Compact Microstrip UWB Bandpass Filter with Triple-Notched Bands and Wide Upper Stopband

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Abstract—A novel compact ultra-wideband (UWB) bandpass filter (BPF) with triple sharply notched bands and wide upper stopband is proposed. The basic UWB BPF is composed of two microstrip interdigital coupled lines and one multiple-mode resonator (MMR). Then, to achieve triple band-notched performance, the proposed triple-mode stepped impedance resonator (TMSIR) is studied and coupled to the interdigital coupled lines of the basic UWB BPF. To validate the design theory, a microstrip UWB BPF with three notched bands respectively centered at 5.2 GHz, 5.8 GHz, and 6.8 GHz is designed and fabricated. Both simulated and experimental results are provided with good agreement.

1. INTRODUCTION

In 2002, the U.S. Federal Communications Commission (FCC) authorized the unlicensed use of ultra-wideband (UWB, from 3.1 to 10.6 GHz) for a variety of applications, such as indoor and hand-held systems [1]. UWB BPFs, as one of the essential components of the UWB systems, have gained much attention in recent years. There are many methods presented to design UWB bandpass filters. For instance, multiple-mode resonator (MMR) [2, 3], defected microstrip structure (DMS) [4], defected ground structure (DGS) [5, 6], multilayer coupled structure [7, 8], and the cascaded low-pass/high-pass filters [9, 10] have been widely used to achieve UWB characteristics.

However, the existing wireless networks, such as WiMAX (i.e., 3.5 GHz bands), WLAN (i.e., 5.2 GHz and 5.8 GHz bands), RFID (i.e., 6.8 GHz bands) and some satellite communication (i.e., 8.0 GHz bands) signals, can interfere with UWB networks. Therefore, compact UWB BPFs with multiple notched bands are emergently needed to reject these undesired interfering signals [11–23]. To achieve a notched band, the radial-uniform impedance resonators (UIR)/stepped impedance resonators (SIR) loaded stub resonator is employed in [11], and the Y-shaped radial stub is used in [12]. On the other hand, one of the two arms in the coupled-line sections is extended and folded in [13], and a stepped impedance resonator (SIR) is embedded in [14] to block unwanted existing radio signals. However, these methods can only achieve one notched band. Then, two embedded open circuited stubs are employed [15], and a coupled simplified composite right/left-handed resonator is used in [16] to get two notched bands. In the same way, a novel E-shaped resonator is coupled to the initial UWB BPF to achieve dual notched bands [17]. However, the selectivity designed with these methods needs to be improved. Double open-circuit stubs are embedded into broadside-coupled stepped impedance resonators on middle layer in [18], and folded stepped impedance resonators are vertically-coupled to the second layer in [19]. Two notched bands can also be introduced into an UWB BPF. However, they are based on a multilayer structure and hardly compatible with the existing microwave-integrated circuit. Two L-shaped folded shunt open-circuited stubs are placed on the feed lines in [20], and two tri-section stepped impedance resonators and a parallel gap-coupled microstrip resonator are used in [21] to get triple notched bands. However, the performance of the filters needs to be improved. Additionally, a

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triple-mode stepped impedance resonator (SIR) in [22] and a square ring short stub loaded resonator (SRSSLR) in [23] are coupled to the main transmission line of the basic microstrip UWB BPF to achieve triple notched bands. But, the proposed UWB BPFs have a relatively narrow upper stopband, and the selectivity are not ideal.

In this paper, we present a novel UWB BPF with triple sharply-notched bands and wide upper stopband. The design procedures are as following: the basic microstrip UWB BPF with wide upper stopband is designed using two microstrip interdigital coupled lines and one multiple-mode resonator (MMR). Then, triple band-notched characteristics are achieved by coupling the proposed triple-mode stepped impedance resonator (TMSIR) to the microstrip interdigital coupled lines of the basic UWB BPF. The triple-notched bands can be easily generated and realized by controlling the locations of even-odd modes resonance frequency of the triple-mode stepped impedance resonator. Finally, the proposed filter is designed, fabricated and measured. Good agreement between measured and simulated results is achieved.

