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QUADRUPLE-MODE STUB-LOADED RESONATOR AND BROADBAND BPF

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Abstract—Novel compact microstrip quadruple-mode stub-loaded resonator and broadband bandpass filter (BPF) are proposed in this letter. As a starting part of designing a quadruple-mode broadband BPF, the initial novel triple-mode open impedance-stepped stub loaded resonator characteristic is investigated to choose its proper dimensions. Based on these pre-determined dimensions of the triple-mode resonator, two identical short-circuited stubs are loaded against the impedance-stepped open stubs in the resonator to generate a tuned resonant mode and a transmission zero in lower stopband which leads to a high rejection skirt. A compact broadband BPF with the quadruple-mode resonator is simulated, fabricated and measured. The measured results agree well with the EM simulations.

1. INTRODUCTION

Recently, compact size, wide stopband and high selectivity microwave BPFs are widely applied to enhance the performance of radio frequency (RF) front-ends. Resonators, as the fundamental elements in a filter, usually determine the size of the filter. There are many ways to reduce the resonator size, however, the important way for the filter size reduction is to modify the traditional resonator to generate additional modes, causing the resonator to have multiple resonate frequencies and thus one physical resonator can be treated as multiple electrical resonators. Examples can be seen from dual-mode ring resonator [1], dual-mode square-ring resonator [2] and dual-mode

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multi-arc resonator [3]. The dual-mode means two degenerate resonant modes of the aforementioned geometrically symmetrical resonators and the two degenerate resonant modes may be split by introducing a perturbation element in a resonator. Subsequently, the dual-mode resonator that odd and even modes do not couple has been given in [4]. Some triple-mode resonators [5, 6] have been presented to design BPFs with high frequency selectivity. However, the fractional bandwidths of the BPFs are less than 5%. Recently, several BPFs with the fractional bandwidth better than 110% are reported using the triple-mode impedance-stepped resonators (SIR), such as stub-loaded multiple-mode resonator (MMR) [7], EBG-embedded MMR [8], one open stub and one short stub loaded MMR [9]. Then, a quadruple-mode SIR by Wong and Zhu [10] is proposed to build up UWB filter with compact size. In [11], instead of using multimode SIR, a dual-mode resonator composed of single stub at the center plane and two sections of transmission lines is introduced for high rejection and wideband BPF with the fractional bandwidth 45%.

The primary objective of this work is to explore a compact high selectivity and broadband BPF with quadruple-mode resonator. As part of the designing quadruple-mode filter, an initial novel compact triple-mode open impedance-stepped stub loaded resonator is firstly constituted in Section 2. Then, two identical short-circuited stubs are properly attached to the triple-mode resonator to form a quadruple-mode resonator in Section 3. After the principle of the quadruple-mode resonator is explained, the performance of the broadband BPF with the quadruple-mode resonator is simulated and optimized by HFSS. Finally, 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.

2. PROPOSED TRIPLE-MODE OPEN IMPEDANCE-STEPPED STUB LOADED RESONATOR

As a starting part of this work, a novel resonator configured by adding two identical impedance-stepped open stubs denoted by length (b, l_2) and width (a, w_1) to a microstrip transmission line with length of $2l_1 + 2m$ and widths of w is shown in Figure 1 and at first discussed. Since the resonator is symmetrical to the P point, Voltage (current) basically vanishes in the T-T' plane when the wide w is very small, leading to the approximate transmission line circuit models represented in Figures 2(a) and (b). So the odd-even-mode method is implemented [4], and $Y_{inodd} = 0$ and $Y_{ineven} = 0$ give rise to the

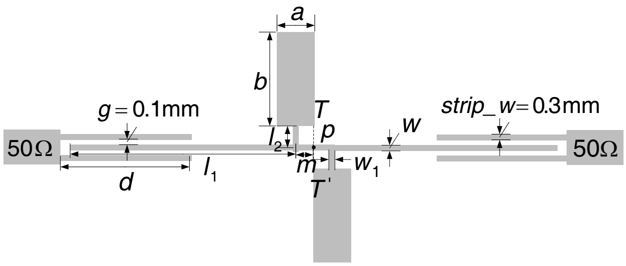

Figure 1. Schematic of the proposed triple-mode open impedance-stepped stub loaded resonator under the couple case.

