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Compact Microstrip UWB Bandpass Filter with Quad Notched Bands Using Quad-Mode Stepped Impedance Resonator

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Abstract—A new microstrip ultra-wideband (UWB) bandpass filter (BPF) with quad notched bands using quad-mode stepped impedance resonator (QMSIR) is investigated in this paper. The resonance properties of the QMSIR are studied. Then, quad notched bands inside the UWB passband are implemented by coupling the proposed QMSIR to the main transmission line of a basic microstrip UWB BPF. The quad notched bands can be easily generated and set at any desired frequencies by varying the design parameters of QMSIR. For verification, a new microstrip UWB BPF with quad notched bands respectively centered at frequencies of 5.2 GHz, 5.8 GHz, 6.8 GHz and 8.0 GHz is designed and fabricated. Both simulated and experimental results are provided with good agreement.

1. INTRODUCTION

In February 2002, the U.S. Federal Communications Commission allocated the $3.1 \sim 10.6$ GHz band as unlicensed spectrum for ultra-wideband (UWB) systems [1]. UWB BPFs, as one of the essential components of UWB systems, have gained much attention in recent years. There are many techniques presented to design UWB bandpass filters. For example, multiple-mode resonator (MMR) [2, 3], multilayer coupled structure [4, 5], defected ground structure (DGS) [5, 6], defected microstrip structure (DMS) [7], and the cascaded low-pass/high-pass filters [8] have been widely used to achieve UWB characteristics.

However, existing wireless networks such as IEEE 802.16 WiMAX system operating at $3.3 \sim 3.6$ GHz, wireless local area network (WLAN) for IEEE802.11a operating at $5.15 \sim 5.35$ GHz/$5.725 \sim 5.825$ GHz, and $6.7 \sim 6.9$ GHz RF identification (RFID) communication signals, X-band ($7.9 \sim 8.2$ GHz) satellite communication systems (XSCS) signals can interfere with UWB systems. Therefore, a compact UWB BPF with multiple notched bands is urgently required to reject these interfering signals [9–15]. To achieve a notched band, one of the two arms in coupled-line sections is extended and folded in [9]. On the other hand, the coupling interdigital line is introduced to block undesired existing radio signals in [10]. However, these two methods can only achieve one notched band. Thus, to introduce dual notched bands, a coupled simplified composite right/left-handed resonator is introduced in [11], and two coupled stepped impedance resonators are employed in [12]. However, the selectivity designed with these two methods needs to be improved. By arranging two asymmetric meander open-loop resonators on the middle layer and a C-shaped resonator on the bottom layer [13] or embedding two open-circuit stubs into broadside-coupled stepped impedance resonators on the middle layer [14], dual notched bands can be introduced into a UWB BPF. Additionally, integrating short-circuited stub resonators [15] or embedding quarter-wavelength coplanar waveguide resonators and inserting a meander slot-line in the detached-mode resonator [16] can also realize dual notched bands. However, these designs are based on multilayer technology which will increase the fabrication cost. A new method based on wave's

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cancelation theory has been proposed to design a UWB BPF with dual notched bands in [17]. However, the center frequencies and bandwidths of the notched bands cannot be adjusted. Two tri-section stepped impedance resonators and a parallel gap-coupled microstrip resonator are used in [18], and two L-shaped folded shunt open-circuited stubs are placed on the feed lines in [19] to achieve triple notched bands. However, the performance of the filter is not ideal. Furthermore, design efficiencies of the filters mentioned above need to be improved.

In this paper, we present a new UWB BPF with quad notched bands using a quad-mode stepped impedance resonator (QMSIR). Firstly, the basic UWB filter is designed based on the previous works [20]. Then, quad notched bands inside the UWB passband are implemented by coupling the proposed QMSIR to the main transmission line of the basic microstrip UWB BPF. The quad notched bands can be easily generated and set at any desired frequencies by varying the design parameters of QMSIR. The design methodology is very efficient and useful for filter synthesis, and the design principle is simple. Moreover, the structure is compact, and the filter has good performance. Finally, the proposed filter is designed, fabricated and measured. Good agreement between measured and simulated results is achieved.