2. CHARACTERISTICS OF THE NOTCHED STRUCTURE

Figure 1 shows the geometry of the proposed triple-mode stepped impedance resonator (TMSIR). The proposed TMSIR is composed of a stepped impedance hairpin resonator and two short-ended stubs. Since the resonator is symmetrical to the A-A' and B-B' plane, the resonance properties of the TMSIR can be analyzed by the even-odd modes analysis method. Under mode excitation, the resonator electrical field distribution of the resonator exhibits either an even or odd mode distribution property as shown in Figure 2. For the even mode condition, the electrical fields exhibit a symmetric distribution along B-B' axis as shown in Figure 2(a). While for the odd mode, the electrical fields exhibit an anti-symmetric distribution along A-A' axis as shown in Figure 2(b) and B-B' axis as shown in Figure 2(c). Thus, based on the electrical field distribution property, the even-odd modes resonance frequencies can be deduced as:
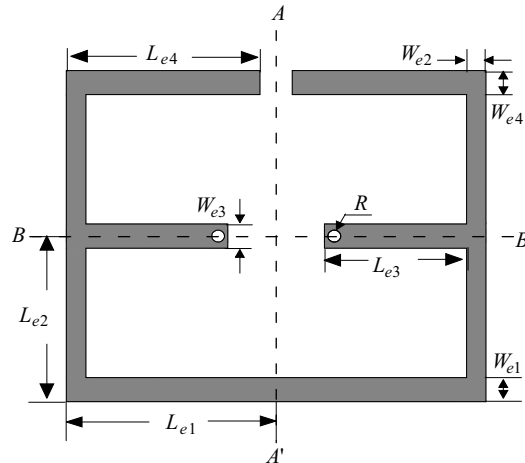
$$f_{notch} = \frac{c}{\lambda_{notch}\sqrt{\varepsilon_{eff}}} \tag{1}$$

$$f_{notch\text{-}even1} = \frac{c}{4(L_{e2} + L_{e3} + L_{e4})\sqrt{\varepsilon_{eff}}} \tag{2}$$
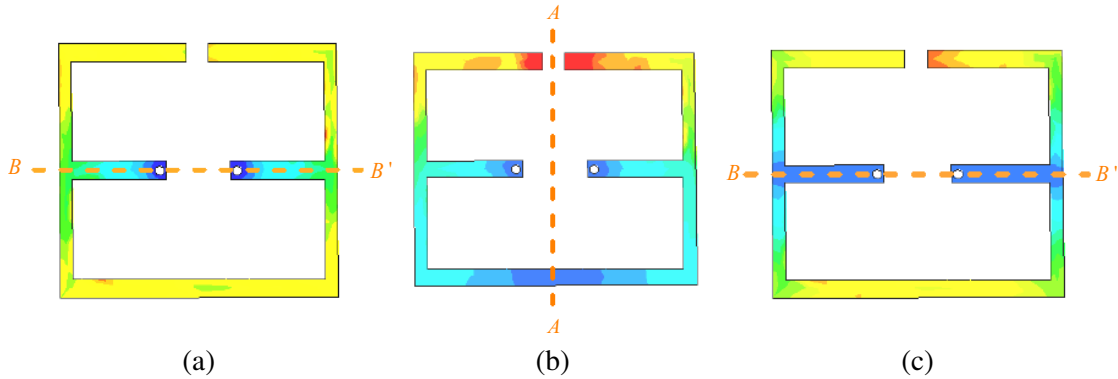
$$f_{notch\text{-}odd1} = \frac{c}{2(L_{e1} + 2L_{e2} + L_{e4})\sqrt{\varepsilon_{eff}}} \tag{3}$$

