Progress In Electromagnetics Research Letters, Vol. 63, 123–128, 2016

Compact UWB Filter with High Selectivity and a Deep Notched Band

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Abstract—A compact ultra-wideband (UWB) bandpass filter with high selectivity and deep notched band attenuation is presented in this letter. The main structure of this filter is a balun-based coplanar waveguide (CPW)-microstrip CPW transition. This structure has UWB bandpass characteristic (2.85–11 GHz) and a transmission zero at its lower transition band. To achieve a transmission zero at its upper transition band, some complementary split ring resonators (CSRR) are added in the ground of microstrip. Therefore, this filter, whose skirt factor is 89%, presents high selectivity. Then, a notched band is created by short-ended stubs for 5.5 GHz WLAN. Owing to the stepped impedance characteristic of these stubs, this filter achieves −41 dB deep notch in its S_{21}. Besides, the size of the whole filter is only $0.38\lambda_g * 0.45\lambda_g$. The simulated and measured results agree well with each other.

1. INTRODUCTION

Since the Federal Communications Commission authorized the ultra-wideband (UWB) frequency spectrum 3.1–10.6 GHz as unlicensed use in 2002, the researches of UWB application have acutely increased. Bandpass filters, as key passive components of UWB wireless systems, have also been discussed in the literature. Various structures are proposed to design UWB filters with high selectivity, low insertion loss, compact size, and wider bandwidth [1–11]. For example, multiple-mode resonator (MMR) and coupling feed lines are widely used to achieve UWB filters [1–8]. Besides, the transition structures between different transmission lines can also be used as UWB filters [9–11].

On the other hand, to block undesired signal interference in the passband of the UWB application, many methods are proposed to introduce a notched band. The simplest method is to cascade the notched band structure at the two ports of a filter [1, 9]. In UWB filters with symmetrical structure, the notched band structure can also be added at the center of a filter [2–4, 10]. Besides, the notched band can be realized by transversal signal interaction [5, 6]. Moreover, in MMR based filters, the notched band can be achieved by adding a cutoff mode in MMR [7, 8].

A microstrip (MS)-to-coplanar waveguide (CPW) transition from balun coupling mechanism is discussed in [12]. A UWB filter based on this MS-CPW-MS transition structure is proposed in [11]. But the filter of [11] presents low selectivity. Its lower stopband has only one transmission zero at DC. To achieve a high selectivity UWB filter, a CPW-MS-CPW (CMC) transition structure (see Fig. 1(a)) is proposed in this letter. This CMC structure has UWB bandpass characteristic and a transmission zero f_{lz} (see Fig. 1(b)) at its lower transition band. Then, some complementary split ring resonators (CSRR) are added in CMC structure. A new transmission zero is introduced at its upper transition band by CSRR. This CMC+CSRR structure can be used as a high selectivity UWB filter. Finally, some short-ended stubs with stepped impedance are cascaded at the two ports of filter. A notched band with strong attenuation is created for 5.5 GHz WLAN. For verification, a prototype of the filter with notched band is fabricated and measured. The measured results of this filter are in good agreement with the simulated ones.

