

# UWB Bandpass Filter with Hybrid Structure and Two Transmission Zeros in the Notched Band

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**Abstract**—An ultra-wideband (UWB) bandpass filter (BPF) with hybrid coplanar waveguide (CPW)/microstrip structure is introduced in this paper. Then a pair of lowpass filters is integrated on the CPW feed lines to achieve a good out-of-band rejection. At last, a notched band with two transmission zeros is realized at 5.8 GHz by using a symmetric E-shaped slot-line and etching slots on microstrip resonator. Two transmission zeros are realized in the desired notched band, and out-of-band rejection is more than 32 dB. In order to prove the validity, the proposed filter is fabricated and measured, and the measured results are in good agreement with simulated ones.

## 1. INTRODUCTION

Since the US Federal Communication Commission (FCC) released the unlicensed use of the ultra-wideband (UWB) (3.1–10.6 GHz) for handheld systems in 2002 [1]. Planar filters are an often considered candidate for the UWB technology and have been studied extensively in the past decade [2]. Compared to microstrip structure, there is little work on hybrid microstrip and coplanar-waveguide structure relatively. In [3–5], a broadside-coupled microstrip-coplanar waveguide structure was proposed with a tightened coupling degree is utilized to design an UWB filter. A bandpass filter with CPW feed-line and microstrip resonator was presented in [6]. This novel structure exhibits good in-band performance and a high out-of-band rejection level. On the other hand, to avoid unexpected signal interference between the UWB system and other wireless systems (e.g., WLAN etc.), a notched band of UWB BPF is required within the defined UWB frequency spectrum is studied in [7–10]. In [7], a notched band is simply created by embedding an asymmetric shunt stub in the feed line, and the notched band can be changeable by adjusting the size of the stub. Multi-narrow notched bands can be introduced by integrating slot-lines on the bottom side of the coplanar waveguide (CPW) BPF is shown in [8], and its notched band can be controlled by changing the length of the slot-lines. In [9, 10], a dual-notch band is formed by embedding two open circuited stubs in the form of defected microstrip structure in [9], and a dual-mode resonator is utilized to generate a dual notch band in [10].

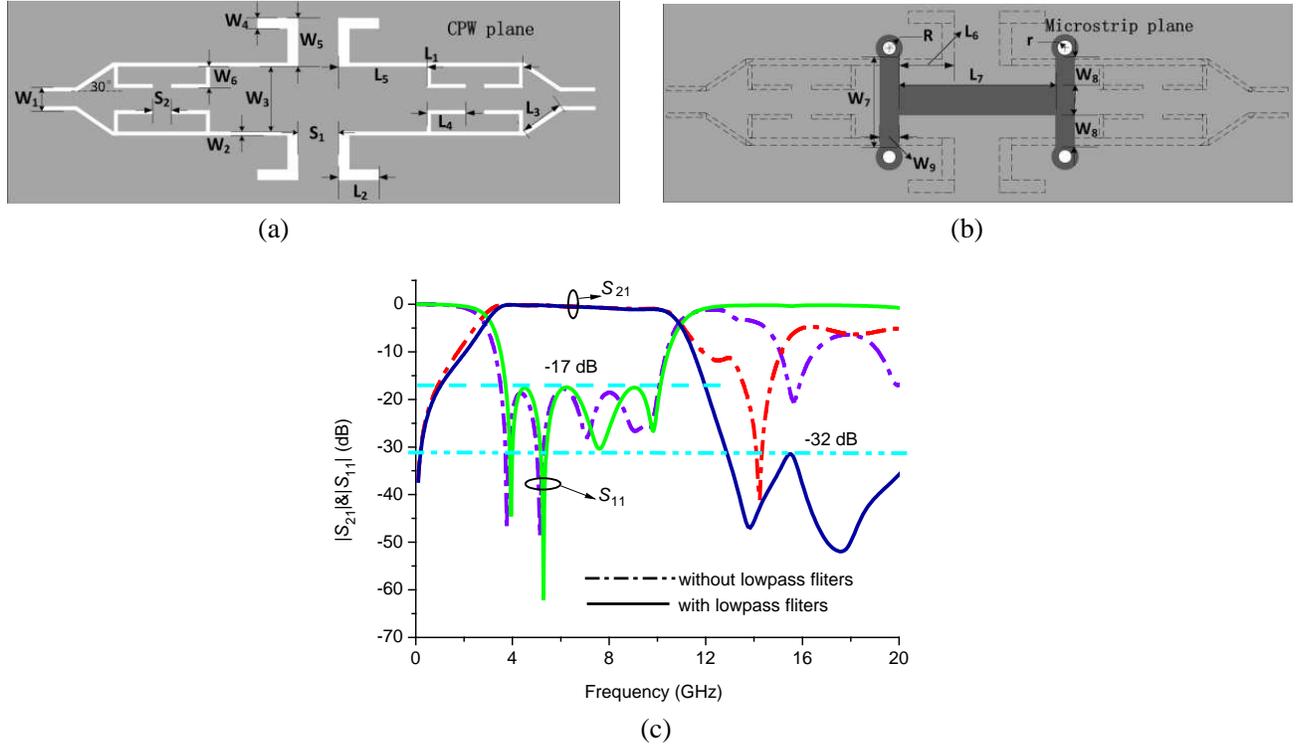
In this paper, we present a UWB BPF with hybrid CPW feed-line and microstrip resonator structure. The schematics are shown in Figure 1(a) and Figure 1(b) with marked dimensions. Two lowpass filters are integrated on the CPW plane as shown in Figure 1(a), and the lowpass filter is constituted by four L-shaped slot-lines. On the microstrip plane, the short-ended H-shaped microstrip resonator which depicted in Figure 1(b) is studied in this letter. A comparison about the simulation results between the UWB BPF with and without lowpass filter is shown in Figure 1(c), and it is obvious seen that a very good out-of-band of more than 32 dB rejection is achieved in the case with lowpass filters. A notched band with two transmission zeros is formed by a symmetric E-shaped slot-line on the ground and etching slots on microstrip resonator. Measured results agree well with the simulated ones.

