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Compact Hexa-Mode Resonator and Its Application on WIFI Dual-Band Filter

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Abstract—This letter presents a compact hexa-mode microstrip resonator which is originated from a traditional stub-load resonator (SLR). Stub in SLR is replaced by a couple of square-loops in the proposed resonator. The advantage of this replacement is that six modes emerge to realize a compact size, and more transmission zeros are generated in its application on filter to enhance the frequency selectivity. For demonstration, a compact dual-band microstrip filter using the proposed resonator is designed in 2.4 GHz/5.2 GHz of WIFI channel, and six transmission zeros are generated to enhance the frequency selectivity.

1. INTRODUCTION

In the recent decade, multi-mode resonator has been intensively studied with the aggressive development of wireless communication systems due to the advantages of compact size, low cost and high performance. Stub loaded resonator (SLR) is one of the mostly used multimode resonators in wideband or multi-band microwave components. It can obtain more resonant modes to realize a compact size. In [1], a dual-mode resonator with a meander short-loaded stub is designed. In [2], a tri-band bandpass filter using a stub-loaded short-ended resonator is designed. Three stubs are symmetrically loaded in folded half wavelength resonator to form a SLR with four controllable resonant modes in [3, 4]. In [5], a new class of multi-stub loaded resonators including tri-mode, quad-mode and hexa-mode resonators with flexibly controlled resonance modes is presented. In [6], a novel hexa-mode stub-loaded ring resonator is proposed by adding short-loaded and open-loaded stubs in uniform impedance resonator (UIR). In [7], an eight-mode resonator is introduced by loading large number of stubs, but poor performance is presented. To summarize the above works of SLR, it can be observed that traditional SLR is a dual-mode resonator. To obtain a multi-mode SLR, more stubs are needed to be loaded on UIR symmetrically. As far as the authors know, the eight-mode resonator in [7] has the highest number of modes in SLR, but the performance is too poor due to large number of loaded stubs. Hexa-mode resonator emerges twice in [5] and [6] with good performance, but the structures of them are too complicated.

In this paper, a hexa-mode microstrip resonator is designed by replacing the stub in SLR with a pair of square-loops. The advantage of this replacement is that six modes emerge to realize a compact size, and more transmission zeros are generated in its application on filter to enhance the frequency selectivity. Moreover, the proposed resonator is simpler in the structure than the hexa-mode resonator using SLR in [5, 6]. To demonstrate the performance of the proposed resonator, a microstrip dual-band filter operating at WIFI channel is designed, fabricated and measured by utilizing the proposed resonator. Compact size and high frequency selectivity can be obtained. It can be seen from the measured results, which show good agreement with the simulated one.

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2. ANALYSIS OF THE PROPOSED HEXA-MODE RESONATOR

Figure 1 depicts the structure of the proposed hexa-modes resonator compared with traditional SLR. It can be seen that a couple of square loops replace the single stub in SLR. Utilizing even-odd-mode method, traditional SLR generates two modes as shown in Figure 1(a), and the proposed resonator owns six modes as shown in Figure 2.

The analysis of each mode in the proposed resonator adopts several even-odd-mode methods. Due to the symmetry of the structure, even-odd-mode method is applied to separate the proposed resonator in odd-mode equivalent circuit and even-mode equivalent circuit as shown in Figure 2. For simplicity, suppose that $Y_2 = 0.5Y_3$, $\theta_1 = \theta_2 + \theta_3$. Then odd mode equivalent circuit is equal to a

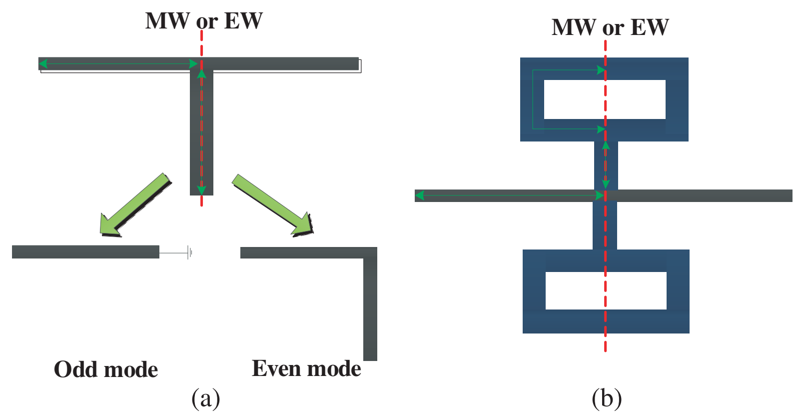

Figure 1. The structure comparison between SLR and proposed resonator. (a) Structure of SLR and its resonance modes. (b) Structure of proposed resonator.

