UWB BPF Design Using Modified Tri-Section SIR

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1. Introduction

Since the U.S. Federal Communications Commission (FCC) approved the unlicensed use of the ultra-wide-band (UWB) (3.1-10.6 GHz) for commercial communication applications in February 2002, many researchers have placed their efforts on developing various UWB components and systems [1], [2]. As an important building block in a UWB communication system, UWB BPFs have been gaining favor in the area of filter design. Although UWB BPFs can be easily realized using tightly coupled microstrip lines [3], the ones in recent published work showed that using multi-mode resonators (MMR) is an effective design method [4], [5]. In [4], the UWB BPF aiming at transmitting signals in the whole UWB band was implemented using a microstrip-line MMR together with the input/output parallel-coupled line sections. By properly locating the first three modes of the MMR and the coupling peak of the parallel-coupled lines at the two sides, one can realize a five-transmission-pole UWB BPF with a uniform passband response. Presented in [5] was a UWB BPF similar to the one reported in [4] but with aperture-backed input/output coupled line sections. With the aperture in the ground plane, the parallel coupling between resonator and feed lines can be largely enhanced and the need of the very small coupling gap can be alleviated.

All the MMRs used in the aforementioned papers are two-section SIRs. The tri-section SIR (TSSIR), as shown in [6], has tunable first three resonant frequencies. Thus it is appropriate to serve as a potential MMR for design of UWB BPFs. In this paper, a new MMR-based UWB BPF is proposed and designed using a modified TSSIR. The high-impedance line sections at the two sides of the modified TSSIR are split into two identical parallel ones to enhance the coupling with the input/output feed lines. By properly locating the first five resonant modes of the TSSIR and the coupling peak of the parallel-coupled lines at the two sides, we can obtain a seven-transmission-pole UWB BPF with a uniform in-band response. The filter design and the obtained results are presented in the following sections.

2. Filter Configuration and Design

The general geometry of the TSSIR considered in this filter design is depicted in Fig. 1. The impedance looking toward the right (or left) side of the TSSIR from its center can be expressed as

$$Z_{in} = j\frac{(-Z_1Z_2Z_3) + Z_1Z_2^2\tan\theta_2\tan\theta_3 + Z_1^2Z_2\tan\theta_1\tan\theta_3 + Z_1^2Z_3\tan\theta_1\tan\theta_2}{Z_1(Z_1\tan\theta_3 + Z_3\tan\theta_2) + (Z_2Z_3\tan\theta_1 - Z_2^2\tan\theta_1\tan\theta_2\tan\theta_3)} \quad (1)$$

where $K_1 = Z_3 / Z_2$ and $K_2 = Z_2 / Z_1$ are impedance ratios. The resonance conditions can be obtained by setting the impedance Z_{in} to zero or infinity. With all three sections of the TSSIR assumed to have the same electric length (i.e., $\theta_1 = \theta_2 = \theta_3 = \theta_0$), the electric lengths for the first five resonant modes of the TSSIR can be derived as $\theta_{01} = \tan^{-1}\sqrt{\dfrac{K_1K_2}{K_1+K_2+1}}$, $\theta_{02} = \tan^{-1}\sqrt{\dfrac{K_1+K_1K_2+1}{K_2}}$, $\theta_{03} = \pi/2$, $\theta_{04} = \pi - \theta_{02}$, and $\theta_{05} = \pi - \theta_{01}$ [6]. In the proposed UWB BPF design, the first five resonant frequencies (f_1, f_2, f_3, f_4, f_5) of the TSSIR are located within the targeted 3.1-10.6 GHz UWB. With all the discontinuity and dispersion effects of the TSSIR neglected, we can obtain the fundamental property of $f_1 : f_2 : f_3 : f_4 : f_5 = \theta_{01} : \theta_{02} : \theta_{03} : \theta_{04} : \theta_{05}$. Once f_1, f_2, and f_3 are specified, the required impedance ratios for the TSSIR can be expressed as [6]

$$K_1 = \frac{(B+AB)}{(1+B)}, \quad K_2 = \frac{(K_1+1)}{(A-K_1)} \tag{2}$$

where $A = \tan^2[\pi f_2/(2f_3)]$ and $B = \tan^2[\pi f_1/(2f_3)]$. With the aid of (2), K_1 and K_2 can be found easily without resorting to any design graph.

In the proposed UWB BPF design, a modified version of the TSSIR shown in Fig. 1 with designated impedance ratios is used as the MMR. As shown in Fig. 2, the high-impedance line sections at the two sides of the modified TSSIR are split into two identical parallel ones to enhance the coupling with the input/output feed lines. In addition, a slot at the outer side of the second section of the modified TSSIR is implemented to provide further coupling between the resonator and the feed lines. The coupling length L_4 can be varied to tune the passband frequency response. By properly locating the first five resonant modes of the TSSIR and the coupling peak of the parallel-coupled lines at the two sides, one can realize a seven-transmission-pole UWB BPF with good insertion loss and return loss in the overall passband.

In this paper, the proposed UWB BPF circuit is to be designed on a 0.635-mm-thick RT/Duroid 6010 substrate with a dielectric constant of 10.2 and a loss tangent of 0.0023. For the first five resonant modes of the modified TSSIR to be appropriately located in the UWB, the first three resonant frequencies of the TSSIR are chosen to be 3.1, 4.65, and 6.2 GHz, respectively. As indicated in (2), the corresponding impedance ratios can then be calculated to be K_1 = 3.42 and K_2 = 1.83. The impedance of each section is designed to be Z_1 = 10.87 Ω, Z_2 = 19.88 Ω, and Z_3 = 68 Ω, and the electric length of each line section at 3.1 GHz and 4.65 GHz can be calculated to be θ_{01} = 45^o and θ_{02} = 67.51^o. Knowing θ_{01} and θ_{02}, $\theta_{04} = \pi - \theta_{02}$ and $\theta_{05} = \pi - \theta_{01}$ can be readily calculated. In this case, the fourth and fifth resonant frequencies are found to be f_4 = 7.75 GHz and f_5 = 9.3 GHz. The modified TSSIR was simulated to exhibit five transmission peaks at 3.1, 4.5, 6.25, 8.54 and 10.22 GHz, which, except the last two, are very close to the ones computed for the non-perturbed TSSIR.

