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A New Compact Microstrip UWB Bandpass Filter with Triple-Notched Bands and Good Stopband Performance

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Abstract—A new compact ultra-wideband (UWB) bandpass filter (BPF) with triple sharply notched bands and good stopband performance has been studied and implemented using a triple-mode stepped impedance resonator (TMSIR). The proposed TMSIR is found to have the advantages of introducing triple-notched bands and providing a higher degree of freedom to adjust the resonant frequencies. To validate the design theory, a new microstrip UWB BPF with three notched bands respectively centered at 5.2 GHz, 6.8 GHz, and 9.2 GHz is designed and fabricated. The simulated and experimental results are provided with good agreement.

1. INTRODUCTION

The Federal Communication Commission (FCC) in USA released the unlicensed use of ultra-wideband (UWB: 3.1 to 10.6 GHz) frequency spectrum for indoor and hand-held wireless communications in 2002 [1]. UWB bandpass filters (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], multilayer coupled structure [6, 7], and the cascaded low-pass/high-pass filters [8, 9] have been widely used to achieve UWB characteristics.

However, the signals from the existing wireless networks such as 3.5 GHz WiMAX signals, 6.8 GHz RFID signals, and some 9.2 GHz X-band satellite communication systems (XSCS) signals can easily interfere with UWB users, so the compact UWB BPF with multiple notched bands is emergently required to reject these interfering signals [10–16]. To achieve a notched band, one of the two arms in the coupled-line sections is largely extended and folded [10], or a coupling interdigital finger is added [11] to block undesired existing radio signals. However, they have achieved only one notched band. A coupled simplified composite right/left-handed (SCRLH) resonator is used [12], or two coupled stepped impedance resonators (SIRs) are employed [13] to introduce dual notched bands. However, they have a relatively low selectivity. Two asymmetric meander open-loop resonators on the middle layer and a C-shaped resonator on the bottom layer are employed [14] or two embedding open-circuit stubs into broadside-coupled SIRs on the middle layer using multilayer liquid crystal polymer technology [15] to achieve dual notched bands. However, these are based on a multilayer structure and hardly compatible with the existing microwave-integrated circuits. Additionally, another UWB BPF with dual notched bands based on wave cancellation theory has been proposed in [16]. However, the center frequencies of the notched bands cannot be easily controlled.

In this communication, a new compact UWB BPF with triple sharply notched bands and good stopband performance is studied and implemented using a triple-mode stepped impedance resonator (TMSIR). Firstly, the basic microstrip UWB BPF with a wide effective stopband is designed using two microstrip interdigital coupled lines and one multiple-mode resonator (MMR). Secondly, the properties

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of the proposed TMSIR are analyzed theoretically. The TMSIR has three resonance frequencies and higher degree of adjusting freedom. The analyzed results reveal that triple band-stop performance can be obtained based on the triple-mode resonant property of the TMSIR. Thirdly, the triple notched-bands characteristic is achieved by putting the TMSIR near the MMR of the basic UWB BPF. The triple-notched bands can be easily generated and realized by controlling the locations of even-odd modes resonance frequencies of the TMSIR structure. Finally, to validate the design concept, a novel compact UWB BPF with triple sharply rejected notched bands respectively centered at frequencies of 5.2 GHz, 6.8 GHz and 9.2 GHz is designed and measured. The simulation and measurement show that the UWB BPF achieves an ultra-wide bandwidth ranging from 3.3 GHz to 10.4 GHz and avoids the WLAN/RFID/XSCS interference.

