A Compact Ultra-Wideband Bandpass Filter Based on Split-Mode Resonator

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***Abstract*—A compact ultra-wideband (UWB) bandpass filter is proposed based on the coplanar-waveguide (CPW) split-mode resonator. By suitably introducing a short-circuited stub to implement the shunt inductance between two quarter wavelength ($\lambda/4$) CPW stepped-impedance resonators, a strong magnetic coupling may be realized so that a CPW split-mode resonator may be constructed. Moreover, by properly designing the dual-metal-plane structure, one may accomplish a microstrip-to-CPW feeding mechanism to provide strong enough capacitive coupling for bandwidth enhancement and also introduce an extra electric coupling between input and output ports so that two transmission zeros may be created for selectivity improvement. The implemented UWB filter shows a fractional bandwidth of 116% and two transmission zeros at 1.705 and 11.39 GHz. Good agreement between simulated and measured responses is observed.**

***Index Terms*—Bandpass filter (BPF), coplanar waveguide (CPW), dual-plane structure, microstrip, split-mode resonator, ultra-wideband (UWB).**

I. INTRODUCTION

THE ultra-wideband (UWB) wireless communication technology has received great attention, especially after the Federal Communications Commission (FCC) decision to permit the unlicensed operation band from 3.1 to 10.6 GHz in February 2002 [1]. The UWB systems have many attractive benefits such as transmitting higher data rates and requiring lower transmit power. However, for developing the UWB filters, there are a lot of challenges to meet the ultra-wide bandwidth requirement.

Over the past few years, the optimum distributed highpass filter prototype [2] was adopted to design the UWB filters. To reduce the circuit size, the technique of using folded lines and shared vias was employed to implement the UWB filters [3]. To further increase the selectivity, a cross coupling between feeding lines was added to create new pairs of transmission zeros [4]. Furthermore, to suppress the spurious response, electromagnetic bandgaps were adopted in [5]. However, these filters have the drawbacks of large circuit area and inconvenient via process.

Multiple-mode resonator is another popular structure used for wideband filter design. In [6], the aperture compensation technology was proposed to increase the coupling between parallel-coupled lines. In [7], a five-pole UWB filter was built up based on a single triple-mode stepped-impedance resonator. In [8], the microstrip-to-CPW transition was used as a feeding structure. Since these filters are based on the half-wavelength ($\lambda/2$) multiple-mode resonators, they have large circuit sizes and poor selectivity.

Recently, dual-plane structures have become a competitive candidate for the filter design. In [9], the wideband filters using microstrip and CPW quarter-wavelength ($\lambda/4$) resonators were reported, however their bandwidths are not wide enough to meet the UWB requirement. In [10], the UWB filters based on the quasi-lumped-circuit elements were proposed. Although these filters possess good performances and compact sizes, their spurious passbands are close to the UWB passband.

In this letter, a compact UWB bandpass filter (BPF) based on the split-mode resonator is fabricated. The split-mode resonator is formed by introducing a CPW short-circuited stub into two $\lambda/4$ CPW stepped-impedance resonators. By properly designing the split-mode resonator, the upper spurious passband may somewhat be suppressed. To accomplish a large capacitive coupling, the broadside-coupled microstrip-to-CPW transitions are adopted as the feeding structures for bandwidth enhancement. Moreover, an extra electric coupling between input and output ports is introduced to create two transmission zeros for selectivity improvement. Specifically, the implemented four-pole UWB filter has the merits of compact size, good insertion/return loss, improved selectivity, flat group delay, and better upper stopband response.

II. FOUR-POLE UWB FILTER

A. Split-Mode Resonator

Fig. 1 shows the proposed four-pole UWB filter using both microstrip and CPW structures. The proposed filter is based on the CPW split-mode resonator. As shown in Fig. 2(a), the split-mode resonator is composed of two $\lambda/4$ stepped-impedance resonators and each resonator is resonated at the central frequency f_0. By introducing a shunt inductance to establish a strong magnetic coupling between two $\lambda/4$ resonators, one may implement a split-mode resonator which has two split resonance frequencies at f_1 and f_2. Specifically, the larger the inductance, the stronger the coupling, the wider the split of two resonance frequencies, and the deeper the minimum in the S_{21} curve. Furthermore, it should be noted that the electric lengths of these two resonators may be reduced by the introduction of inductance.

