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A New Compact UWB Bandpass Filter with Quad Notched Characteristics

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Abstract—A new approach to design a microstrip ultra-wideband (UWB) bandpass filter (BPF) with quad sharply notched bands and good selectivity is proposed using quad parallel defected microstrip structures (PDMSs). The initial UWB BPF comprises interdigital coupled lines and an E-shaped multiple-mode resonator (EMMR) to achieve two transmission zeros on both sides of the passband thus to improve skirt selectivity. Then, four PDMSs are introduced, which have the properties of achieving four band-notched characteristics and provide high degree of adjusting freedom. To validate the design theory, a new microstrip UWB BPF with four notched bands respectively centered at 5.3, 5.9, 6.4, and 7.4 GHz is designed and fabricated. Both simulated and experimental results are provided with good agreement. The designed methodology is very efficient and useful for filter synthesis though the design principle is simple.

1. INTRODUCTION

In February 2002, the U.S. Federal Communications Commission allocated 3.1–10.6 GHz band as unlicensed spectrum for ultra-wideband (UWB) systems. UWB bandpass filters (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 BPFs [1–5]. For example, multiple-mode resonator (MMR) [1, 2], cascaded low-pass/high-pass filters [3], and multilayer coupled structure [4, 5] have been widely employed to achieve UWB characteristics.

However, the existing wireless networks like WLAN (i.e., 5.2 and 5.8 GHz bands), C-band phased array radar (i.e., 6.4 GHz bands), and satellite communication (i.e., 8.0 GHz bands) signals can interfere with UWB networks, thus compact UWB BPFs with multiple notched bands are emergently required to reject these interfering signals [6–10]. In [6], a pair of asymmetric loading stubs is introduced to block undesired radio signals, but only one notched band is achieved. In [7], a novel asymmetric coupling strip is used to generate dual notched bands, but the out-of-band harmonic suppression of the proposed UWB BPF needs to be improved. In [8, 9], a coupled triple-mode stub loaded resonator is employed to obtain three notched bands; however, the proposed UWB BPF has a relatively low selectivity, and the rejection level in notch bands is not ideal. In [10], a compact UWB bandpass filter with triple notched bands is designed using defected microstrip structure, but the proposed UWB BPF has only three notched bands.

In this communication, a new approach to design a UWB bandpass filter (BPF) with quad sharply notched bands and good selectivity using quad parallel defected microstrip structures (PDMSs) is proposed based on the previous works [9, 10]. An E-shaped multiple-mode resonator (EMMR) is utilized to realize an initial UWB BPF with a pair of transmission zeros appearing in the lower and upper stopbands to improve skirt selectivity. Then, four PDMSs are etched into the EMMR to obtain quad

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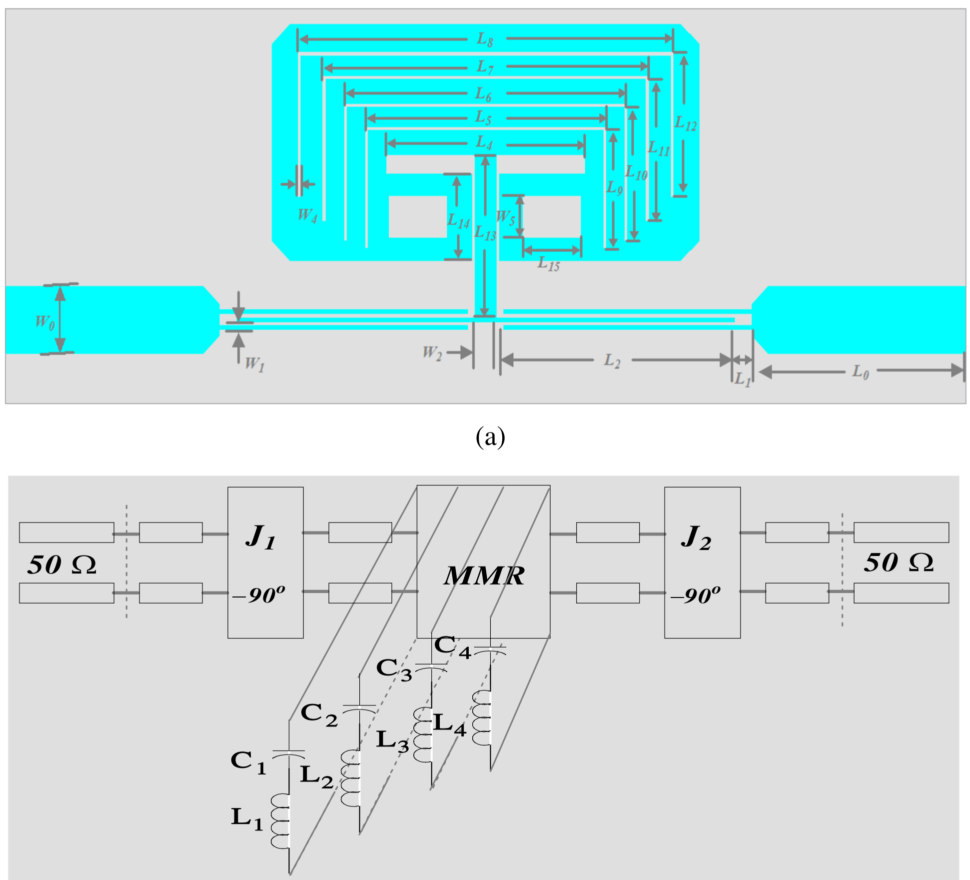
sharply notched bands with high degree of adjusting freedom. Finally, both simulation and measurement results are provided to verify the design method. Good agreement between measured and simulated results is achieved. The designed methodology is very efficient and useful for filter synthesis though the design principle is simple. Moreover, the structure is compact, and the filter has good performance.

