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HIGH REJECTION BROADBAND BPF WITH TRIPLE-MODE STUB-LOADED RESONATOR

H.-W. Deng, B. Liu, Y.-J. Zhao, X.-S. Zhang, and W. Chen

College of Information Science and Technology
Nanjing University of Aeronautics and Astronautics
Nanjing 210016, China

Abstract—In this letter, a novel broadband bandpass filter (BPF) with compact size and high rejection performance is proposed using the triple-mode stub-loaded resonator. The resonator is formed by attaching one T-type open stub at the center plane and two identical short-circuited stubs symmetrical to high impedance microstrip line. It can generate one odd-mode resonant frequency f_{m2} and two even-mode f_{m1}, f_{m3} in the desired band. The f_{m2} can be approximately determined by the high impedance microstrip line. The short-circuited stubs and T-type open stub can be applied not only to separately adjust the f_{m1} and f_{m3} while the other two keep relatively stationary, but also to separately create transmission zero near the lower and upper cut-off frequencies, leading to a high rejection skirt. As a result of the source-load coupling, two transmission zeros in the upper-stopband are generated to deepen and widen the upper-stopband. A high rejection BPF with the fractional bandwidth 76% is simulated, fabricated and measured. The measured results agree well with the EM simulations.

1. INTRODUCTION

As wireless communication technology makes a rapid development, broadband microstrip filters with high frequency selectivity, compact size, and wide stopband are highly demanded [1–4]. Multi-mode resonators (MMR) are attractive because each MMR can be used as a multiple tuned resonant circuit and, therefore, the number of resonators required for a given degree of filter is greatly reduced, resulting in a compact filter configuration [5]. Hence, it has been widely used as an important technique to design broadband or ultra wideband

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Corresponding author: Hong-Wei Deng (ceceliayan1008@yahoo.com.cn).

bandpass filters with improved performances and varied shapes [6–11]. In [6], Zhu et al. originally made use of the first three resonant modes of an initial MMR with stepped-impedance configuration to build up a BPF with the fractional bandwidth 110%. Several other triple-mode UWB filters have been reported based on varied MMRs such as stub-loaded MMR [7], EBG-embedded MMR [8], one open stub and one short stub loaded MMR [9]. Recently, two quadruple-mode UWB filters with compact size are proposed. By introducing two short-circuited stubs with one quarter-wavelength to the modified triple-mode UWB filter, a quadruple-mode UWB bandpass filter with sharp out-of-band rejection is presented in [10]. Another quadruple-mode UWB BPF with improved upper-stopband performance is given using the new MMR which is formed by attaching three circular impedance-stepped stubs in shunt to a high impedance microstrip line [11]. But the Broadband BPFs still suffer poor rejection near the lower cut-off frequency. Nevertheless, the lower stopband suppression is as important as the higher one.

In this letter, a compact and high selectivity BPF with the fractional bandwidth 76%, as shown in Fig. 1, is proposed using the triple-mode stub-loaded resonator. The resonator generates three resonant frequencies which can be conveniently adjusted to the desired passband. The short-circuited stubs and T-type open stub can generate two transmission zeros near the lower and upper cut-off frequencies, which improve the selectivity. Due to the source-load coupling, two additional transmission zeros can be created in the upperstopband, leading to a wide and deep upperstopband. Meanwhile, the broadband BPF is very compact in size, for the stub-loaded resonator is folded. The electrical size is approximately by $0.315\lambda_g \times 0.135\lambda_g$, where λ_g is the guided wavelength at the centre frequency. One broadband BPF prototype is fabricated for experimental verification of the predicted results. The substrate is RT/Duroid 5880 with a thickness of 0.508 mm, permittivity of 2.2 and loss tangent 0.0009.

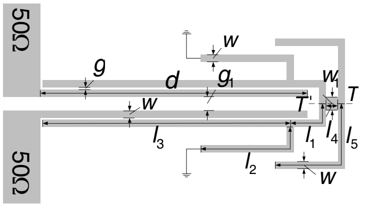

Figure 1. Schematic of the proposed high rejection broadband BPF.