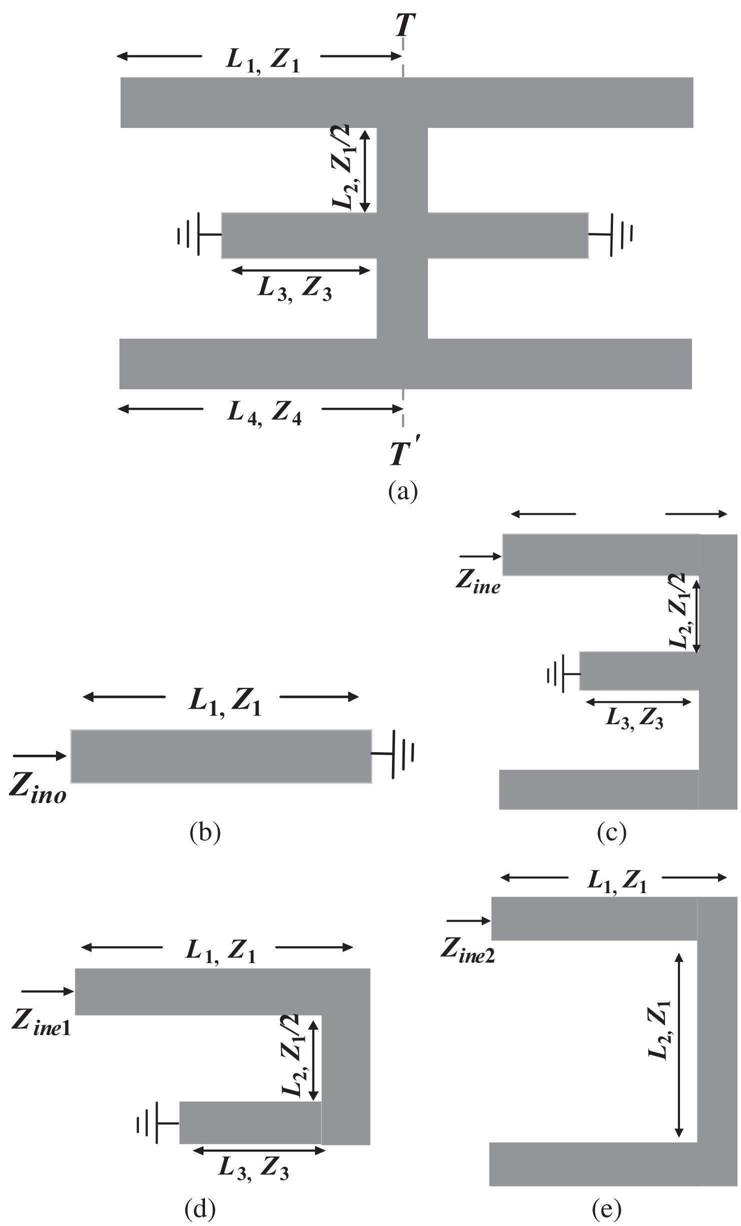


Figure 1. (a) Configuration of the proposed new TMSIR, (b) odd-mode equivalent circuit, (c) even-mode equivalent circuit, (d) path I of even-mode equivalent circuit, (e) path II of even-mode equivalent circuit.

2. TRIPLE-MODE STEPPED IMPEDANCE RESONATOR UNIT ANALYSIS

Figure 1(a) shows the geometry of the proposed TMSIR. It consists of two half-wavelength SIRs and two short-circuited stubs on its center plane. Since the resonator is symmetrical to the T-T' plane, the odd-even-mode method is implemented. For odd-mode excitation, the equivalent circuit is one quarter-wavelength resonator with one end grounded, as shown in Fig. 1(b). From the resonance condition of $Y_{ino} = 0$, the odd-mode resonant frequency can be deduced as:

$$f_{\text{ino}} = \frac{c}{4L_1\sqrt{\varepsilon_{\text{eff}}}} \tag{1}$$

where f_{ino} is the center frequency of the notch band, ε_{eff} the effective dielectric constant, and c the light speed in free space.