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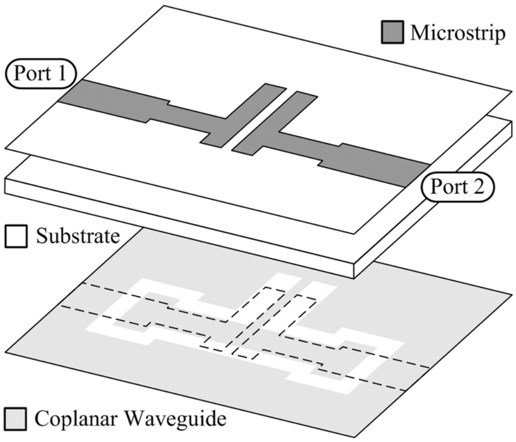
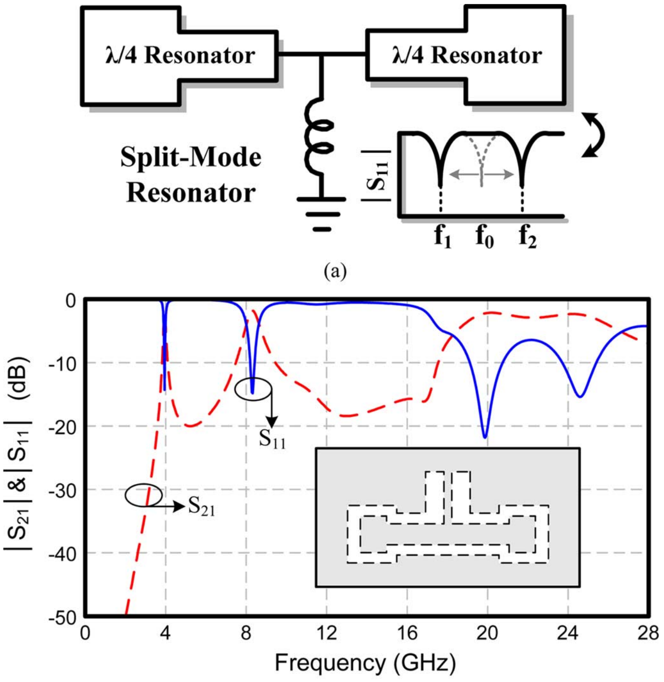


Fig. 1. Three-dimensional physical layout of the proposed four-pole UWB filter.



(a)

(b)

Fig. 2. Circuit structure and simulated responses of proposed CPW split-mode resonator.

To avoid using lumped-elements and metal vias, the CPW short-circuited stub is used to realize the shunt inductance. Under the ultra-wide bandwidth requirement, the CPW short-circuited stub must be designed so as to widely separate the two split resonance frequencies. By combining the two $\lambda/4$ CPW resonators and the short-circuited stub, a CPW split-mode resonator is implemented. To investigate the resonance frequencies associated with the split-mode resonator, the simulator ADS Momentum is used. Fig. 2(b) shows the simulated S-parameters of the CPW split-mode resonator which is weakly coupled to the feeding structure. The simulated responses show that two split resonance frequencies f_1 and f_2 are observed at 4 and 8.3 GHz. Moreover, due to the use of $\lambda/4$ stepped-impedance resonator which makes the spurious passband beyond the triple center frequency, higher unwanted resonances appear around 19.87 and 24.61 GHz. Note that these higher unwanted resonances would dominate the spurious passband of the proposed UWB filter.

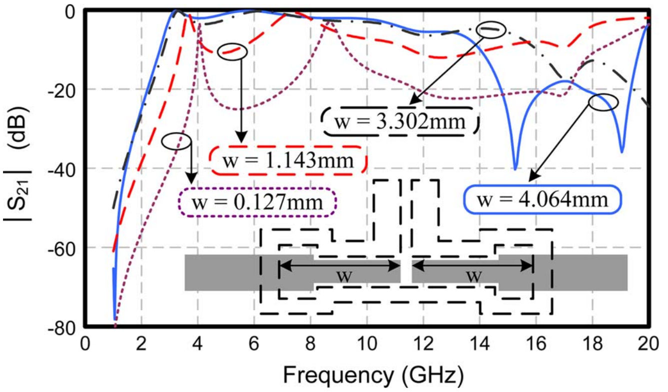


Fig. 3. Simulated frequency responses of the filter with transitions of various microstrip length w.

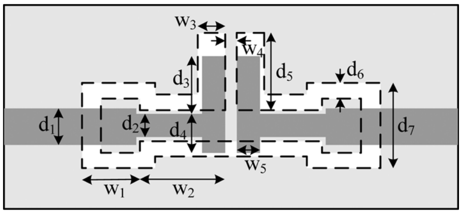


Fig. 4. Top-/bottom-layer circuit layouts of the proposed four-pole UWB filter. (w_1 = 1.905 mm, w_2 = 2.794 mm, w_3 = 0.889 mm, w_4 =0.381 mm, w_5 = 0.762 mm, d_1 = 1.194 mm, d_2 = 0.762 mm, $d3$ = 1.905 mm, d_4 = 1.27 mm, d_5 = 2.54 mm, d_6 = 0.508 mm, and d_7 = 2.794 mm).

B. Transition and Extra Electric Coupling

Strong couplings in input and output stages are required in designing a broadband filter. In this study, to fit in with the UWB requirement, the broadside-coupled microstrip-to-CPW transitions are adopted as the input/output feeders so as to provide strong enough capacitive couplings for bandwidth enhancement. Here, the simulated responses associated with the transition structure are illustrated in Fig. 3. By increasing the microstrip length w (Fig. 3) to increase the overlap area between microstrip and CPW, the insertion loss around the minimum is reduced and becomes smooth.