Received 28 September 2016, Accepted 24 October 2016, Scheduled 9 November 2016

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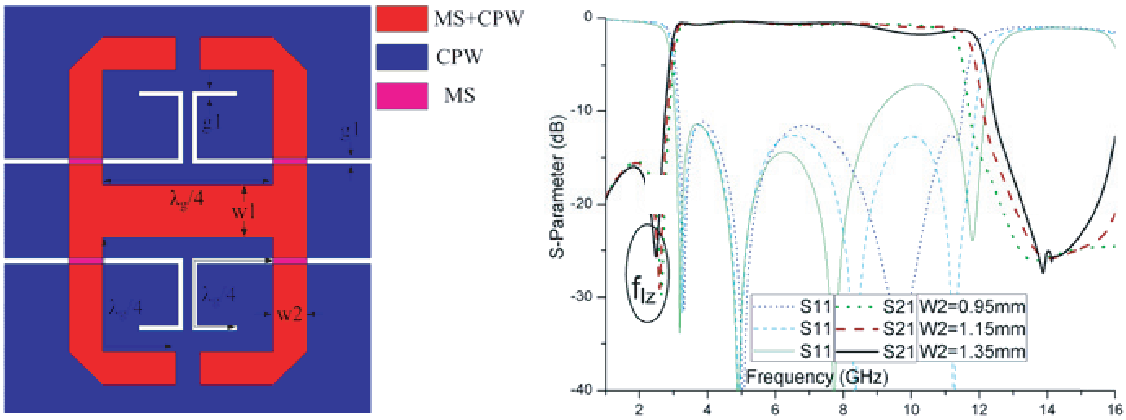


(a) (b)

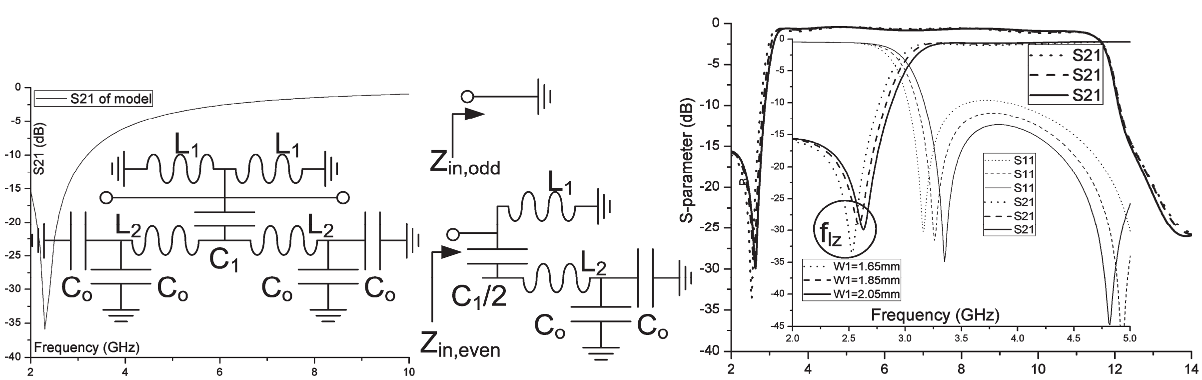
Figure 1. (a) Layout of CMC. (b) S-parameter of CMC.

2. THE DESIGN AND ANALYSIS OF THE PROPOSED FILTER

As shown in Fig. 1(a), the CMC transition structure is composed of four short-ended slotline stubs, four open-ended MS stubs and an MS line. Because the eight stubs are bent, this CMC transition structure presents a compact size. Because the transmission characteristic of the basic MS-to-CPW transition has been explained theoretically in [11, 12], it is known that the lengths of stubs and MS line are all $\lambda_g/4$ (guided wavelength at 6.85 GHz). Besides, the effects to tune the widths of stubs and MS line will be discussed in this letter.

As mentioned above, the basic MS-to-CPW transition is based on balun coupling mechanism. Its high frequency coupling depends on the crossovers of MS and slotline stubs, and its low frequency coupling depends on the overlap of CPW and MS line. As shown in Fig. 1(b), the MS stub width $w2$ mainly affects the high frequency performance of filter. Tuning $w2$ from 0.95 mm to 1.35 mm, the upper edge of 3 dB passband is raised from 11.4 GHz to 12 GHz, but the high frequency return loss is degenerated from 13 dB to 7 dB. The effect of tuning the slotline width $g1$ is similar to tuning $w2$. Wider $g1$ means higher upper edge of passband. Thus this filter design can be simplified as constant $g1$ (the gap of 50 Ω CPW port) and tunable $w2$. Correspondingly, the low frequency performance of filter depends on the MS line width $w1$. To explain the low frequency selectivity improvement of CMC (zero f_{lz} in Fig. 1(b)), a lumped model is proposed in Fig. 2.