For even-mode excitation, the equivalent circuit is shown in Fig. 1(c), which contains two resonant circuits: a quarter-wave-length resonator and a half-wavelength resonator, as shown in Figs. 1(d) and (e). The even-mode resonant frequencies can be determined as follows:

$$f_{\text{ine1}} = \frac{c}{4(L_1 + L_2 + L_3)\sqrt{\varepsilon_{\text{eff}}}} \tag{2}$$

$$f_{\text{ine2}} = \frac{c}{(2L_1 + 2L_2 + 2L_4)\sqrt{\varepsilon_{\text{eff}}}} \tag{3}$$

where $Z_1 = Z_3 = Z_4$ is assumed for simplicity. The resonance frequencies can be determined by the electrical length. Moreover, the proposed structure can provide three resonant frequencies and a higher degree of freedom in adjusting the locations of the resonant modes.

The proposed TMSIR can result in triple band-stop performance when being placed next to the microstrip line, and it can be equivalent to three shunt-connected series resonance circuits, as shown

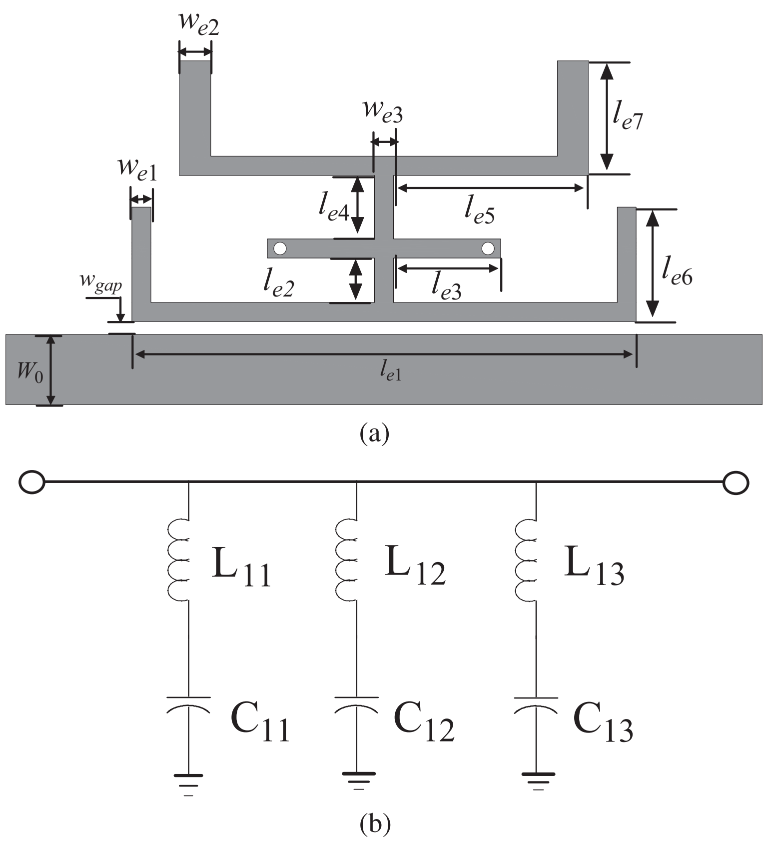


Figure 2. Geometry and equivalent circuit of the proposed coupled TMSIR.