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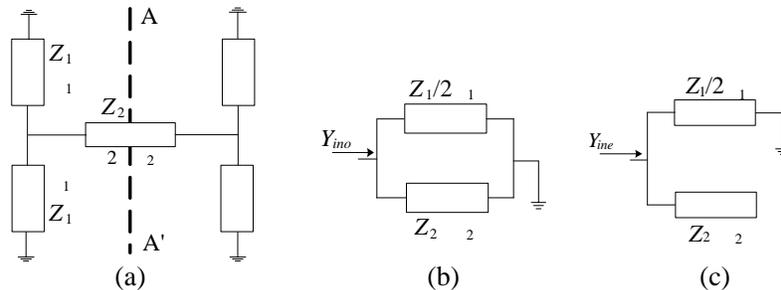
**Figure 1.** Schematic and simulation of proposed UWB BPF. (a) Layout of CPW plane. (b) Layout of microstrip plane. (c) Comparison between the proposed structure with and without lowpass filter.

## 2. SHORT-ENDED H-SHAPED MICROSTRIP RESONATOR

Looking into the H-shaped resonator, a short-ended step impedance resonator can be seen as depicted in Figure 2(a). It consists of a low impedance line section in the middle section and four identical high impedance short-circuited line sections of the two sides, and the individual high impedance of one side can be described as two parallel short-ended stubs. A-A' in Figure 2(a) is the symmetric plane and the characteristic of the high impedances of the resonator are defined as  $Z_1$ , and the low impedances are defined as  $Z_2$ .  $\theta_1$  and  $\theta_2$  are the corresponding electrical lengths.  $R = Z_2/Z_1$  is defined as the impedance ratio of low and high impedance lines.

Figure 2(b) shows the condition under the odd mode excitation, and the symmetric plane is short-circuit. We can easily obtain the input admittance  $Y_{ino}$ .

$$Y_{ino} = -j \frac{2Y_1 \tan \theta_2 + Y_2 \tan \theta_1}{\tan \theta_1 \tan \theta_2}$$



**Figure 2.** (a) H-shaped resonator structure. (b) Odd mode. (c) Even mode.

$Y_1$  and  $Y_2$  are corresponding input admittance of  $Z_1$  and  $Z_2$ .

Figure 2(c) shows the condition under the even mode excitation, and the symmetric plane is open-circuit. Herein, the input admittance  $Y_{ine}$  is given below.