3. Simulated and Measured Results

Following the approach outlined in the last section, an example UWB BPF circuit was fabricated and measured for performance demonstration. Dimensions of this prototype UWB BPF are L_1 = 4.14, L_2 = 3.51, L_3 = 3.44, L_4 = 4.74, W_1 = 0.1, W_2 = 2.5, W_3 = 5.63, W_4 = 0.15, S_1 = 0.1, and S_2 = 0.2 (all units are in mm). Fig. 3 shows the simulated and measured frequency responses of *S*-parameters. The measured insertion loss is found less than 1.0 dB within 3- 10.2 GHz, whereas the 3-dB cutoff frequencies are 2.7 and 10.65 GHz at the lower and upper UWB edges. Also shown in Fig. 3 is the measured group delay which varies between 0.39 and 0.47 ns within the passband (i.e., a maximum in-band variation of about 0.08 ns).

4. Conclusion

A novel MMR-based UWB BPF is proposed and designed using a modified TSSIR. By properly locating the first five resonant modes of the TSSIR and the coupling peak of the input/output parallel-coupled lines, a seven-transmission-pole UWB BPF was realized. A prototype of the proposed UWB BPF has been fabricated and measured for performance verification. Besides a return loss of higher than 10 dB for the whole passpand, the measured results show a very good UWB transmission performance with a maximum insertion loss of less than 1.0 dB and a group delay variation of less than 0.1 ns.

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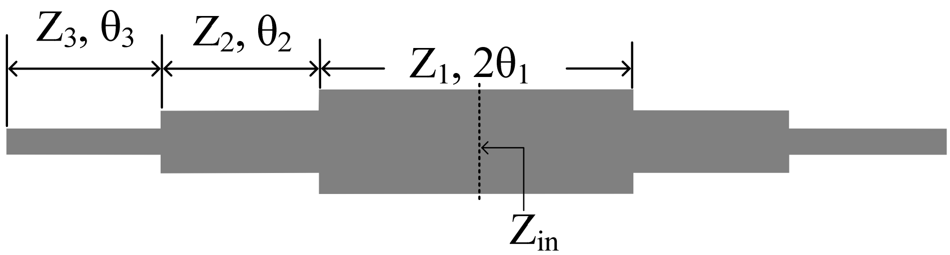

Fig. 1. The general λ/2 TSSIR structure.

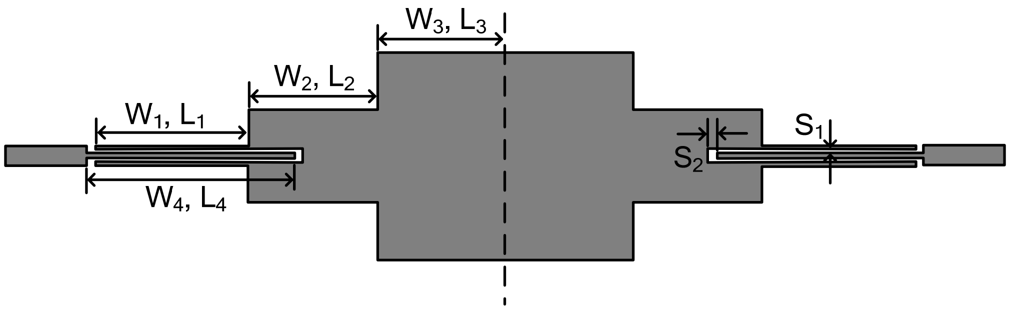

Fig. 2. Configuration of the proposed UWB BPF.

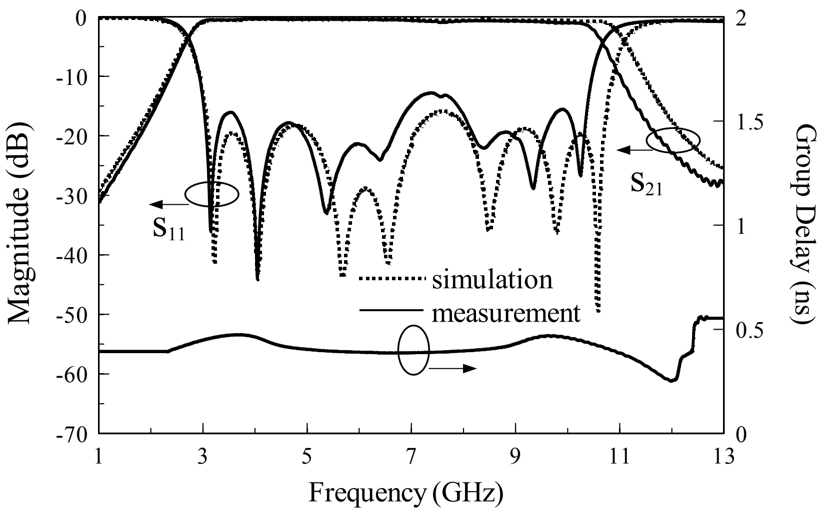

Fig. 3. Simulated and measured frequency responses of the UWB BPF.