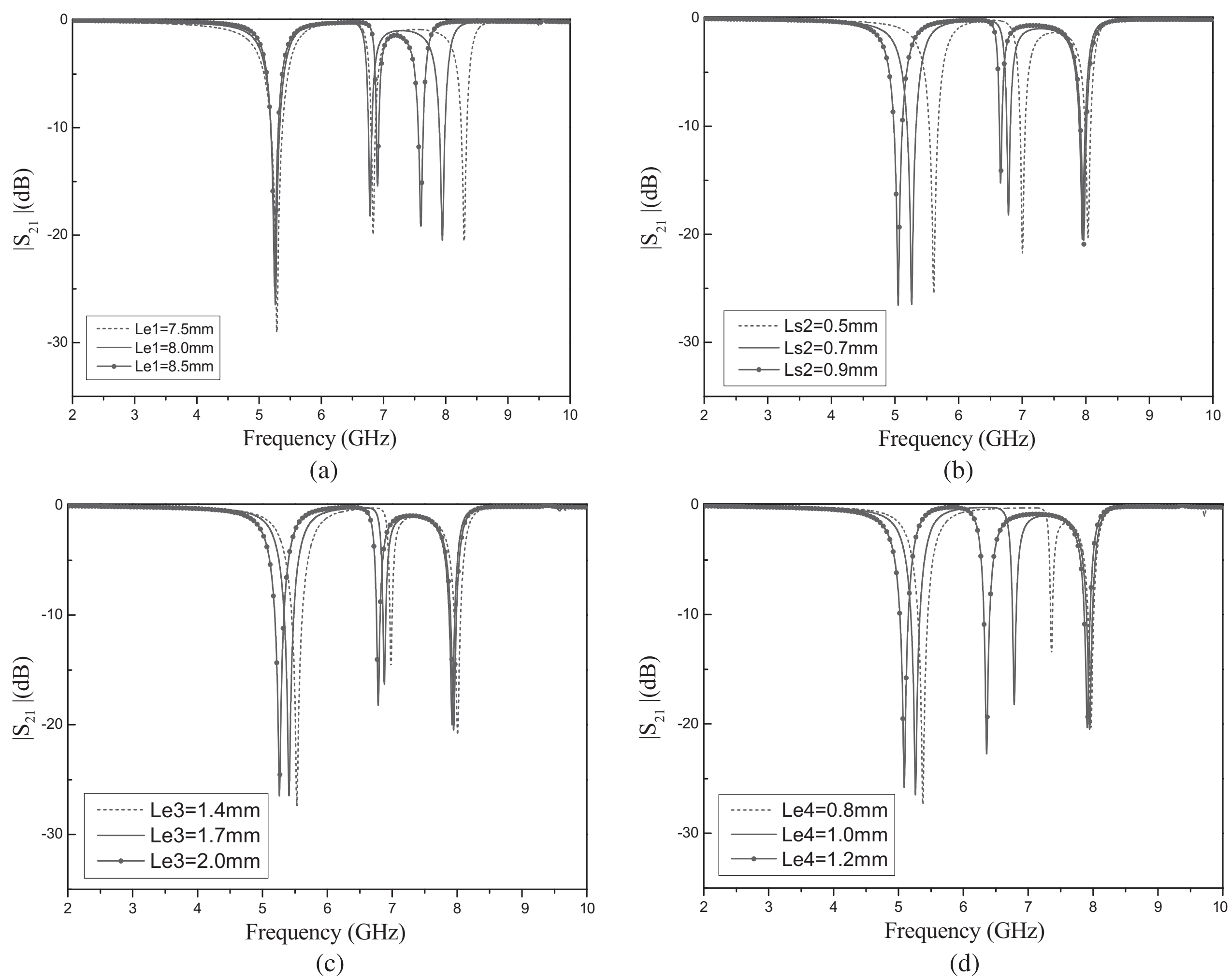
in Fig. 2. In this paper, the TMSIR dimensions are selected as follows: $w_{e1} = 0.3\,\text{mm}$, $w_{e2} = 0.5\,\text{mm}$, $w_{e3} = 0.3\,\text{mm}$, $l_{e1} = 8.0\,\text{mm}$, $l_{e2} = 0.7\,\text{mm}$, $l_{e3} = 1.7\,\text{mm}$, $l_{e4} = 1.0\,\text{mm}$, $l_{e5} = 3.4\,\text{mm}$, $l_{e6} = 1.3\,\text{mm}$, $l_{e6} = 1.5\,\text{mm}$, $r_e = 0.1\,\text{mm}$.