$$f_{notch\text{-}odd2} = \frac{c}{4(L_{e2} + L_{e4})\sqrt{\varepsilon_{eff}}} \tag{4}$$
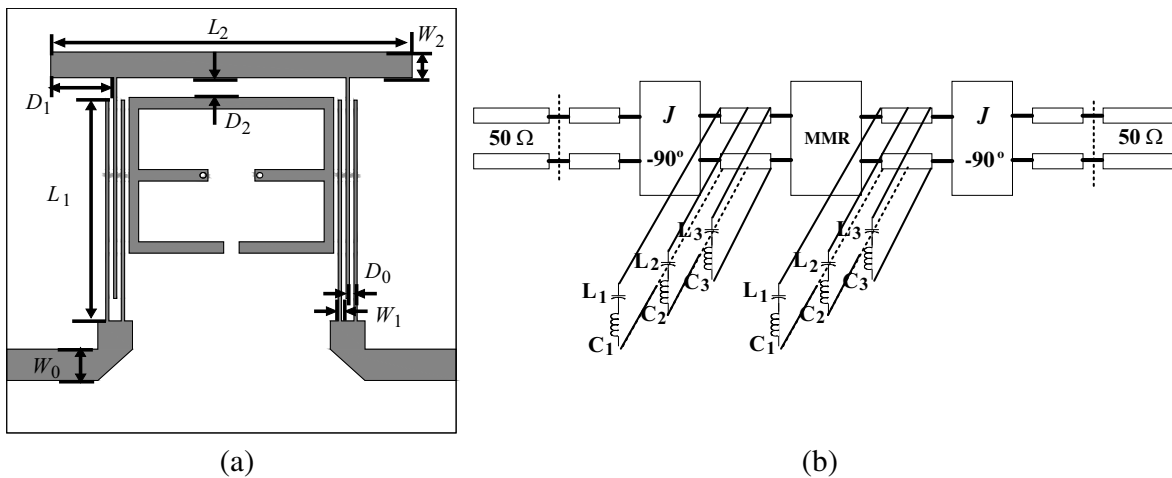
where λ_{notch} is the wavelength of the center frequency of the notched band, f_{notch} the center frequency of the notched band, ε_{eff} the effective dielectric constant, and c the light speed in free space.

Figure 1. Geometry of the proposed TMSIR.

Figure 2. Electrical field distribution of the proposed TMSIR: (a) even mode, (b) odd mode, (c) odd mode.


Figure 3. Schematic layout and equivalent circuit network of the presented UWB BPF with triple-notched bands: (a) schematic layout, (b) equivalent transmission line network.

3. UWB BPF WITH NOTCHED-BANDS DESIGN

Figures 3(a) and 3(b) illustrate the schematic and equivalent transmission line model, respectively. Figure 3(a) comprises one multiple-mode resonator and two microstrip interdigital coupled lines, which is coupled to a triple-mode stepped impedance resonator (TMSIR). Herein, the two microstrip interdigital coupled lines are formed to provide sufficiently strong coupling degree in the desired UWB band. The equivalent transmission-line network of the proposed filter is shown in Figure 3(b). The interdigital coupled lines can be deemed as two single transmission lines at two sides and a J-inverter susceptance in the middle. The TMSIR coupled into the interdigital coupled lines of the basic UWB BPF can be modeled as three shunt series resonant branches.

The initial MMR is first proposed by [24] aiming at allocating its first three resonant modes located within 3.1–10.6 GHz. However, the out-of-band rejection and selectivity of the proposed UWB filter are not ideal. Thus, two short open-circuited stubs are shunt-connected to the initial MMR to achieve more resonant modes. The simulated S_{21}-magnitudes of the basic UWB bandpass filter under weak coupling are plotted in Figure 4(a). Five resonant peaks can be obviously observed in UWB passband, i.e., f_1, f_2, f_3, f_4, and f_5 are used to conconstitute the desired UWB passband. By canceling the other resonant modes, the upper-stopband of the basic UWB bandpass filter can be significantly extended. Two transmission zeros are generated by two short open-circuited stubs near the lower and upper cut-off frequencies, leading to a higher rejection skirt outside the desired passband.