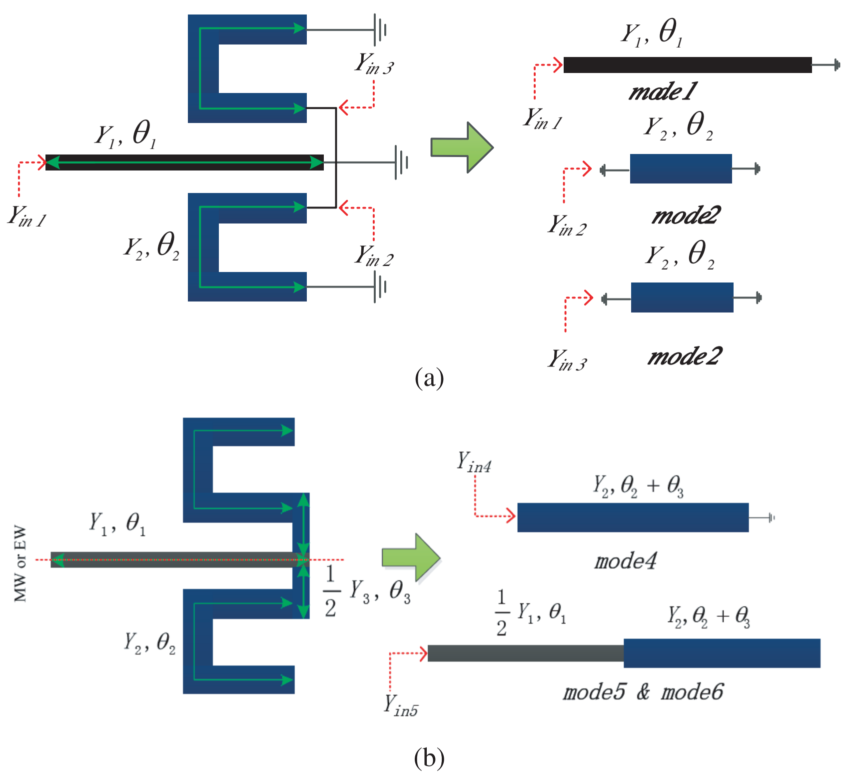

Figure 2. Odd- and even-mode equivalent circuits of proposed resonator. (a) Odd-mode equivalent circuit. (b) Even-mode equivalent circuit.

short-ended resonator and two double-short-ended resonators which are parallel with each other, as shown in Figure 2(a). Even mode equivalent circuit, as shown in Figure 2(b), is a half of the resonator with Magnetic Wall (MW) on the symmetry plane. Even-odd-mode method is applied again to analyze the even-mode equivalent circuit. As a result, the circuit can be converted to a quarter-wavelength resonator and a SIR. Resonant frequency of each mode is calculated by $Y_{in(i)} = 0$ ($i = 1 \sim 5$), and the electrical length conditions and resonance frequency expressions are shown in Table 1.

Table 1. Electrical length condition and frequency expression of six modes in proposed resonator. (c is the speed of light in free space and ε_e is the equivalent dielectric constant of microstrip).

Mode	Electrical Length Condition	Frequency
1	$\theta_1 = \pi/2$	$c/((4L_1 + 2L_2)\sqrt{\varepsilon_e})$
2	$\theta_2 = \pi$	$c/(2(L_4 + L_3)\sqrt{\varepsilon_e})$
3	$\theta_2 = \pi$	$c/(2(L_4 + L_3)\sqrt{\varepsilon_e})$
4	$\theta_2 + \theta_3 = \pi/2$	$c/(4(L_4 + L_3 + d_3)\sqrt{\varepsilon_e})$
5	$\theta_1 + \theta_2 + \theta_3 = \pi$	$c/(4(L_4 + L_3 + d_3)\sqrt{\varepsilon_e})$
6	$\theta_2 + \theta_3 = \arctan\sqrt{\frac{Y_1}{2Y_2}}$	$\frac{\arctan\sqrt{\frac{Y_1}{2Y_2}}\,c}{\pi(L_4+L_3+d_3)\sqrt{\varepsilon_e}}$