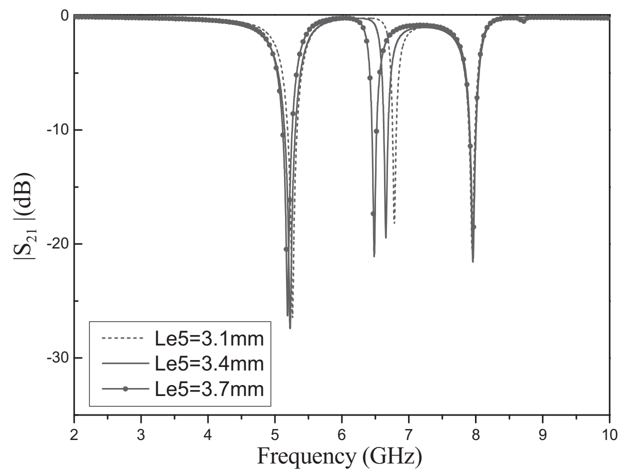
The frequency characteristics of the coupled TMSIR with various dimensions are investigated by HFSS 11.0 to validate the multi-mode resonant property as shown in Fig. 3. It can be seen that the frequency locations of the first and second notched bands move down simultaneously as the dimensions of $le2$ and $le4$ are increased. And the frequency locations of the second and third notched bands move down simultaneously as the dimensions of $le1$ are increased. However, only the first notched band increases as $le3$ is decreased, and the second notched band increases as $le5$ is decreased. Therefore, by appropriately adjusting the resonator dimensions, triple notched bands can be achieved at desired frequencies.

In addition, the bandwidth of the notched band can be controlled by tuning the coupling coefficient k_m of the coupled TMSIR. It should be mentioned that the coupling coefficient k_m is defined by:

$$k_m = \frac{f^2_{\text{notch-ino}} - f^2_{\text{notch-ine1}}}{f^2_{\text{notch-ino}} + f^2_{\text{notch-ine1}}} \tag{4}$$

Referring to Fig. 4, the coupling coefficient k_m decreases as W_{gap} is increased. In this paper, the coupling coefficient is selected as $k_m = 0.442$.





(e)

Figure 3. Simulated S-parameters of the coupled TMSIR for various dimensions: (a) $le1$, (b) $le2$, (c) $le3$, (d) $le4$, (e) $le5$.

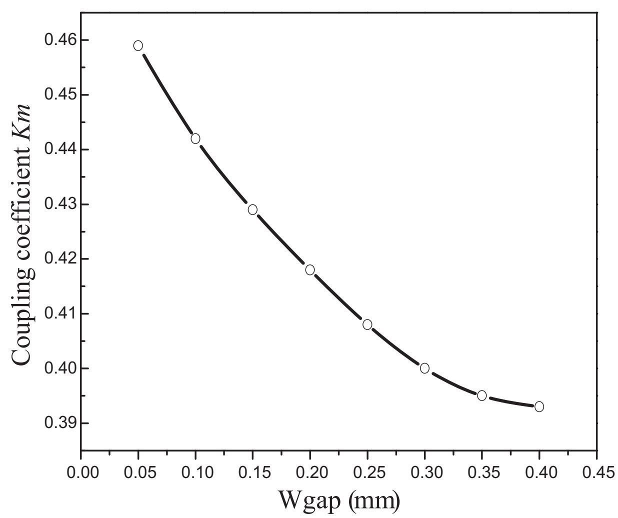


Figure 4. Simulated coupling coefficient k_m of the coupled TMSIR with different W_{gap}.

3. UWB BPF WITH NOTCHED-BANDS DESIGN

Figures 5(a) and 5(b) illustrate the schematic and equivalent transmission line model, respectively. Fig. 5(a) comprises one multiple-mode resonator and two interdigital coupled lines coupled to a TMSIR. Herein, the two microstrip interdigital coupled lines are formed to provide sufficiently strong coupling in the desired UWB. The equivalent circuit network of the proposed filter is shown in Fig. 5(b). The interdigital coupled lines can be considered 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.