As a starting part of this work, a basic microstrip UWB BPF is designed. The simulated scattering parameters are shown in Figure 4(b). Referring to Figure 4(b), the proposed UWB BPF has an
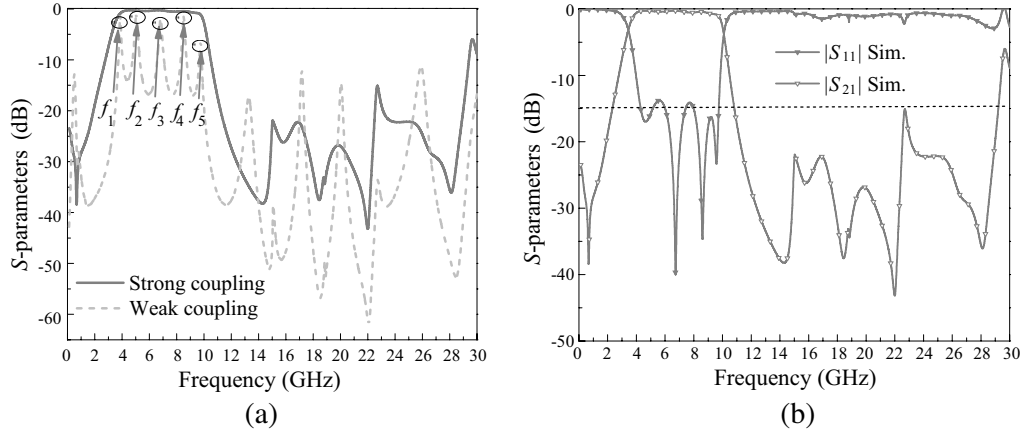
Figure 4. Simulated S-parameters of the proposed basic UWB BPF: (a) weak coupling, (b) strong coupling.
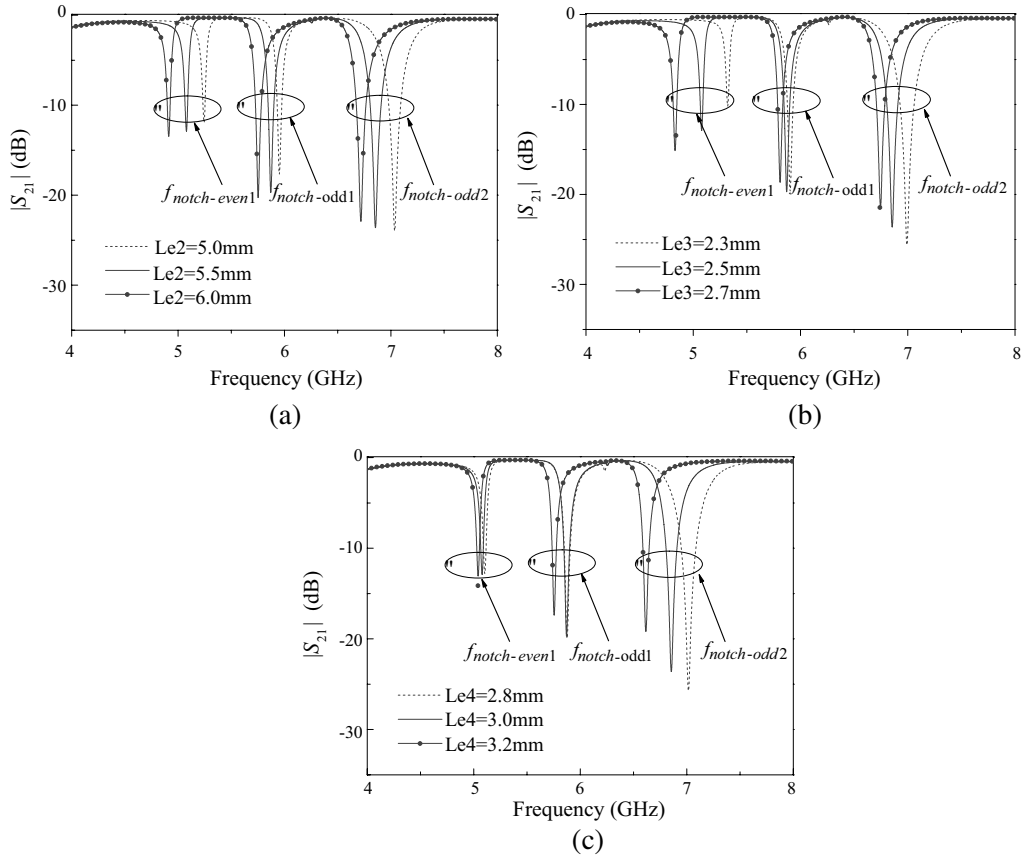
Figure 5. Simulated S-parameters of the new structure with various dimensions: (a) L_{e2}, (b) L_{e3}, (c) L_{e4}.