3. DUAL-BAND FILTER ON WIFI CHANNEL

For demonstration, a compact dual-band microstrip filter using the proposed resonator is designed in 2.4 GHz/5.2 GHz of WIFI channel. Figure 3 shows the layout of the proposed dual-band filter. A pair of square loops is loaded on a half-wavelength resonator (HWR). Assigning the values of lengths L_1, L_2, L_3 and L_4 according to Table 1, mode 1 resonates at 2.4 GHz while modes 2 & 3 resonate at 5.2 GHz. For simplicity, assigning the length of $L_1 + 0.5L_2$ is equal to the length of $L_3 + L_4$, then modes 4 & 5 will resonate near 2.4 GHz and can be adjusted by gap of d_3. Resonant frequency of mode 6 is near 5.2 GHz and can be adjusted by the gap of d_3 and ratio of Y_1 to $2Y_2$. Resonant frequency variation by gap of d_3 is shown in Figure 4. It can be observed that the resonant frequencies of modes 1 & 2 & 3 keep stable, and resonant frequencies of modes 4 & 5 & 6 decrease while d_3 increases. In addition,

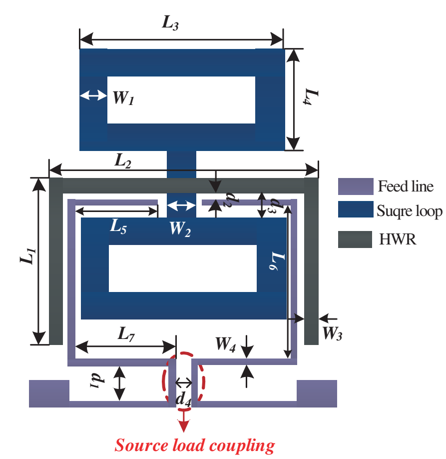

Figure 3. Layout of proposed dual-band filter ($L_1 = 7.25$ mm, $L_2 = 9.74$ mm, $L_3 = 8.3$ mm, $L_4 = 4.7$ mm, $L_5 = 1.9$ mm, $L_6 = 6$ mm, $L_7 = 3$ mm, $d_1 = 0.15$ mm, $d_2 = 0.25$ mm, $d_3 = 0.77$ mm, $d_4 = 1.1$ mm, $W_1 = 0.3$ mm, $W_2 = 0.6$ mm, $W_3 = 1.2$ mm, $W_4 = 0.2$ mm).

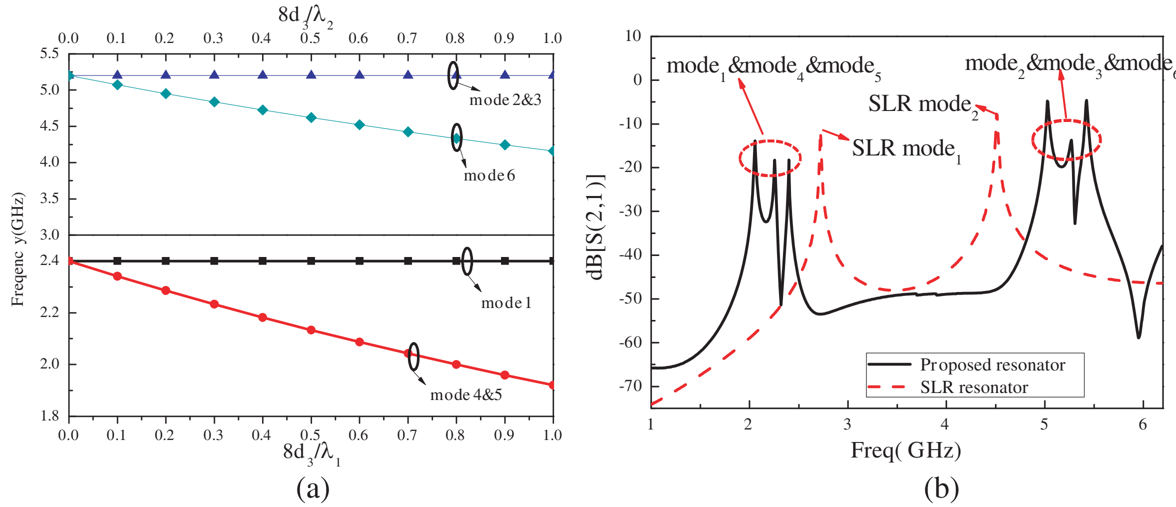

Figure 4. (a) The resonant frequency variation by gap of d_3 (The ratio of Y_1 to $2Y_2$ is set to be 1; λ_1 and λ_2 are the wavelength of 2.4 GHz and 5.2 GHz in free space). (b) Resonant modes of proposed resonator compared with SLR modes.