2. PROPOSED TRIPLE-MODE STUB-LOADED RESONATOR

A triple-mode resonator configured by adding one T-type open stub denoted by lengths (l_4, l_5) and widths (w_1, w) at the center plane and two identical short-circuited stubs (l_2, w) symmetrically to high impedance microstrip line with length of $2l_1 + 2l_3$ and width of w is illustrated in Fig. 2(a). Since the resonator is symmetrical to the T-T' plane, the odd-even-mode method is implemented. Voltage (current) vanishes in the T-T' plane, leading to the approximate transmission line circuit models represented in Fig. 2(b) and Fig. 2(c) (we suppose $w_1 = 2w$) [12]. As shown in Fig. 2, θ_1, θ_2, θ_3, and θ_4 refer to the electrical lengths of the sections with lengths l_1, l_2, l_3, and $(l_4 + l_5)$, respectively. And Y refers to characteristic admittance of the width w. From the condition $Y_{inodd} = 0$ and $Y_{ineven} = 0$, the resonant frequencies of the odd excitation and even excitation in Fig. 2(b) and Fig. 2(c) can be extracted:

$$\tan\theta_1 \tan\theta_2 \tan\theta_3 - \tan\theta_1 - \tan\theta_2 = 0 \tag{1}$$

$$\tan(\theta_1 + \theta_4) \tan\theta_2 + \tan\theta_2 \tan\theta_3 - 1 = 0 \tag{2}$$

The identical short-circuited stubs are applied to push one resonant mode to the desired passband while sharpening the rejecting skirt of the passband [9, 10]. According to the formulas (1) and (2), the specific effect of the length l_2 is investigated and shown in Fig. 3, where l_1 is equal to 1.95 mm on account of the little coupling between the short-circuited stubs. The other parameters herein are chosen as: $l_3 = 10.95$ mm, $l_4 = 0.65$ mm, $l_5 = 5.5$ mm, and $w = 0.3$ mm. It can be

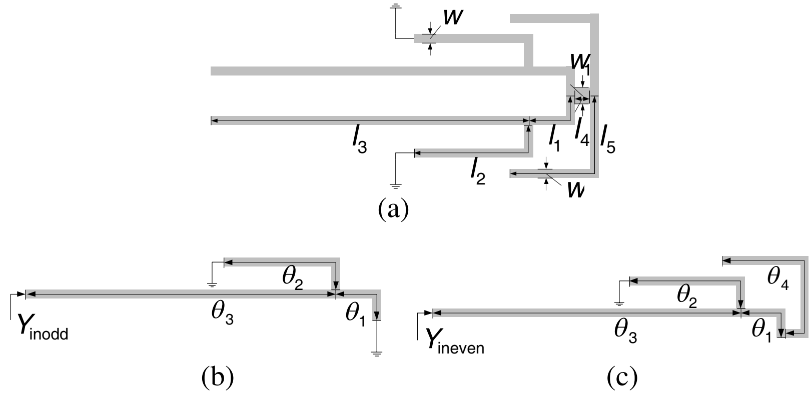

Figure 2. (a) Structure of triple-mode stub-loaded resonator, (b) odd-mode equivalent circuit, and (c) even-mode equivalent circuit.

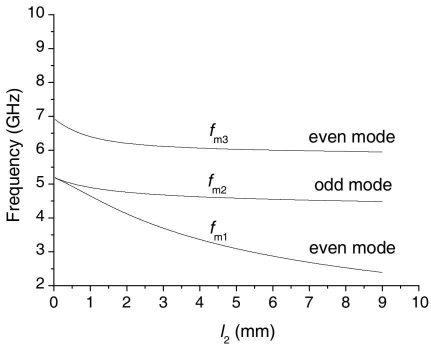

Figure 3. Resonant-mode frequencies with varied l_2.