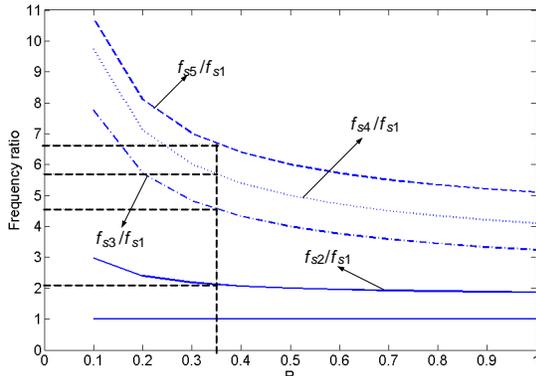
$$Y_{ine} = -j \frac{2Y_1 \cot \theta_2 - Y_2 \tan \theta_1}{\tan \theta_1 \cot \theta_2}$$

Under the resonance condition, the input admittances  $Y_{ino}$  and  $Y_{ine}$  are equal to zero, so the resonance frequency depends on  $\theta_1$  and  $\theta_2$ .

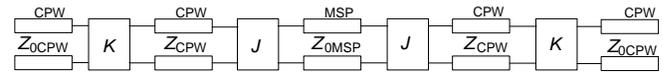
If  $2\theta_1 = \theta_2 = \theta$ , three resonance frequencies can be obtained.

$$\begin{aligned} \theta(f_{s1}) &= 2 \arctan \sqrt{\frac{R}{R+1}}; \\ \theta(f_{s2}) &= 2 \arctan \sqrt{4R+1}; \\ \theta(f_{s3}) &= 2\pi - 2 \arctan \sqrt{4R+1}; \\ \theta(f_{s4}) &= 2\pi - 2 \arctan \sqrt{\frac{R}{R+1}}; \\ \theta(f_{s5}) &= 2\pi \end{aligned}$$

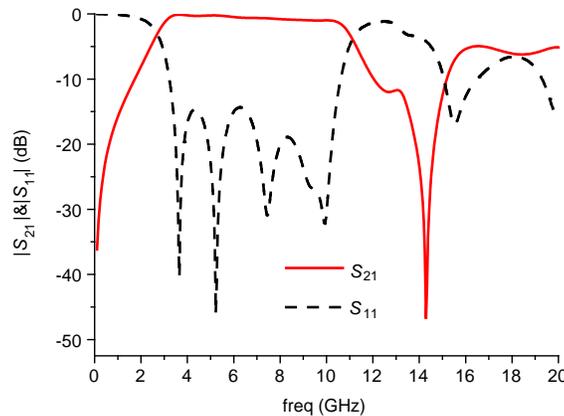
Obviously, only the first resonance frequency  $\theta(f_{s1})$  is in the desired passband as shown in Figure 3(a), and the other four resonance frequencies are out of band at the value of  $R = 0.35$ . In



(a)



(b)



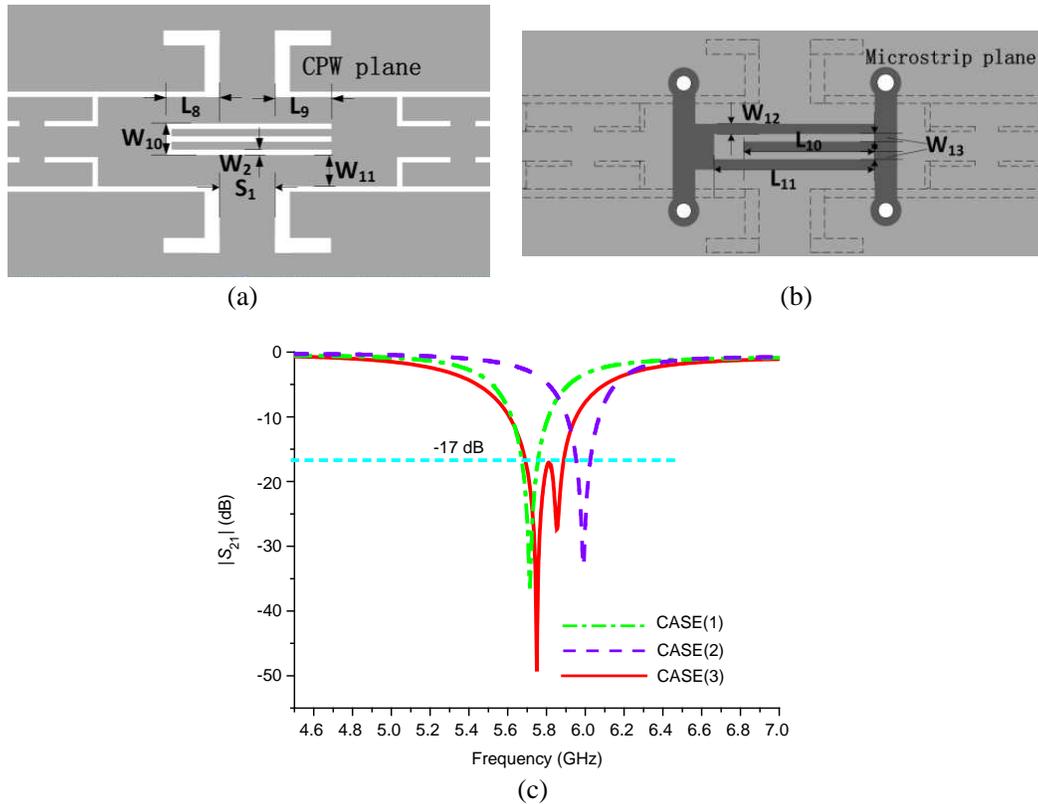
(c)