2. UWB BANDPASS FILTER DESIGN

Here, an initial microstrip UWB BPF is designed based on our previous works [20]. For the design, the best chromosome after 25 generations consists of four empty elements, five transmission lines, and four stubs. The proposed filter is realized on a substrate Duroid 4350B ($\varepsilon_r = 3.45$, $h = 0.508$). Table 1 lists the electrical and final physical parameters. The simulated scattering parameters are shown in Fig. 3. Referring to Fig. 1, the proposed UWB BPF has an insertion loss better than 3 dB over the $3.3 \sim 11.1$ GHz bandwidth, and the upper-stopband with -10 dB attenuation is up to 15 GHz. In addition, the return loss is under -15 dB over most part of the passband.

Table 1. Electrical and physical parameters of the basic UWB BPF.

No.	Name	Electrical Parameters (at $f_0 = 6.85$ GHz)				Physical Parameters in mm			
		z_{01}	θ_{01}	z_{02}	θ_{02}	W_{01}	L_{01}	W_{02}	L_{02}
1	Short	97.8	70.3	0	0	0.3	5.4	0	0
2	TL	52.2	47.8	0	0	1.1	3.5	0	0
3	Empty	0	0	0	0	0	0	0	0
4	TL	72.7	66.7	0	0	0.6	5	0	0
5	TL	67.3	71.0	0	0	0.7	5.3	0	0
6	Empty	0	0	0	0	0	0	0	0
7	SIR_Short	52.2	66.9	67.3	21.4	1.1	4.9	0.7	1.6
8	TL	58.6	74.3	0	0	0.9	5.5	0	0
9	Empty	0	0	0	0	0	0	0	0
10	Open	72.7	20.6	0	0	0.6	1.5	0	0
11	Empty	0	0	0	0	0	0	0	0
12	TL	72.9	37.3	0	0	0.6	2.8	0	0
13	SIR_Short	87.3	84.0	67.3	20.1	0.4	6.4	0.7	1.5

3. TRIPLE-MODE SIR ANALYSIS

To realize band-notched characteristics, we introduce a novel QMSIR into the initial UWB BPF. This structure is simple and flexible for blocking undesired narrow band radio signals that may appear in UWB band. Fig. 2 shows the geometry of the proposed QMSIR. It consists of two half-wavelength SIRs

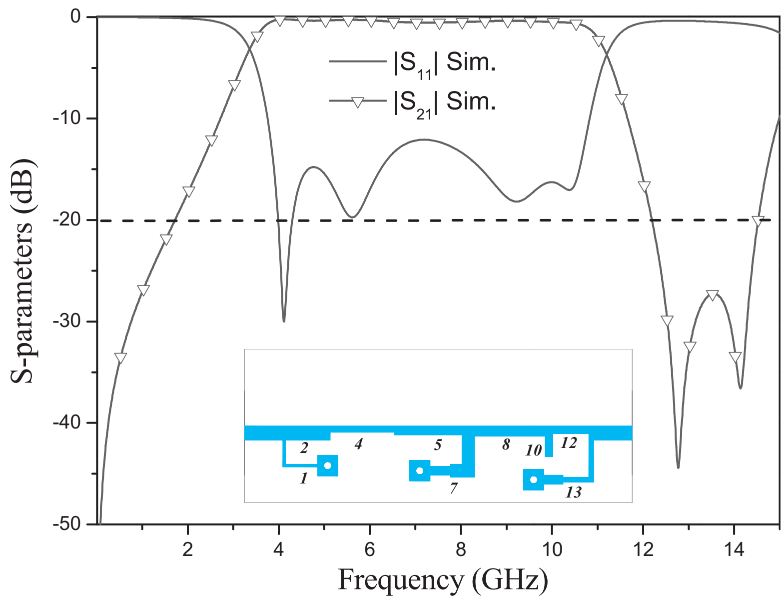

Figure 1. Simulated performance of proposed basic UWB BPF.

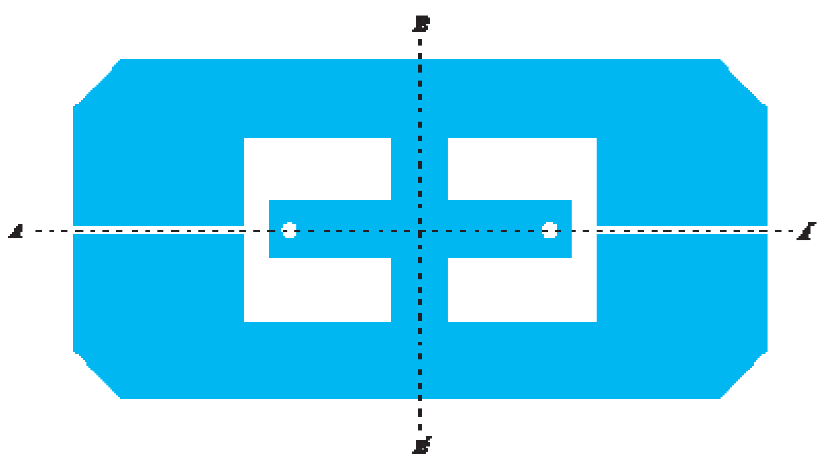

Figure 2. Geometry of the quad-mode stepped impedance resonator (SIR).