insertion loss better than $3\,\mathrm{dB}$ over the 3.4–$10.1\,\mathrm{GHz}$ bandwidth, and the upper-stopband with $-15\,\mathrm{dB}$ attenuation is up to $29.2\,\mathrm{GHz}$. In addition, the return loss is under $-20\,\mathrm{dB}$ over most part of the passband.

Then, a triple-mode stepped impedance resonator (TMSIR) is coupled to the two microstrip interdigital coupled lines of the basic UWB BPF to realize triple band-notched characteristics. The structure is simple and flexible for blocking unwanted narrow band radio signals that may appear in UWB band. The resonant frequencies of all notched bands simultaneously move down with increasing

L_{e2}. However, to achieve these notch bands at desired frequencies, $f_{notch\text{-}odd2}$ can be determined by varying the length of L_{e2}, then $f_{notch\text{-}even1}$ can be simply controlled by varying the length of L_{e3}. Finally, $f_{notch\text{-}odd1}$ can be simply controlled by varying the length of L_{e4}. Thus, by appropriately varying the TMSIR dimensions, three notched bands can be achieved at desired frequencies. The transfer characteristics of the proposed TMSIR with various dimensions are studied by HFSS 11.0, as shown in Figure 5. Thus, by appropriately varying the TMSIR dimensions, triple notched bands can be adjusted at desired frequencies.

4. EXPERIMENTAL RESULTS

The UWB BPF with triple notched bands and wide upper stopband has been designed on substrate Rogers RT/Duroid 5880 with a dielectric constant of 3.38, thickness of 0.508 mm, and loss tangent of 0.0027. The structural parameters for the optimal UWB filter circuit are selected as follows: (as illustrated in Figures 1 and 3) $L_1 = 7.8$ mm, $L_2 = 11.5$ mm, $W_0 = 1.1$ mm, $W_1 = 0.1$ mm, $W_2 = 0.9$ mm, $D_0 = 0.1$ mm, $D_1 = 2.1$ mm, $D_1 = 0.7$ mm, $L_{e1} = 6.5$ mm, $l_{e2} = 5.5$ mm, $L_{e3} = 2.8$ mm, $L_{e4} = 3.0$ mm, $W_{e1} = 0.4$ mm, $W_{e2} = 0.3$ mm, $W_{e3} = 0.4$ mm, $W_{e4} = 0.4$ mm, and $R = 0.1$ mm.