As a starting part of this work, a basic microstrip UWB BPF is designed. The simulated scattering parameters are shown in Fig. 6. Referring to Fig. 6, the proposed UWB BPF has an insertion loss less than 3 dB over the 3.3–10.4 GHz bandwidth, and a stopband with −15 dB attenuation up to 29.4 GHz. In addition, the return loss is under 15 dB over most part of the passband.

Then, by coupling a TMSIR to the interdigital coupled lines of the basic UWB BPF, triple band-notched characteristics are realized. The structure is simple and flexible for blocking unwanted narrow band radio signals that may appear in UWB.

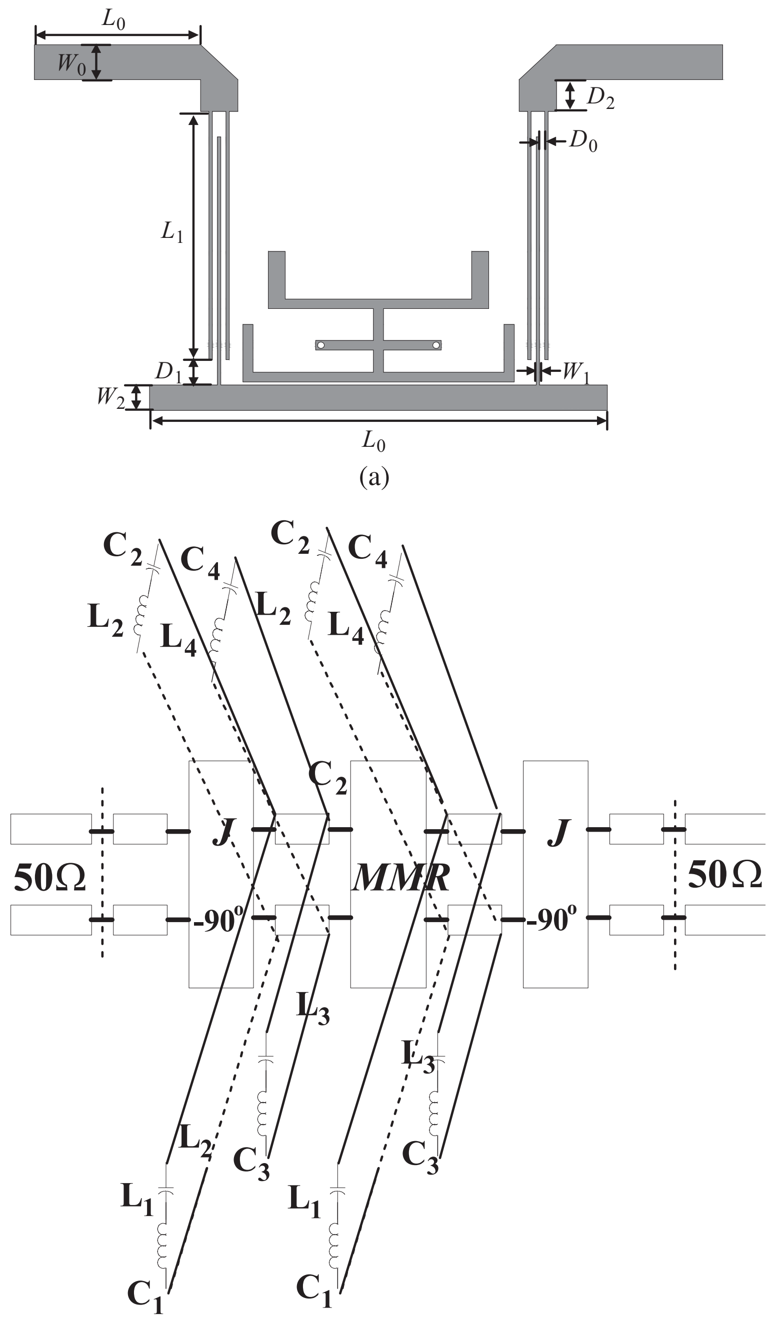


Figure 5. Schematic layout and equivalent circuit network of the presented UWB BPF with triple-notched bands: (a) schematic layout, (b) equivalent transmission line network.