and two short-circuited stubs on its center plane. Since the resonator is symmetrical in the A-A' and B-B' planes, and the odd-even-mode method is implemented.

Figure 3 shows the simulated current distribution on the surface of the resonator at four frequencies: 5.2, 5.8, 6.8 and 8.0 GHz. The figure shows that the current is more sparsely distributed as it nears the areas marked in blue, while its distribution grows denser in the red areas. Maximum and minimum values are set to be equal in order to allow an accurate comparison among Figs. 3(a)–(d). Therefore, by appropriately adjusting the resonator dimensions, quad notched bands can be achieved at desired frequencies.

4. EXPERIMENTAL RESULTS

The designed UWB BPF is measured with an Agilent N5244A vector network analyzer. Fig. 4 shows the comparison between the simulated and measured results. It can be seen that the fabricated UWB BPF has a passband from 3.2 $\sim$ 11.1 GHz as we expected. Three notched bands with respective 3 dB FBWs

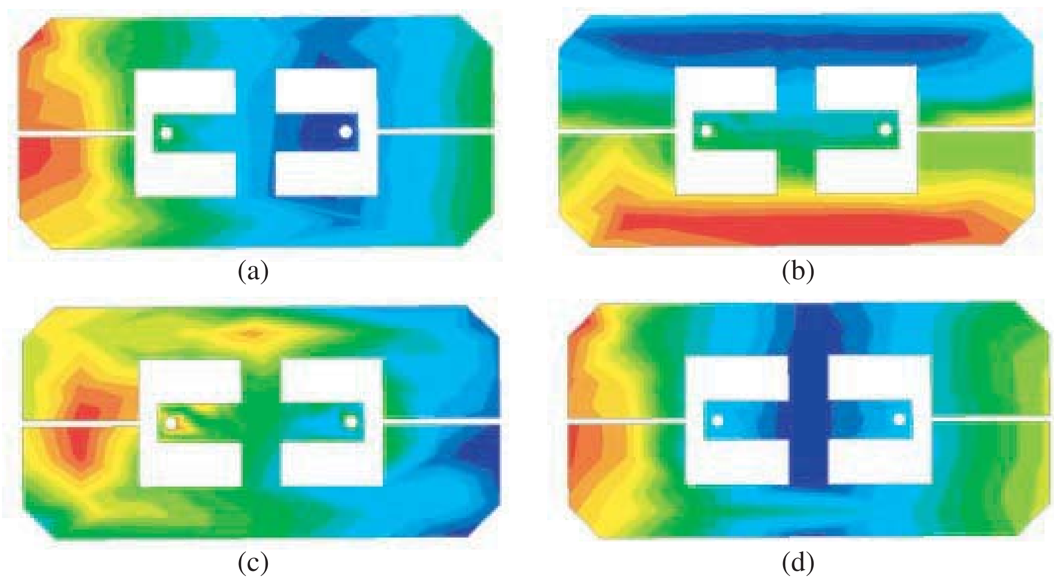

Figure 3. Simulated current distribution of the proposed structure at the four resonant frequencies. (a) 5.2 GHz, (b) 5.8 GHz, (c) 6.8 GHz, (d) 8.0 GHz.