Figure 2(a) is a low frequency equivalence of CMC structure. L_1 is the equivalent inductor of two



(a) (b) (c)

Figure 2. (a) Lumped model of CMC in low frequency and its S_{21}. (b) Odd-even-mode equivalent circuit. (c) Effects of $w1$ tuning.

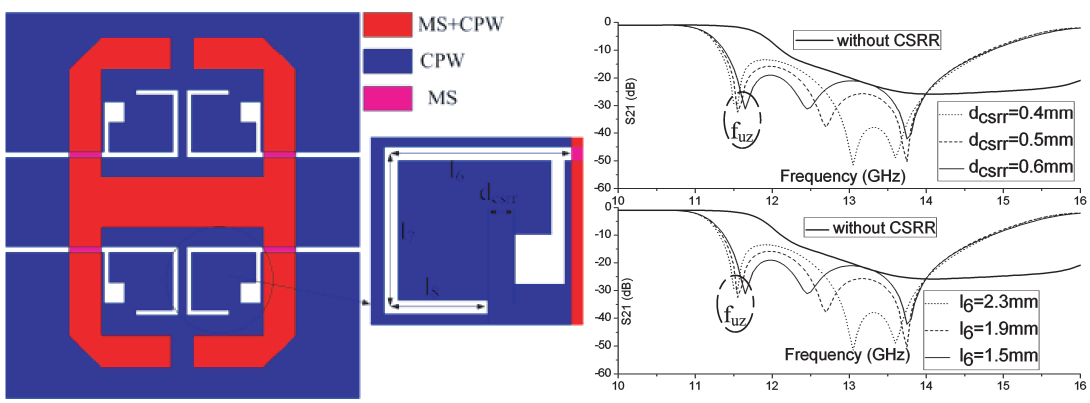
short-ended CPW stubs. C_1 is the coupling capacitor between MS line and CPW. L_2 is the equivalent inductor of MS line. C_o is the equivalent capacitor of four open-ended MS stubs. This symmetrical circuit can be analyzed by the odd-mode and even-mode methods as in Fig. 2(b). The even mode impedances $Z_{in,even}$ can be written as Eq. (1), and the odd mode impedances $Z_{in,odd} = 0$. Then the transmission zero condition of $Z_{in,odd} = Z_{in,even}$ can be solved as in Eq. (2), which is the lower transition band zero f_{lz}. The chief effect of broadening MS line width $w1$ is reducing the MS line equivalent inductor L_2. According to Eq. (2), wider $w1$ means higher f_{lz}. The effect of $w1$ tuning is shown in Fig. 2(c). When $w1$ is broadened from 1.65 mm to 2.05 mm, f_{lz} is raised from 2.53 GHz to 2.63 GHz, and the low frequency return loss is improved from 10 dB to 13 dB.

$$Z_{in,even} = j\omega L_1 // (2/j\omega C_1 + j\omega L_2 + 1/2j\omega C_o) \tag{1}$$