2. CIRCUIT DESIGN

Figure 1 shows the layout and equivalent circuit network of the designed UWB BPF. It comprises interdigital coupled lines and an E-shaped multiple-mode resonator with four parallel defected microstrip structures embedded. The equivalent circuit network of the proposed filter is shown in Fig. 1(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 QPDMSs embedded into the middle section of the EMMR can be modeled as four shunt series resonant branches.



(a)

(b)

Figure 1. Layout and equivalent circuit network of the proposed UWB BPF with quad sharply notched bands. (a) Layout of the UWB BPF. (b) Equivalent circuit network.

The designed central frequency of the notch-band can be achieved by adjusting the length of PDMS which is about half wavelength at the desired frequency. That is to say, each PDMS is a half-wavelength resonator. The resonant frequency can be expressed as:

$$f_{\text{notch\_1}} = \frac{c}{2\left(L_8 + 2L_{12}\right)\sqrt{\varepsilon_{eff}}} \tag{1}$$

$$f_{\text{notch\_2}} = \frac{c}{2\left(L_7 + 2L_{11}\right)\sqrt{\varepsilon_{eff}}} \tag{2}$$

$$f_{\text{notch\_3}} = \frac{c}{2\left(L_6 + 2L_{10}\right)\sqrt{\varepsilon_{eff}}} \tag{3}$$

$$f_{\text{notch\_4}} = \frac{c}{2\left(L_5 + 2L_9\right)\sqrt{\varepsilon_{eff}}} \tag{4}$$

where ε_{eff} is the effective dielectric constant, and c is the light speed in free space. The frequency characteristics of PDMSs with various dimensions are simulated by HFSS 13.0 to validate the resonant properties, as shown in Fig. 2. It can be found that by respectively varying each PDMS dimension, the frequency location of corresponding notched band can be widely adjusted, while the other three frequency locations of the notched bands keep almost unchanged. Therefore, four notched bands can be independently achieved at desired frequencies.

The UWB BPF has been designed on substrate RT/Duroid 5880 with a dielectric constant of 3.38, thickness of 0.813 mm, and loss tangent of 0.0027. The structural parameters for the UWB filter circuit