4. EXPERIMENTAL RESULTS

The UWB BPF with triple notched bands and a wide effective 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 0.003. The structural parameters for the optimal UWB filter circuit are selected as follows: (as illustrated in Figs. 2 and 4) $l_1 = 7.8$ 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, $d_2 = 0.7$ mm, $l_{e1} = 8.5$ mm, $l_{e2} = 0.6$ mm, $l_{e3} = 1.8$ mm, $l_{e4} = 1.1$ mm, $l_{e5} = 3.6$ mm, $l_{e6} = 1.2$ mm, $l_{e6} = 1.4$ mm, $w_{e1} = 0.3$ mm, $w_{e2} = 0.5$ mm,$w_{e3} = 0.3$ mm.

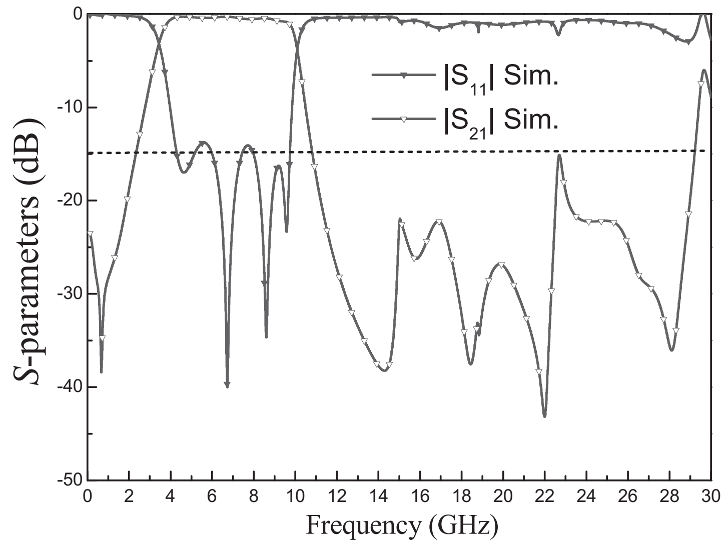


Figure 6. Simulated S-parameters of the proposed basic UWB BPF.

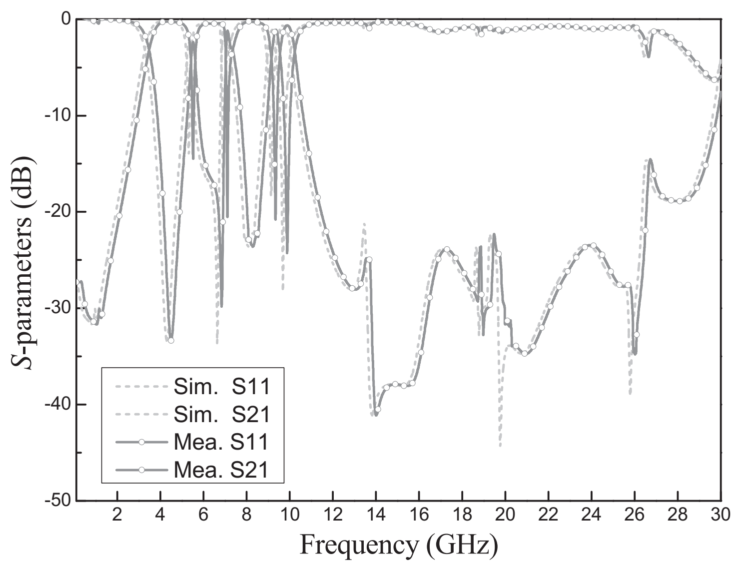


Figure 7. Simulated and measured S-parameters of the designed UWB BPF.