$$f_{lz} = \sqrt{2/C_1 L_2 + 1/2C_o L_2}/2\pi \tag{2}$$

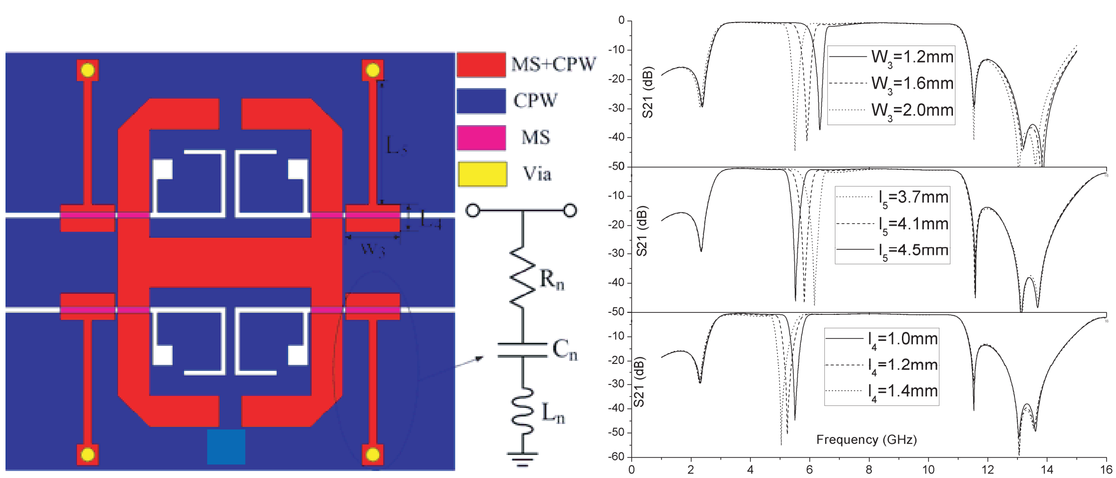
As shown in Fig. 3(a), four CSRRs are added in the ground of MS to make the upper transition band selectivity better. The equivalent circuit of CSRR is a parallel LC resonator [13]. The zero f_{uz} in Fig. 3(b) is caused by this structure. The frequency f_{uz} could be lowered by reducing the split of CSRR (keeping $l_7 + l_8$ as a const value, and the split d_{csrr} is reduced by decreasing l_7 and increasing l_8) or increasing the slotline length of CSRR (l_6 is a part of slotline ring).

As shown in Fig. 4, the four short-ended stubs with stepped impedance create a notched band, and



(a) (b)

Figure 3. (a) Layout of CMC+CSRR. (b) Transmission zero of CSRR.



(a) (b)

Figure 4. (a) Configuration of whole filter. (b) Notched band of short-ended stubs.

every stub is a serial LC resonator. Lager area $L_4 * W_3$ means lager capacitance of C_n, which leads to lower Q-factor of resonator, wider notched band and stronger attenuation. Similarly, shorter length of L_5 means smaller inductance of L_n, which also leads to lower Q-factor of resonator, wider notched band and stronger attenuation.

3. EXPERIMENTAL RESULTS

The final dimensions of the fabricated filter optimized by Ansoft HFSS 13 are (see Fig. 5): $l_1 = 5.9$ mm, $l_2 = 3.925$ mm, $l_3 = 2.55$ mm, $l_4 = 1$ mm, $l_5 = 4.5$ mm, $l_6 = 2.3$ mm, $l_7 = 2.1$ mm, $l_8 = 1.55$ mm, $l_9 = 1.2$ mm, $l_{10} = 10.4$ mm, $l_{11} = 14$ mm, $w_1 = 1.85$ mm, $w_2 = 1.15$ mm, $w_3 = 2$ mm, $w_4 = 0.3$ mm, $w_5 = 3.25$ mm, $w_6 = 0.3$ mm, $\phi_1 = 0.5$ mm, $d_1 = 0.8$ mm, $d_2 = 0.75$ mm, $d_{csrr} = 0.4$ mm, $g_1 = 0.2$ mm. The substrate is 0.508 mm thick with $3.66\varepsilon_r$. According to the measured results (Fig. 6), the 3 dB bandwidth of filter is 2.85–11 GHz. Zero f_{lz} is 2.35 GHz/30 dB. Zero f_{uz} is 11.5 GHz/35 dB. The notched band attenuation is 41 dB. The passband return loss is 10 dB (simulated 12 dB). A comparison of similar filters is listed in Table 1.