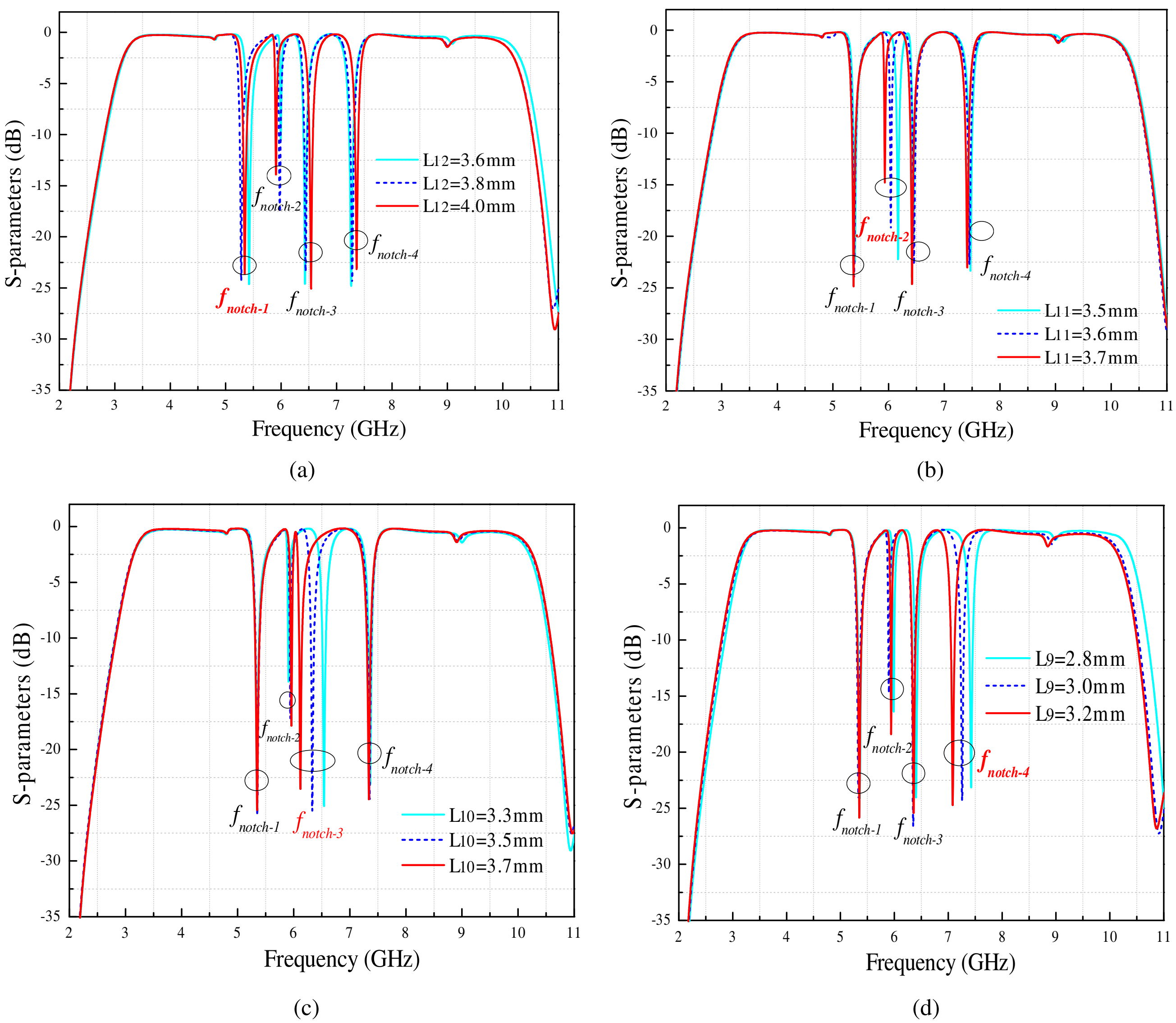


Figure 2. Simulated S-parameters of the QPDMSs for various dimensions: (a) L_{12}, (b) L_{11}, (c) L_{10}, (d) L_9.

are (as illustrated in Fig. 1): $L_0 = 7.0\,\text{mm}$, $L_1 = 0.5\,\text{mm}$, $L_2 = 6.5\,\text{mm}$, $L_4 = 5.6\,\text{mm}$, $L_5 = 6.8\,\text{mm}$, $L_6 = 8.0\,\text{mm}$, $L_7 = 9.2\,\text{mm}$, $L_8 = 10.6\,\text{mm}$, $L_9 = 3.1\,\text{mm}$, $L_{10} = 3.5\,\text{mm}$, $L_{11} = 3.7\,\text{mm}$, $L_{12} = 3.7\,\text{mm}$, $L_{13} = 4.2\,\text{mm}$, $L_{14} = 2.2\,\text{mm}$, $L_{15} = 1.4\,\text{mm}$, $W_0 = 1.7\,\text{mm}$, $W_1 = 0.1\,\text{mm}$, $W_2 = 0.6\,\text{mm}$, $W_4 = 0.1\,\text{mm}$, $W_4 = 1.0\,\text{mm}$. Fig. 3 shows a photograph of the fabricated UWB BPF with quad sharply notched bands. The overall size is only $27 \times 12\,\text{mm}^2$.

Finally, the fabricated UWB BPF is measured with an Agilent N5244A vector network analyzer. Simulated and measured scattering parameters are described in Fig. 4 with good agreement. Referring to Fig. 4, the fabricated UWB BPF has a passband from 3.1 to 10.4 GHz, and the upper-stopband with −10 dB attenuation is up to 17.0 GHz. The return loss is under −20 dB over most part of the passband. Four notched bands with insertion losses over 15 dB at 5.3, 5.9, 6.4, and 7.4 GHz are achieved. For the four sharply notched bands, the measured 3 dB fractional bandwidths (FBWs) are 3.8% at 5.3 GHz, 1.7% at 5.9 GHz, 3.1% at 6.4 GHz, and 2.7% at 7.4 GHz, respectively. The deviations of the measurements from the simulations are attributed to the fabrication tolerance as well as SMA connectors. Fig. 5 shows the measured group delay of the designed UWB BPF with quad notched bands. Comparisons with other reported UWB BPFs are listed in Table 1. It shows that our proposed UWB filter has good performance.