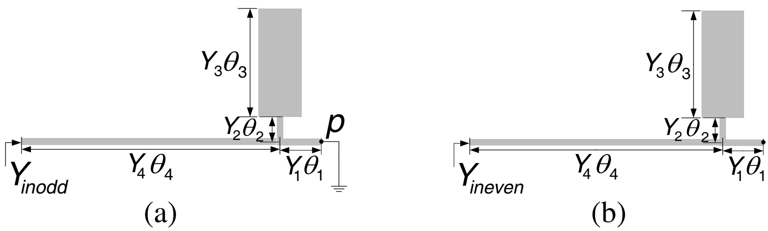

Figure 2. (a) Odd-mode equivalent circuit, and (b) even-mode equivalent circuit.

conditions for the odd mode resonator and even mode resonator in Figure 2(a) and Figure 2(b) (Herein, we choose $w = w_1 = 0.3\,\text{mm}$):

$$(\tan\theta_1 \tan\theta_4 - 1)(Y_1 - Y_2 \tan\theta_2 \tan\theta_3) + Y_1 \tan\theta_2 + Y_2 \tan\theta_3 = 0 \quad (1)$$

$$(\tan\theta_1 + \tan\theta_4)(Y_1 - Y_2 \tan\theta_3 \tan\theta_2) + Y_2 \tan\theta_3 + Y_1 \tan\theta_2 = 0 \quad (2)$$

where θ_1, θ_2, θ_3, θ_4 refer to the electrical lengths of the sections of lengths m, l_2, b and l_1, respectively. And Y_1 and Y_2 refer to characteristic admittances of the widths w and a, respectively.

We may choose the parameters of the impedance-stepped open stub: $a = 2\,\text{mm}$, $b = 5\,\text{mm}$, $l_2 = 1\,\text{mm}$, $w_1 = 0.3\,\text{mm}$. Under the total parameters $l_1 + m = 12.7\,\text{mm}$ keeping unchanged, resonant-mode frequencies varied m from the formulas (1) and (2) are interpreted in Figure 3. It can be seen that there are two odd modes and one even mode in the range of 0.1–7 GHz and the length m can adjust the locations of three resonant modes. When the impedance-stepped open stub moves near the center plane, it basically has no impact on the odd mode frequency f_{m1}. So, the f_{m1} is approximately determined by the following expression:

$$f_{m1} = \frac{c}{4(l_1 + m)\sqrt{\varepsilon_{eff}}} \quad (3)$$

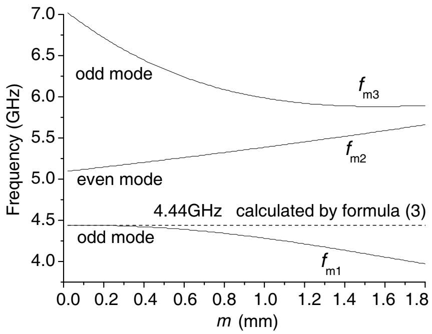

Figure 3. Resonant-mode frequencies with varied m.

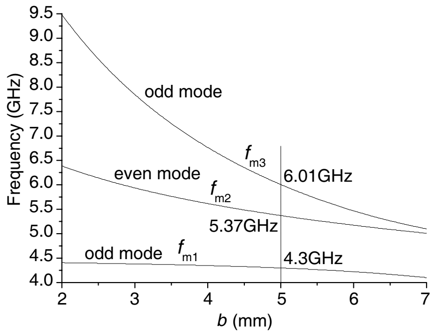

Figure 4. Resonant-mode frequencies with varied b.