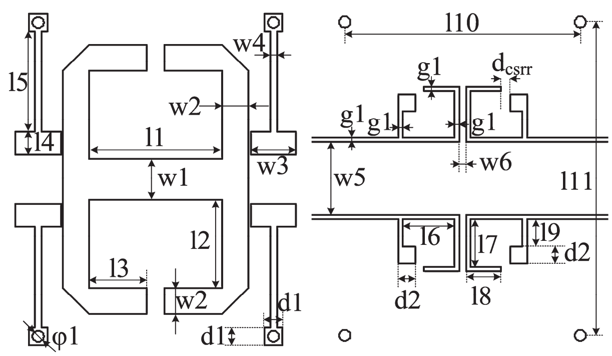


Figure 5. Dimensions of this UWB filter.

Table 1. Comparison between the proposed filter and others.

Ref.	S.F. = $\frac{\Delta f\|3\,\mathrm{dB}}{\Delta f\|30\,\mathrm{dB}}$	3 dB FBW	Insertion/ Return-loss (dB)	Notched band/ Attenuation (GHz/dB)	Size ($\lambda g \times \lambda g$)
[1]	0.79	112%	1.5/10	5.25/15	0.64 × 0.2
[2]	0.59	115%	0.7/15	6/17	0.45 × 0.41
[3]	0.70	110%	1.5/10	5.5/20	0.51 × 0.31
[4]	0.75	110%	0.6/11	8.07/18	0.69 × 0.5
[5]	0.87	123%	0.94/12	5.2/23	0.89 × 0.15
[6]	0.89	108%	NG/10	5.7/10.3	1.01 × 0.76
[7]	0.81	110%	0.8/12	8.05/18	0.373 × 0.236
[8]	0.74	95%	0.8/13	5.8/30	0.88 × 0.41
[9]	NG	113%	1.77/17	5.8/18	0.87 × 0.66
[10]	0.58	108%	1.2/12	7.9/30	0.50 × 0.38
[11]	0.73	111%	1/10	No Notched Band	0.85 × 0.2
This Work	0.89	118%	1/10	5.5/41	0.38 × 0.45

$\Delta f|3$ dB, $\Delta f|30$ dB: 3 dB and 30 dB bandwidth of the passband; S.F.: skirt factor; Attenuation: $|S_{21}|$ in the notched band; NG: Not given; λg: the guided wavelength at 6.85 GHz.

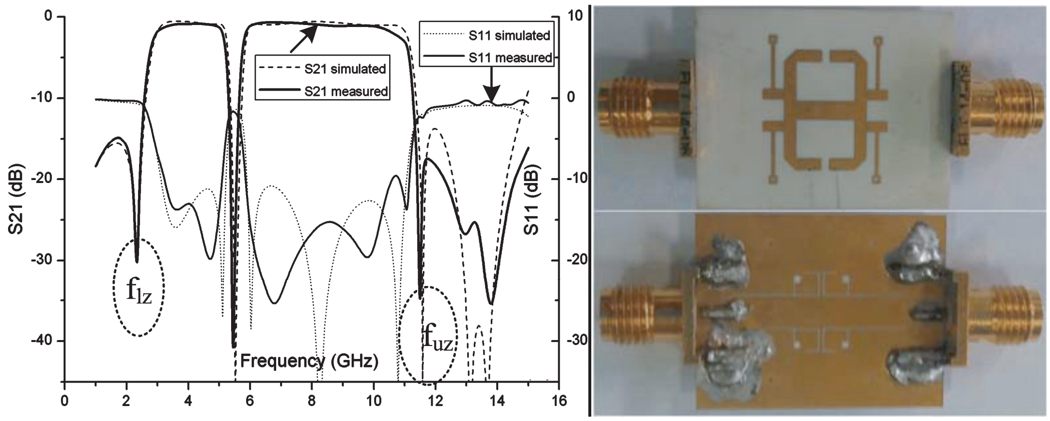


Figure 6. (a) Simulated and measured S-parameters. (b) Photograph of the fabricated filter.

4. CONCLUSIONS

In this letter, a novel UWB BPF with a notched band based on CPW-microstrip transition is presented. It has high selectivity (S.F. = 0.89), compact size ($0.38\lambda_g * 0.45\lambda_g$), deep attenuation notch (41 dB), and is a good candidate for UWB application.

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