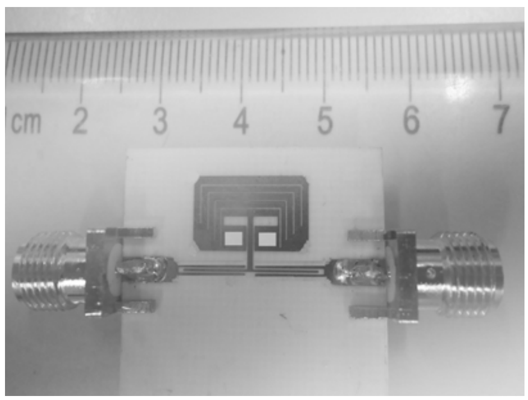


Figure 3. Photograph of the proposed UWB BPF with quad notched bands.

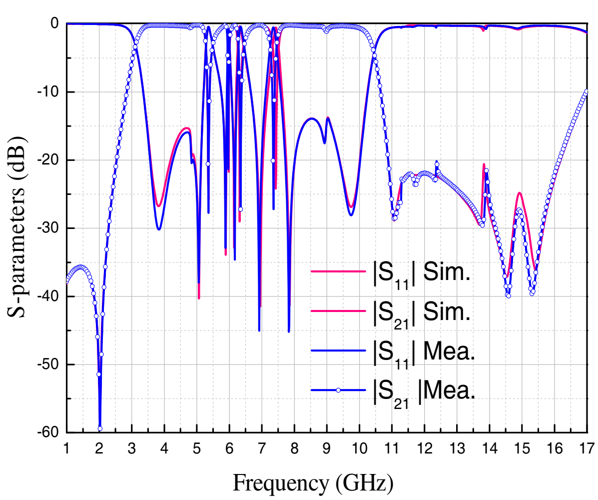


Figure 4. Simulated and measured S-parameters of the designed UWB BPF with quad notched bands.

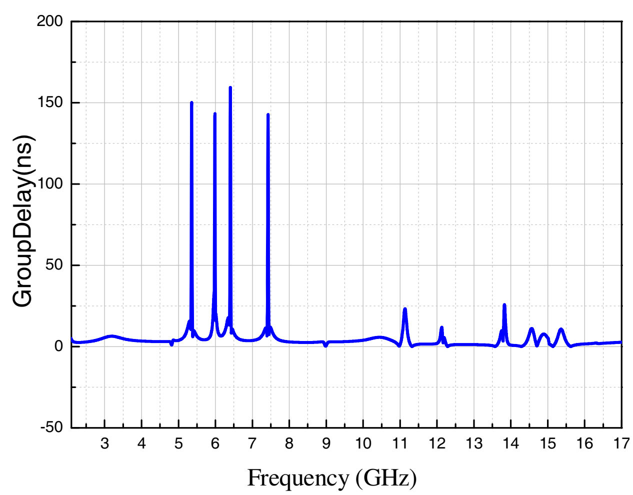


Figure 5. Measured group delay of the designed UWB BPF with quad notched bands.

Table 1. Comparisons with other reported UWB BPFs with notched bands.

Ref.	Circuit Size (λ_g: at 6.85 GHz)	Roll-off Rate (dB/GHz)	Notch Frequency (GHz)/ Attenuation (dB)	Stop-band (GHz)
[4]	1.10×0.34	10	$5.2/5.8 > 10$	14
[6]	0.98×0.11	9	6.6/20	13
[7]	0.80×0.09	18	4.3/8.0/20	14
[8]	1.05×0.67	16	$3.6/5.9/8.0 > 10$	20
[9]	1.03×0.38	14	$4.5/5.9/8.0 > 10$	15
[10]	0.63×0.36	34	$5.2/5.8/8.0 > 15$	17
This work	0.61×0.34	40	$5.3/5.9/6.4/7.4 > 15$	17

*Roll-off Rate is defined as $|\alpha_{\max} - \alpha_{\min}|/|f_s - f_c|$, where $\alpha_{\max}$ is the 25 dB attenuation point and $\alpha_{\min}$ is the 3 dB attenuation point; f_s is the 25 dB stopband frequency and f_c is the 3 dB cutoff frequency. Roll-off Rate for reported ones is estimated from the figures in papers.

3. CONCLUSION

A new approach to design compact UWB BPF has been proposed. The prototype can provide quad band-notched characteristics and a pair of transmission zeros on both sides of the UWB passband to improve the filter selectivity. The quad sharply notched bands with high degree of adjusting freedom are introduced to reject undesired interfered signals. Good agreement between simulation and measurement results demonstrates the validity of the method. The proposed filter is very useful for modern UWB wireless communication systems due to its simple topology, compact size, and excellent performance.

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