**Figure 3.** (a) Normalized resonant frequencies. (b) Equivalent  $J$  &  $K$ -inverter network. (c) Simulation of the proposed structure without lowpass filter.

this novel coupling structure, two modes are achieved by the strong coupling [11, 12] between the CPW and the microstrip line, whereas the other two modes are achieved by the tapered feed line. The sections from the short-ended microstrip line to tapered feed line are quarter-wavelength (at 6.85 GHz), and these two sections can be modeled as a  $K$ -inverter. As a result, the network of the proposed structure can be described as Figure 3(b). Another four modes are achieved by two  $J$ -inverters and two  $K$ -inverters. The simulation of the proposed UWB bandpass filter with tapered feed line is depicted in Figure 3(c).

### 3. THE NOTCH BAND WITH TWO TRANSMISSION ZEROS

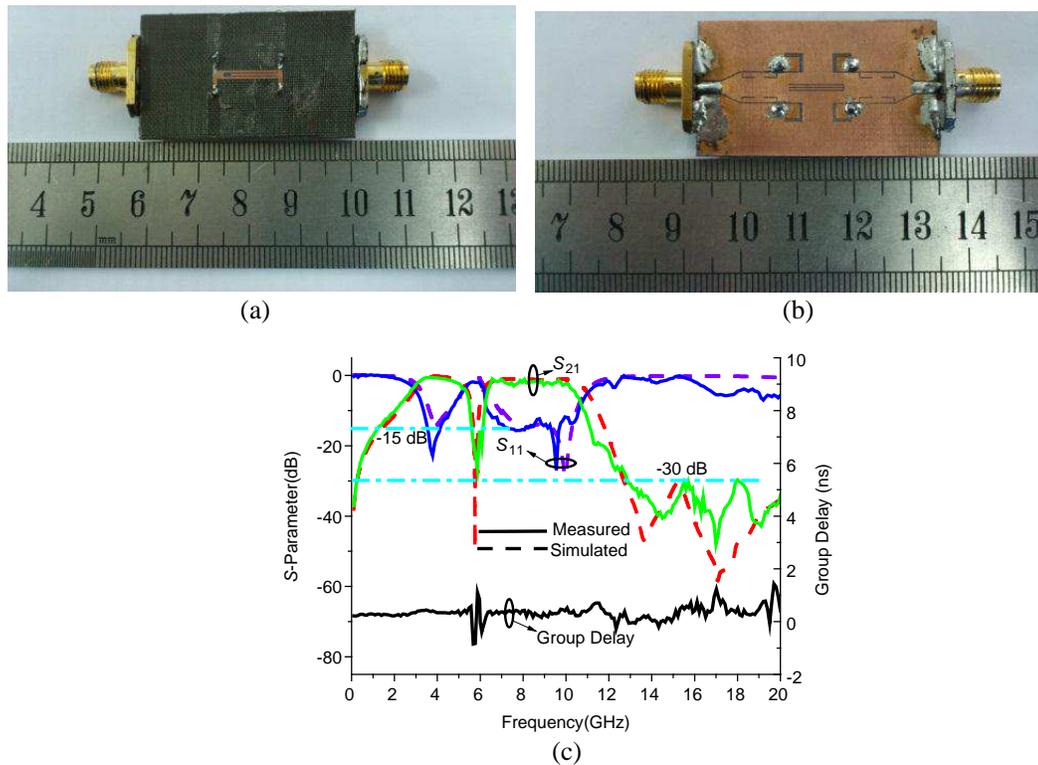
In order to generate a notched band with two transmission zeros, a symmetric E-shaped slot-line is introduced on the CPW plane to produce one transmission zero as shown in Figure 4(a). Another transmission zero is produced by an embedded open circuited stub in the low impedance part of the H-shaped resonator as shown in Figure 4(b). The center frequency of the notched band is adjustable when altering the length of E-shaped line or the open circuited stub. When the lengths of the E-shaped slot and stub are equal to a quarter-wavelength with respect to the center frequency of the notch-band, the two notched bands are close to each other to form a second order notched band. Figure 4(c) shows three different types of forming notched band: CASE(1) describes the notched band only with E-shaped slot-line; CASE(2) depicts the notched band only with open circuited stub; CASE(3) shows the notched band with E-shaped slot-line and open circuited stub. The center frequency of the notched band is designed at 5.8 GHz for the application of a WLAN system.