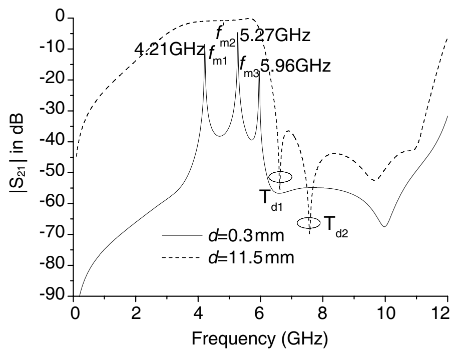

Figure 5. Simulated $|S_{21}|$ in dB of weak and tight coupling triple-mode resonator.

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

Furthermore, the specific effect of the length b on the resonant-mode frequencies is investigated and shown in Figure 4, where m is equal to 0.95 mm. As the length b varies from 2 mm to 7 mm, the resonant frequencies (f_{m2}, f_{m3}) tend to shift downwards and the resonant frequency (f_{m1}) remains stationary. Thus, f_{m1} can be allocated in the lower cut-off frequency by reasonably choosing l_1 and m, and the other two resonant frequencies can be adjusted within the desired passband by simply varying the parameter b.

The triple-mode resonator coupled to 50 Ω input/output interdigital feeding lines under the selected coupling lengths of $d = 0.3$ mm (the weak coupling case) and $d = 11.5$ mm (the tight coupling case) [8] is simulated by HFSS and shown in Figure 5, where $b = 5$ mm, $g = 0.1$ mm, strip_w=0.3 mm. Under the weak coupling case, the first three simulated resonant-mode frequencies, $f_{m1} = 4.21\,\text{GHz}$, $f_{m2} = 5.27\,\text{GHz}$ and $f_{m3} = 5.96\,\text{GHz}$, can work together to make up the desired passband. Under tight coupling case, two transmission zeros T_{d1} and T_{d2} near the upper cut-off frequency are shown in Figure 5 and separately generated by the identical impedance-stepped open stubs and the interdigital feeding lines [7], leading to a high upper rejection skirt. However, there is a poor rejection skirt in lower cut-off frequency.

3. QUADRUPLE-MODE STUB-LOADED RESONATOR AND BPF

Figure 6 illustrates the schematic of the proposed quadruple-mode stub-loaded resonator. Two identical short-circuited stubs with length l_3 and width w_1 are placed against the impedance-stepped open stubs in the triple-mode resonator. They are utilized to push the fourth resonant mode into the desired passband [10]. The fourth resonant frequencyf_{m4} is approximately expressed by:

$$f_{m4} = \frac{c}{4(l_1 + l_3)\sqrt{\varepsilon_{eff}}} \tag{4}$$

Under the weak coupling case, the simulated $|S_{21}|$ in dB of the quadruple-mode resonator for different values of l_3 is interpreted in Figure 7. It is found that the resonant frequencies f_{m1}, f_{m2} and f_{m3} are less affected by l_3, when it is changed from 1 to 3 mm. Hence, the fourth resonant frequency (f_{m4}) moves up and works together with the three resonant frequencies (f_{m1}, f_{m2}, f_{m3}) to form a novel quadruple-mode broadband BPF under the tight coupling case. Figure 9(a) interprets the simulated $|S_{21}|$ in dB of the BPF and four resonant frequencies are in the passband (where $l_3 = 3.1\,\text{mm}$, $d = 11.5\,\text{mm}$). Compared

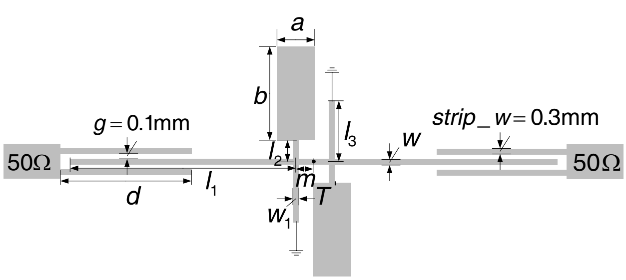

Figure 6. Schematic of the quadruple-mode stub-loaded resonator under the couple case.