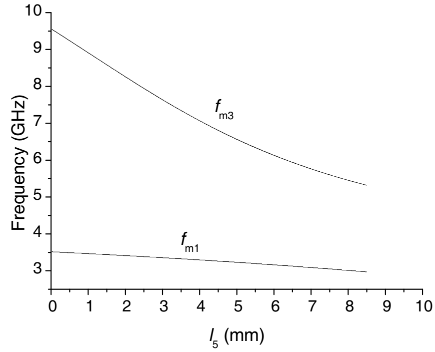

Figure 4. Even-mode resonant frequencies with varied l_5.

seen from the Fig. 3 that there are one odd-mode and two even-modes in the range of 0.1–10 GHz. As the length l_2 increases from 0.1 mm to 9 mm, the even-mode resonant frequency f_{m1} moves towards the lower frequency, whereas the f_{m2} and f_{m3} merely have smaller change. Therefore, the short-circuited stubs can be mainly applied to adjust the resonant frequency f_{m1} and have less impact on the f_{m2}, f_{m3}. Thus, the f_{m2} and f_{m3} are approximately determined by the following expression:

$$f_{m2} = \frac{c}{4(l_1 + l_3)\sqrt{\varepsilon_{eff}}} \tag{3}$$

$$f_{m3} = \frac{c}{2(l_1 + l_3 + l_4 + l_5)\sqrt{\varepsilon_{eff}}} \tag{4}$$

where c is the speed of light and ε_{eff} is equivalent dielectric constant.

With the other parameters keeping unchanged, the even-mode resonant-mode frequencies varied l_5 are interpreted in Fig. 4, for the reason that the T-type open stub at the center plane merely controls the even-mode resonant frequencies. As the length l_5 increases from 0.1 mm to 8.5 mm, the even-mode resonant frequency f_{m3} shifts towards the lower frequency and the f_{m1} relatively remains stationary. According to Fig. 3 and Fig. 4, the f_{m1} can be controlled by the l_2 and approximately expressed by:

$$f_{m1} = \frac{c}{4(l_2 + l_3)\sqrt{\varepsilon_{eff}}} \tag{5}$$

Thus, the odd-mode resonant frequency f_{m2} can be allocated in the center frequency of the passband by reasonably choosing l_1 and l_3, and the even-mode resonant frequencies f_{m1}, f_{m3} can be adjusted within the desired passband by simply varying the parameters l_2 and l_5

3. COMPACT AND HIGH SELECTIVITY BROADBAND BPF

Based on the triple-mode stub-loaded resonator, the first three resonant modes (f_{m1}, f_{m2}, f_{m3}) can be used to make up of a compact broadband BPF, if the resonator is properly fed with increased coupling degree [6–11]. We choose the parameters of the triple-mode resonator: $l_1 = 1.95\,\text{mm}$, $l_2 = 4.8\,\text{mm}$, $l_3 = 10.95\,\text{mm}$, $l_4 = 0.65\,\text{mm}$, $l_5 = 5.5\,\text{mm}$, $w = 0.3\,\text{mm}$, and $w_1 = 0.6\,\text{mm}$. Three resonant-mode frequencies f_{m1}, f_{m2} and f_{m3} are 3.14 GHz, 4.59 GHz, and 6.03 GHz, respectively. The resonator coupled to $50\,\Omega$ input/output parallel coupling feeding line under the tight coupling case with $g = 0.1\,\text{mm}$, $g_1 = 0.6\,\text{mm}$, $d = 11.5\,\text{mm}$ is simulated by HFSS. As illustrated in Fig. 6(a), the three simulated resonant-mode frequencies are $f_{m1} = 3.13\,\text{GHz}$, $f_{m2} = 4.97\,\text{GHz}$ and $f_{m3} = 6.51\,\text{GHz}$. Two additional resonant-mode frequencies $f_{m4} = 4.01\,\text{GHz}$ and $f_{m5} = 5.7\,\text{GHz}$ are generated by the input/output parallel feeding line [6]. Two transmission zeros T_{z1}, T_{z2} near the lower and upper cut-off frequencies are separately created by the short-circuited stubs [9, 10, 12] and T-type open stub [13], leading to a high rejection skirt. The broadband BPF has two additional transmission zeros in the upper stopband to deepen and widen the upper-stopband. The zeros T_{z3}, T_{z4} are attributed to the cross-coupling between input and output parallel coupling feeding lines [3, 14].