Based on the magnetic coupling provided by the split-mode resonator, it is easy to create two transmission zeros at the lower and upper stopbands by introducing an extra electric coupling between the input and output ports. Taking advantages of the dual-metal-plane layout, the required electric coupling may be implemented by introducing the microstrip stubs of length (d_3+d_4) as shown in Fig. 4. Fig. 4 shows the top-/bottom-layer circuit layouts of the proposed UWB filter. The effect of adjusting the microstrip stub length d_3, which controls the electric coupling level, is illustrated in Fig. 5. Specifically, the lower and upper transmission zeros will move close to the passband edge as the stub length d_3 is increased.

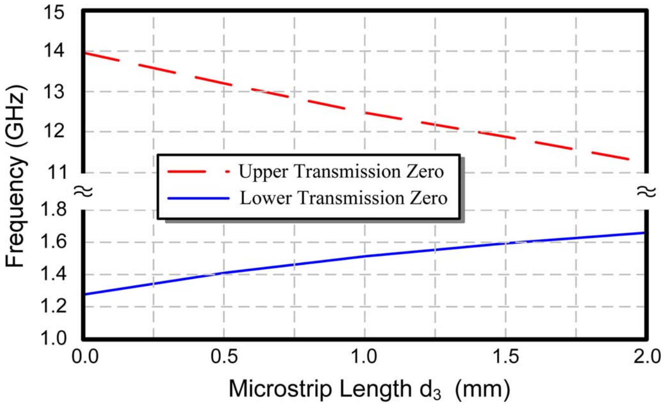
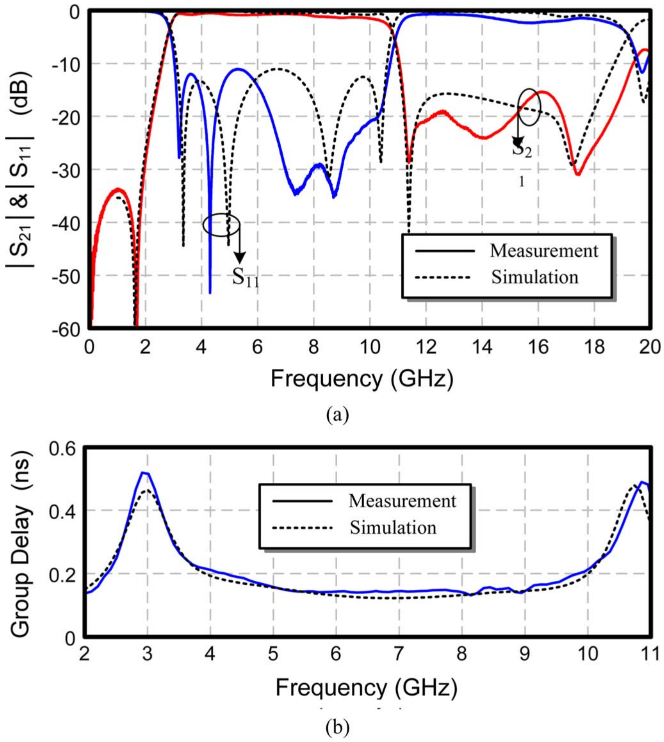


Fig. 5. Curves to relate the transmission-zero frequencies to the values of the microstrip length d_3 specified in Fig. 4.



(a)

(b)

Fig. 6. Measured and simulated results of the proposed four-pole UWB filter (Fig. 4). (a) Scattering parameters. (b) Group delay.

C. Measurement and Simulation Results

Fig. 6(a) shows the measured and fullwave simulated frequency responses of the four-pole UWB filter (see Fig. 4), which is fabricated on the Rogers RO4003C substrate with $\varepsilon_r = 3.38$, tan $\delta = 0.002$, and thickness $h = 0.508$ mm. The measured center frequency is at 6.8 GHz and the measured 3-dB fractional bandwidth is 116 %. The implemented filter has an insertion loss better than 0.53 dB and a return loss greater than 11 dB within the passband. Two transmission zeros are found at 1.705 and 11.39 GHz and no spurious passband is observed from 12 to 19 GHz. Moreover, the simulated return loss shows that the proposed filter has four poles. The extra two poles are contributed by the input and output feeding structures [6].

Fig. 6(b) exhibits a flat group delay response below 0.51 ns over the whole passband. The four-pole UWB filter has a compact dimension of 9.625 mm × 4.375 mm, which is approximately $0.36\lambda_g \times 0.167\lambda_g$, where λ_g is the guided wavelength of microstrip structure at the center frequency of 6.8 GHz.

III. CONCLUSION

In this letter, a four-pole UWB filter based on the CPW split-mode resonator has been realized and carefully examined. The split-mode resonator is implemented by the CPW structure and has two split resonance frequencies in the UWB passband. By the dual-metal-plane layout, the broadside-coupled microstrip-to-CPW transitions and extra electric coupling may be incorporated in the filter design so that a compact UWB filter may be implemented with two transmission zeros created for selectivity improvement. Note that the implemented UWB filter has no spurious passband from 12 to 19 GHz, since the spurious harmonics of split-mode resonator have moved up to the higher frequencies. Compared to our previous work [10], this four-pole UWB filter has better performance than the three-pole one and more compact size than the five-pole one. The implemented filter has the merits of compact size and better performance when compared with the previously fabricated UWB filters.

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