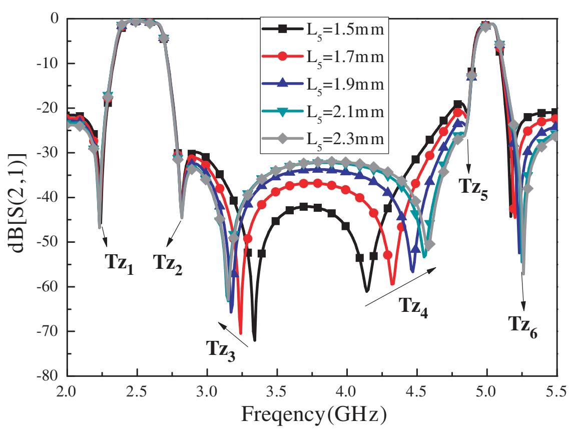

Figure 5. The variation of transmission zeros by length of L_5.

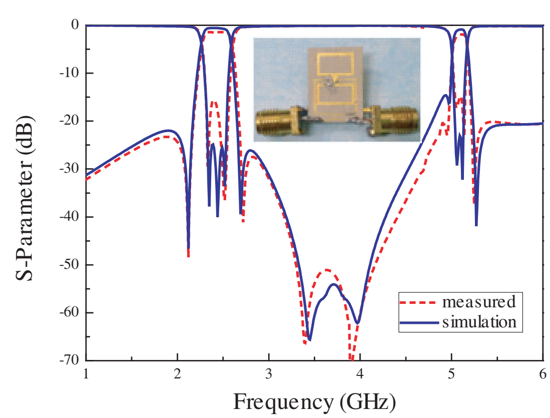

Figure 6. Results of proposed dual-band filter.

modes 1 & 4 & 5 almost resonate at the same frequency of 2.4 GHz, and modes 2 & 3 & 6 resonate at 5.2 GHz. Figure 4 shows the transmission parameter of the proposed filter compared with SLR under weak feeding.

To enhance the frequency selectivity of the proposed dual-band filter, a pair of coupling feed lines is designed as shown in Figure 3. The input and output feed lines are coupled with each other to construct a source-load coupling structure to generate transmission zeros. As a result, there six transmission zeros in transmission parameter of the proposed filter. Figure 5 shows the six transmission zeros and their variation by length of L_5. It can be observed that Tz_1 and Tz_2 are located around the first passband, and Tz_5 and Tz_6 are near the second passband. These four transmission zeros are generated by the source load coupling structure. Tz_3 and Tz_4 are located between the two passbands and influenced by the length of feed line which can be controlled by length L_5. When the length of L_5 increases from 1.5 mm to 2.3 mm, Tz_3 moves to lower frequency while Tz_4 moves to higher frequency.

According to the above analysis, adopting the proposed hexa-mode resonator and a pair of source-load coupling feed lines, a dual-band filter operating at WIFI channel is designed on the substrate with a relative dielectric of 10.2 and thickness of 0.65 mm. Simulation and optimization are performed by IE3d.

Figure 6 shows a photograph of fabricated filter. The circuit size is approximately 12.5 mm $*$ 17.2 mm. Measurement is performed on Agilent 5071C PNA. The measured results are in good agreement with simulated ones, as illustrated in Figure 5. Some slight discrepancies between simulation and measurement may be due to unexpected tolerances in fabrication. Good frequency selectivity is achieved by introducing six transmission zeros. Six transmission zeros are located at 2.1 GHz, 2.6 GHz, 3.4 GHz, 4 GHz, 5 GHz and 5.3 GHz.

4. CONCLUSIONS

A hexa-mode resonator with a pair of square loops is presented. To demonstrate the performance of the proposed resonator, a dual-band filter is designed, fabricated and measured, which possesses excellent selectivity, low insertion loss and return loss. Due to the inherent characteristics of the proposed resonator, six transmission zeros are generated at the band edges to improve the selectivity of the filter, which make the proposed filter attractive for WIFI systems.

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