After studying the characteristics of the high rejection broadband BPF, the filter is fabricated on the RT/Duroid 5880 substrate, and its photograph is shown in Fig. 5. The size of the fabricated filter, if the feed lines are ignored, is $13.1\,\text{mm} \times 5.6\,\text{mm}$, i.e., approximately by $0.315\lambda_g \times 0.135\lambda_g$, where λ_g is the guided wavelength at the center

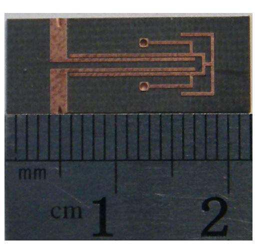

Figure 5. Photograph of the fabricated high rejection broadband BPF.

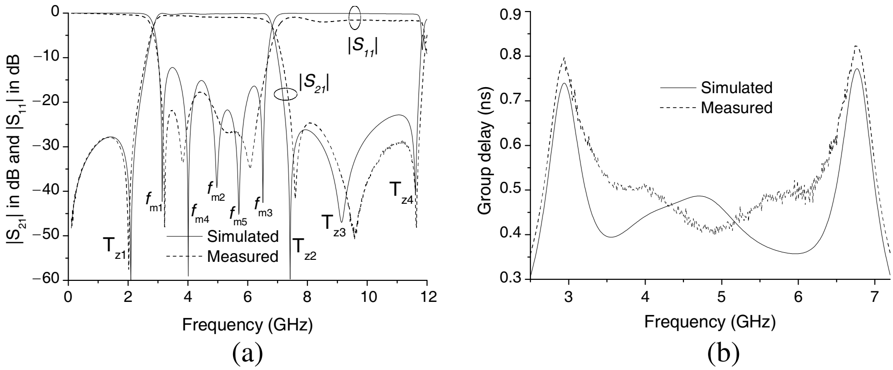

Figure 6. Simulated and measured frequency responses of the high rejection broadband BPF. (a) $|S_{21}|$ in dB and $|S_{11}|$ in dB. (b) Group delay.

frequency. The filtering performance is measured by Agilent network analyzer N5230A. The measured $|S_{11}|$ in dB and $|S_{21}|$ in dB as well as group delay are shown in Fig. 6 and illustrated good agreement with simulated results. The measured 3 dB passband is in the range of 3.01 to 6.72 GHz and its measured input return loss ($|S_{11}|$ in dB) is less than −12.1 dB. The upper-stopband in experiment is extended up to 11.9 GHz with an insertion loss better than −27.1 dB. In addition, the measured in-band group delay is varying from 0.4 to 0.75 ns, which is quite small and flat in all the passband.

4. CONCLUSION

Based on the proposed triple-mode stub-loaded resonator, a compact broadband BPF with the source-load coupling is designed to exhibit its attractive sharp rejection skirts and wide upper-stopband. The resonator can generate one odd-mode and two even-modes in the desired band. The odd-mode f_{m2} can be approximately determined by the high impedance microstrip line. The short-circuited stubs and T-type open stub can be applied not only to separately adjust the f_{m1} and f_{m3} while the other two keep relatively stationary, but also to separately create transmission zero near the lower and upper cut-off frequencies, leading to a high rejection skirt. Due to the source-load coupling, two transmission zeros in the upper-stopband are generated to deepen and widen the upper-stopband. A filter prototype with the fractional bandwidth 76% is fabricated to demonstrate the predicted performances in experiment.

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