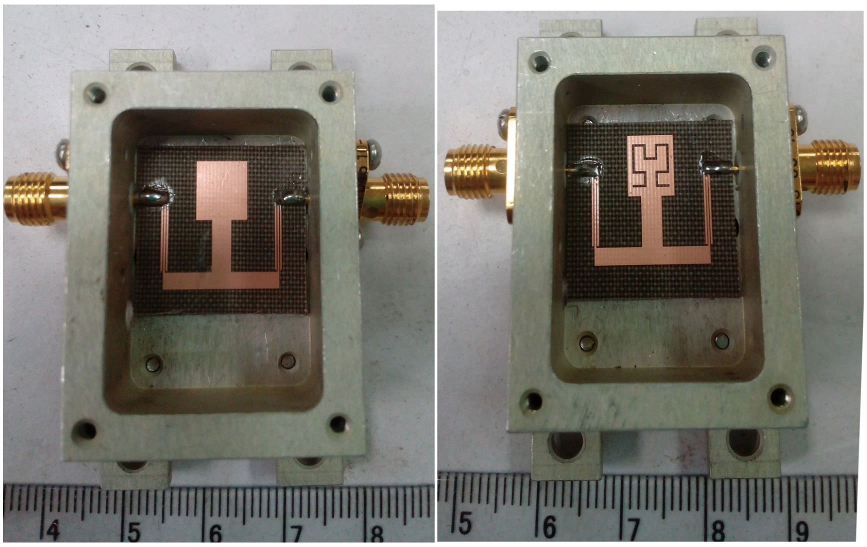
notched band can be obtained in the desired frequency range.

3. Experiment Results and Discussions

The proposed filters with or without a narrow notched band are fabricated, as shown in **Figure 7**, and measured to demonstrate their performance. A SMA connector is attached to the 50 ohm microstrip feeding line of W = 1.35 mm. SMA connectors are included in the simulation model. The overall sizes of the filters are 20 mm × 20 mm. The simulation shows that the dimensions of the metallic boxes have little influence on the performance. The structure parameters are: W_1 = 0.2, W_2 = 1.925, W_3 = 2.25, W_4 = 6, W_s = 0.18, L_s = L_1 = 7.8, L_2 = 6.75, L_3 = 6.1, L_4 = 7, S_1 = 0.1, and S_2 = 0.2.

Figure 8 illustrates the simulated and measured results of the UWB bandpass filter without a notched band. The measured pass band is from 3.3 GHz to 10 GHz with a return loss less than −10 dB.

Figure 9 depicts the simulated and measured results of the UWB bandpass filter with a narrow notched band. The design parameters for the notch are: x_h = 4.4, y_h = 5, w_h = 0.3, and s_h = 2. It has a measured notched band



(a) (b)

Figure 7. Photographs of the filters. (a) Without a notched band; (b) With a notched band.

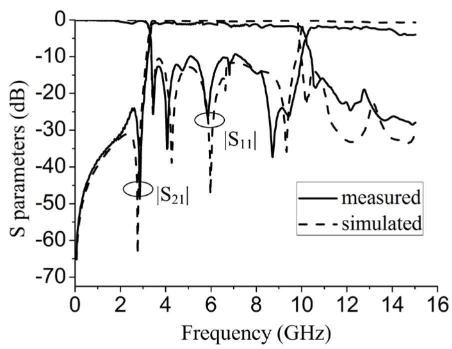
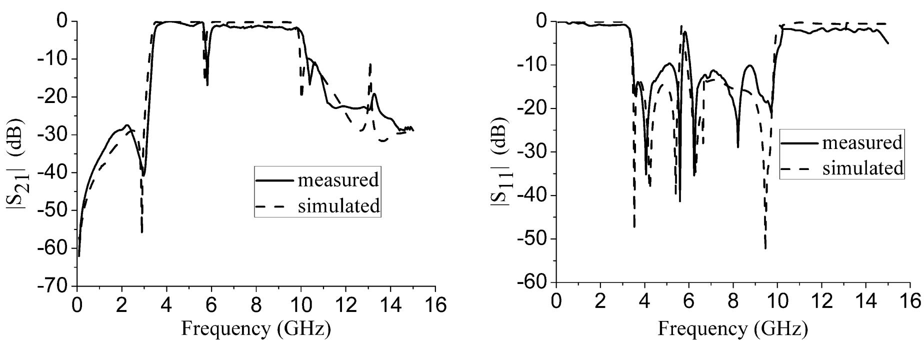


Figure 8. Simulated and measured S parameters of the proposed UWB filter without notched band.



(a) (b)

Figure 9. Simulated and measured S parameters of the filter with a notched band (a) $|S_{21}|$; (b) $|S_{11}|$.

from 5.7 GHz to 6.0 GHz and the attenuation is less than −15 dB at the center frequency. The deviations of the measurements from the simulations may be attributed to tolerance in the fabrication process and diversity of material parameters.

4. Conclusion

In this paper, very compact UWB bandpass filters with or without a narrow notched band are designed and realized. The fabricated filters have a wide passband from 3.3 GHz to 10 GHz with sharp rejection at the band edges. A Hilbert fractal curve slit is etched on the stepped-impedance stub to obtain the notched band around 5.8 GHz without increasing the circuit area. With good frequency performances and compact sizes, the proposed filters are attractive to UWB applications.

Acknowledgements

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