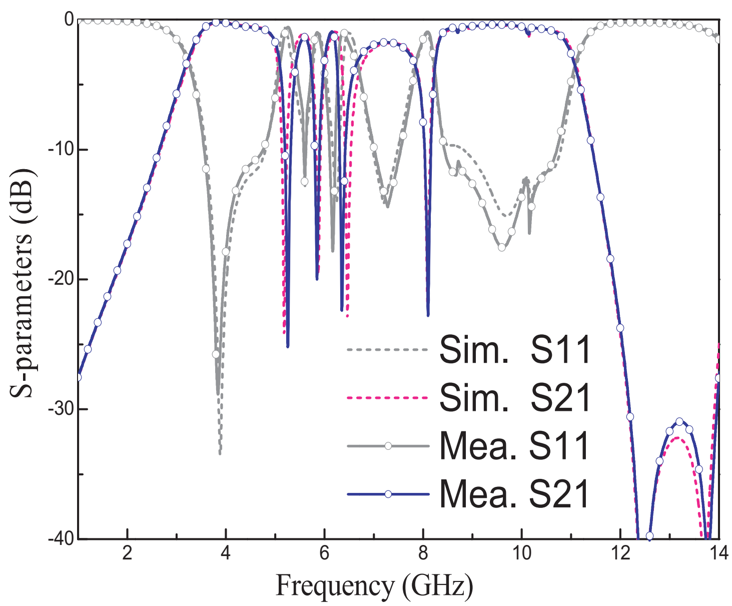

Figure 4. Simulated and measured S-parameters of the designed UWB BPF.

of 4.0%, 3.8%, 4.2%, and 4.4% are achieved, which ensure a high selectivity for the designed UWB filter. Inside each notched band, the attenuation is better than −10 dB at the center frequencies of 5.2, 5.8, 6.8, and 8.0 GHz. The minor discrepancy between simulation and measurement results is mainly due to the reflections from the SMA connectors and the finite substrate. Fig. 5 shows a photograph of the fabricated UWB BPF. Comparisons with other reported UWB BPFs with notched bands are listed in Table 2. It shows that the proposed filter has good performance.

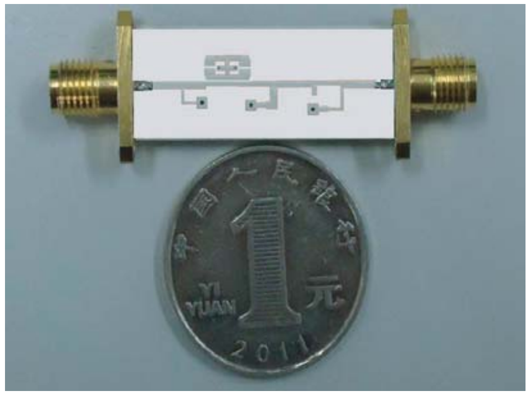

Figure 5. Photograph of the fabricated UWB BPF with quad-notched bands.

Table 2. Comparisons with other proposed UWB BPF with notched band.

Ref.	Circuit size (λ_g: at 6.85 GHz)	Circuit dimension	Pass band (GHz)	Insertion loss (dB)	Notch frequency (GHz) /attenuation (dB)	Upper stop-band (GHz)
[9]	0.81×0.17	2-D	$3.6 \sim 10.2$	0.6	$5.59 > 15$	26
[10]	0.81×0.10	2-D	$3.1 \sim 10.6$	1.0	$5.75 > 20$	12
[11]	1.16×0.68	2-D	$2.8 \sim 10.9$	1.0	$5.85/8.05 > 15$	14
[12]	0.98×0.63	2-D	$3.1 \sim 11.0$	1.0	$5.2/5.8 > 15$	12
[13]	0.53×0.51	3-D	$2.6 \sim 9.6$	1.5	$3.5/5.8 > 15$	11
[14]	1.18×0.26	3-D	$3.2 \sim 10.3$	1.0	$5.38/6.0 > 10$	18
[15]	0.36×0.46	3-D	$2.8 \sim 10$	0.6	$5.23/5.81 > 20$	15
[16]	0.95×0.7	3-D	$4.5 \sim 10.7$	1.5	$5.47/6.05 > 20$	18
[17]	0.88×0.19	2-D	$3.2 \sim 12.0$	1.0	$6.55/8.62 > 20 > 20$	15
[18]	1.27×0.28	2-D	$3.2 \sim 12.4$	1.2	$5.63/6.47/8.93$	16
[19]	2.29×0.69	2-D	$2.5 \sim 10.6$	2.0	$5.57/6.49/9.05 > 15$	12
Our work	1.03×0.38	2-D	$3.1 \sim 10.9$	1.6	$5.2/5.8/6.8/8.0 > 10$	20

5. CONCLUSION

A new microstrip UWB BPF with four highly rejected notched bands has been proposed and designed in this paper. The performance of quad-notched bands is easily generated and realized by controlling the resonance properties of the QMSIR. Good agreement between simulation and measurement results validates the introduced design method. The proposed filter is very useful for modern UWB wireless communication systems due to its distinct properties of simple topology, compact size, and good performance.

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