Finally, the fabricated UWB filter is measured with an Agilent N5244A vector network analyzer. Simulated and measured scattering parameters are described in Fig. 7 with good agreement. Referring to Fig. 7, the designed UWB filter has a passband from 3.3 to 10.4 GHz and a stopband with -15 dB attenuation up to 30 GHz. The return loss is under -15 dB over most part of the passband. For the three highly rejected notched bands, the measured results show that a better 15 dB insertion loss at 5.2 GHz, 6.8 GHz, and 9.2 GHz with the respective 3 dB FBW of 1.5%, 2.0% and 2.6% is achieved. The deviations of the measurements from the simulations are expected mainly due to the reflections from the connectors and the finite substrate. Fig. 8 shows a photograph of the fabricated UWB BPF. The overall size is only about $16.0 \times 10.0\,\mathrm{mm}^2$. The comparison with other reported UWB BPFs is shown in Table 1 [10–16], which depicts that the proposed filter has good characteristics with compact size and wide effective stopband.

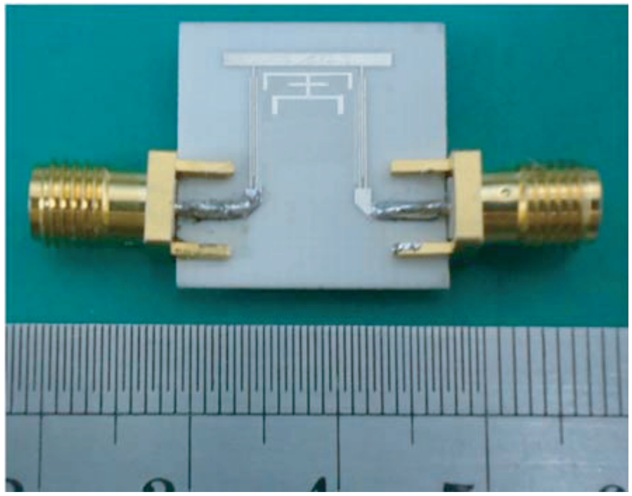


Figure 8. Photograph of the fabricated UWB filter.

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

Ref.	Circuit size (λg: at 6.85 GHz)	Circuit dimension	Pass band (GHz)	Insertion loss (dB)	Notch frequency(GHz)/ attenuation (dB)	Good stop-band (GHz)
[10]	0.81×0.17	2-D	$3.6 \sim 10.2$	0.6	$5.59 > 15$	26
[11]	0.81×0.10	2-D	$3.1 \sim 10.6$	1.0	$5.75 > 20$	12
[12]	1.16×0.68	2-D	$2.8 \sim 10.9$	1.0	$5.85/8.05 > 15$	14
[13]	0.98×0.63	2-D	$3.1 \sim 11.0$	1.0	$5.2/5.8 > 15$	12
[14]	0.53×0.51	3-D	$2.6 \sim 9.6$	1.5	$3.5/5.8 > 15$	11
[15]	1.18×0.26	3-D	$3.2 \sim 10.3$	1.0	$5.38/6.0 > 10$	18
[16]	0.88×0.19	2-D	$3.2 \sim 12.0$	1.0	$6.55/8.62 > 20$	15
Our work	0.48×0.49	2-D	$3.3 \sim 10.4$	0.6	$5.2/6.8/9.2 > 15$	30

5. CONCLUSION

A new compact high-performance UWB BPF has been implemented and investigated. The prototype achieves a wide passband with triple sharply notched bands and good stopband performance by properly adjusting the parameters of the new structure. The triple notched-bands can be easily tuned to the desirable frequency locations by controlling the parameters of the proposed TMSIR. The presented UWB BPF covers the frequency range for the UWB systems, between 3.3 GHz and 10.4 GHz, with a rejection band around WLAN, RFID, and XSCS. The introduced TMSIR is simple and flexible for blocking undesired narrow band radio signals appearing in UWB band. To summarise, the proposed planar monopole UWB BPF is very useful for modern UWB wireless communication systems owing to its marked properties of simple topology, compact size, and excellent performance.

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