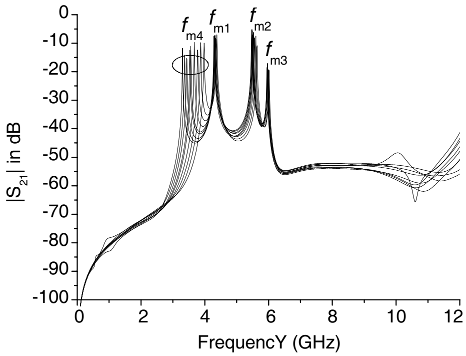

Figure 7. Simulated $|S_{21}|$ in dB of weak coupling quadruple-mode stub-loaded resonator varied with l_3.

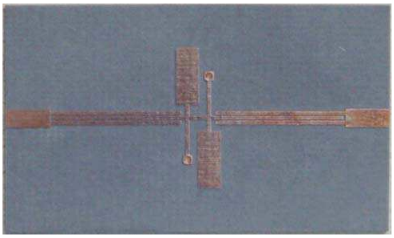

Figure 8. Photograph of the fabricated quadruple-mode BPF.

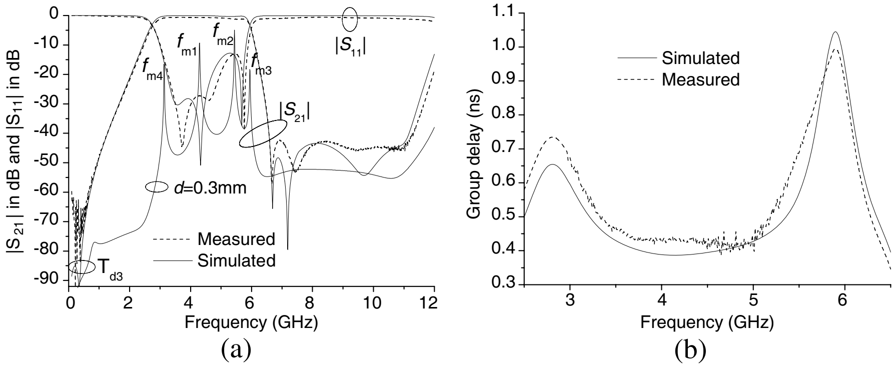

Figure 9. Simulated and measured frequency responses of the quadruple-mode broadband BPF. (a) $|S_{21}|$ in dB and $|S_{11}|$ in dB. (b) Group delay.

to the result in Figure 5, this quadruple-mode broadband BPF has enlarged attenuation skirt near the lower cut-off frequency attribute to the transmission zero T_{d3} created by the short-circuited stubs [10], in addition to keeping its high upper rejection skirt and wide upper-stopband performance.

After studying the characteristics of the quadruple-mode broadband BPF, the filter is fabricated on the RT/Duroid 5880 substrate, and its photograph is shown in Figure 8. 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 Figure 9 and illustrated good agreement with simulated results. The measured 2 dB passband is in the range of 2.96 to 5.81 GHz and its measured input return loss ($|S_{11}|$ in dB) is less than -12.5 dB. The upper-stopband in experiment is extended up to 11.5 GHz with an insertion loss better than -30 dB. In addition, the measured in-band group delay is varying from 0.4 to 0.9 ns, which is quite small and flat in all the passband.

4. CONCLUSION

In this letter, a novel compact triple-mode impedance-stepped stub loaded resonator is first studied and designed. The filter with the resonator under the tight coupling case has high upper rejection skirt and wide upper-stopband performance. After that, a quadruple-mode resonator is constituted by introducing two short-circuited stubs to the initial triple-mode resonator. Based on the resonator, a broadband BPF with the fractional bandwidth 65% is designed to exhibit its attractive sharp rejection skirts and wide upper-stopband. A filter prototype is fabricated to demonstrate the predicted performances in experiment.

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