**Figure 4.** Layout and simulation of the E-shaped slot-line and open circuited stub structure. (a) Layout of E-shaped slot-line. (b) Layout of etching slots on H-shaped resonator. (c) Simulation of three different CASEs.

### 4. IMPLEMENTATION AND EXPERIMENTAL RESULTS

To demonstrate the proposed UWB filter experimentally, the proposed UWB filter is fabricated, and the dimensions of the UWB BPF are shown in Table 1. All simulations are based on ADS Momentum. The filter is fabricated on a substrate with relative dielectric constant of 2.55 and thickness of 0.8 mm, and photographs of the fabricated UWB BPF are shown in Figures 5(a) and (b). Figure 3(c) provides a comparison of the simulated and measured  $S$ -parameters of the filter.



**Figure 5.** Photograph Measured results and measured results of the proposed UWB bandpass filter. (a) Photograph of the microstrip plane of fabricated UWB BPF. (b) Photograph of the CPW plane of fabricated UWB BPF. (c) Results of measured and simulated.

**Table 1.** Dimensions of proposed UWB filter unit: mm.

$W_1$	$W_2$	$W_3$	$W_4$	$W_5$	$W_6$	$W_7$	$W_8$	$W_9$	$W_{10}$	$W_{11}$	$W_{12}$	$L_1$	$L_2$	$L_3$
2.45	0.2	5.4	0.7	3.48	1	6.2	2.35	0.7	1.2	2.1	0.35	11	3.3	3.35
$L_4$	$L_5$	$L_6$	$L_4$	$L_5$	$L_6$	$L_7$	$L_8$	$L_9$	$L_{10}$	$L_{11}$	$S_1$	$S_2$	$R$	$r$
2.4	4.5	3.45	2.4	4.5	3.45	12	2	2.53	9.01	10.75	5.1	1.4	0.6	0.3

**Table 2.** Comparison of various UWB bandpass filters.

	Notched band order	Size	Return Loss	Stopband
This work	2	27.1 mm × 14.16 mm	> 15 dB	Good
[2]	N/A	16.4 mm × 15.65 mm	> 20 dB	Poor
[4]	1	13 mm × 7.2 mm	> 12 dB	Poor
[8]	1	9.5 mm × 2.8 mm	> 10 dB	Poor
[11]	N/A	750 mm × 80 mm	> 12 dB	Poor

The measured 3 dB FBWs are 50.6% (ranging from 3.1 GHz to 5.2 GHz) for the first passband and 52.38% (ranging from 6.2 GHz to 10.6 GHz) for the second passband. The minimum insertion loss of the first passband is 0.68 dB and 0.9 dB for the second. Table 2 provides the comparisons between proposed structure and other UWB bandpass filters, and the notched band order and stopband performance are the distinguished advantages of the proposed UWB filter. The notch band is well located at 5.8 GHz with two transmission zeros inside, and the attenuation is better than 15 dB in measurement. The upper-stopband is beyond 20 dB from 10.8 GHz to 20 GHz, much better in high frequency in measurement. A good agreement is achieved between simulation and measurement.

## 5. CONCLUSION

A UWB BPF with hybrid structure and a second order notched band has been presented in this letter. By using this CPW/microstrip transition structure, the return loss can be achieved 17 dB over the passband. Moreover, the out-of-band rejection can achieve better than 30 dB from 13–20 GHz. In addition, a notched band with two transmission zeros inside is obtained by symmetric E-shaped slotline and an open circuited stub. The attenuation is more than 15 dB at the center frequency of 5.8 GHz. The simulated and measured results show a good agreement.

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