Finally, the fabricated UWB filter is measured with an Agilent N5244A vector network analyzer. Simulated and measured scattering parameters are described in Figure 6 with good agreement. Referring to Figure 6, the fabricated UWB filter has a passband from 3.0 to 10.3 GHz, and the upper-stopband with -15 dB attenuation is up to 30 GHz. The return loss is under -15 dB over most part of the passband. For the two highly rejected notched bands, the measured results show that a better 15 dB insertion loss at 5.2 GHz, 5.8 GHz, and 6.8 GHz with the respective 3 dB FBW of 2.0%, 2.7% and 3.8% are achieved. The measured group-delay result exhibits that the UWB BPF obtains a flat group delay response as shown Figure 7. The deviations of the measurements from the simulations are expected mainly due to the reflections from the connectors and the finite substrate. Figure 8 shows a photograph of the fabricated UWB BPF. The overall size is only about 16.5×10.6 mm^2. The comparison with other reported UWB BPFs is shown in Table 1 [11–23], which depicts that the proposed filter has good characteristics with compact size and wide upper stopband.
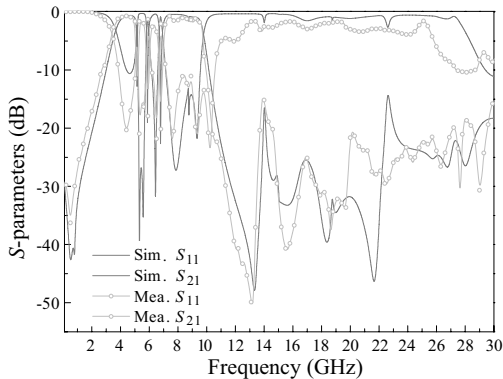
Figure 6. Simulated and measured S-parameters of the designed UWB BPF.
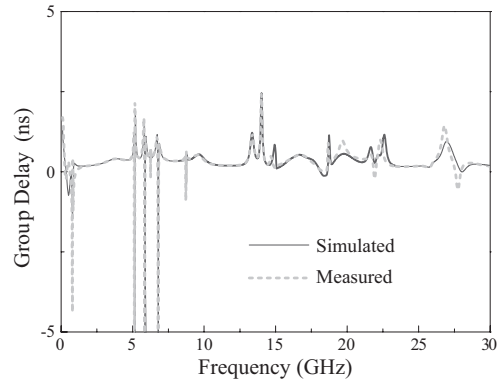
Figure 7. Simulated and measured group delay of the designed UWB BPF.
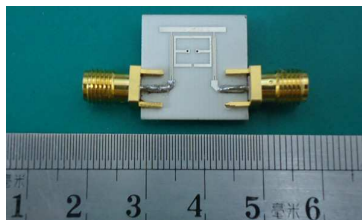
Figure 8. Photograph of the fabricated UWB filter.

Table 1. Comparisons with other proposed UWB BPFs with notched band.

Ref.	Circuit size (λg: at 6.85 GHz)	Circuit dimension	3 dB Passband (GHz)	Insertion loss (dB)	Notch frequency (GHz) /attenuation (dB)	Upper stopband (GHz)
[11]	0.76×0.76	2-D	$3.0 \sim 10.8$	0.5	$5.0/5.5 > 15$	15
[12]	0.55×0.35	2-D	$3.0 \sim 10.8$	0.4	$8.1 > 20$	17
[13]	0.81×0.17	2-D	$3.6 \sim 10.2$	0.6	$5.6 > 15$	26
[14]	0.91×0.75	2-D	$2.7 \sim 11.8$	0.5	$5.2 > 20$	20
[15]	0.65×0.55	3-D	$3.1 \sim 14$	1.5	$5.5/8.0 > 20$	25
[16]	1.16×0.68	2-D	$2.8 \sim 10.9$	1.0	$5.9/8.1 > 15$	14
[17]	1.03×0.34	2-D	$3.2 \sim 10.9$	0.4	$5.9/8.0 > 15$	14
[18]	1.18×0.26	3-D	$3.2 \sim 10.3$	1.0	$5.38/6.0 > 10$	18
[19]	1.36×0.32	3-D	$2.6 \sim 10.6$	0.75	$6.4/8.0$	18
[20]	2.29×0.69	2-D	$2.5 \sim 10.6$	2.0	$5.8/6.5/9.1 > 15$	12
[21]	1.27×0.28	3-D	$3.2 \sim 12.4$	1.2	$5.6/6.5/8.93 > 10$	16
[22]	1.16×0.68	2-D	$2.8 \sim 11.0$	1.0	$5.2/5.9/8.0 > 10$	20
[23]	1.03×0.38	2-D	$3.1 \sim 10.9$	0.8	$4.3/5.8/8.1 > 15$	15
This work	0.48×0.49	2-D	$3.4 \sim 10.1$	0.6	$5.2/5.8/6.8 > 15$	30

5. CONCLUSION

A novel compact UWB BPF has been proposed and designed. The prototype achieves a wide passband with triple sharply notched bands and wide upper stopband by properly tuning the parameters of the new structure. Good agreement between simulation and measurement results demonstrates the validity of the proposed method. Due to its simple topology, compact size, and excellent performance, the proposed filter is very attractive for use in future UWB wireless technologies.

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