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COMPACT DUAL-MODE OPEN STUB-LOADED RESONATOR AND BPF

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Abstract—A compact dual-mode open stub-loaded resonator and bandpass filter (BPF) is proposed in this paper. The resonator, which is formed by attaching a disc-shaped open stub and circular open stubs in pairs to a high impedance microstrip line, generates two operating modes in the desired band, and the even-mode resonance frequency can be flexibly controlled by the disc-shaped open stub at central plane, whereas the odd-mode one is fixed. The four transmission zeros are created to sharpen the rejection skirt, suppress two high harmonic resonant modes and deepen upper-stopband, respectively. Experimental results of the dual-mode filter which incorporates this resonator with parallel-coupled feed line with tuning stub at 5.8 GHz show good agreement with the simulated ones. The size for the resonator is only 4.7 × 3.4 mm ($0.29\lambda_g \times 0.21\lambda_g$ in which λ_g is the guided wavelength of 50 Ω microstrip at 5.8 GHz).

1. INTRODUCTION

As wireless communication technology develops rapidly, the microstrip filters with high frequency selectivity, compact size, and wide stopband are highly demanded [1–4]. The primary planar microstrip dual-mode filter was presented by Wolff [5]. Since then numerous researchers have proposed various dual-mode resonator configurations. Several types of dual-mode microstrip resonators with perturbation element have been investigated, including EBG-based resonator [6], ring resonator [7], square-ring resonator [8], multi-arc resonators [9]. The dual-mode here means two degenerate resonant modes of the aforementioned geometrically symmetrical resonator, and the two

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degenerate resonant modes may be split by introducing a perturbation element in a resonator. The filter in [6–9] using degenerate modes of the resonator has two transmission zeros near the lower and upper cut-off frequencies, leading to sharper rejection skirt outside the desired passband. Recently, the dual-mode resonators that even and odd modes do not couple have been investigated with an analysis method of the even and odd mode resonances. In [10], the loading element inside the open loop does not affect the odd-mode characteristic, and the two operating modes of the resonator do not couple, even with a mode split. The dual-mode open-loop resonator is applied to design a four-pole filter with two transmission zeros on each side of the passband by implementing nonresonating nodes. A dual-mode open loop resonator with perturbation element is presented in [11], and the filter exhibits a desirable stopband response where the first spurious passband naturally occurs at $3f_0$. However, the high harmonic resonant frequency of the even and odd mode resonators can not be well suppressed.

In this paper, a novel compact BPF with good out-band rejection performance is realized using the dual-mode open stub-loaded resonator. The proposed resonator shown in Figure 1 is simple in structure, configured by attaching a disc-shaped open stub and circular open stubs in pairs to a high impedance microstrip line. The advantageous feature of the resonator is that the operating even-mode resonance frequency can be controlled exclusively by the disc-shaped open stub. By feeding this resonator with parallel-coupled feed line with tuning stub at two sides, a dual-mode BPF at 5.8 GHz can be constructed. The four transmission zeros are created to sharpen the rejection skirt, suppress two high harmonic resonant modes and deepen

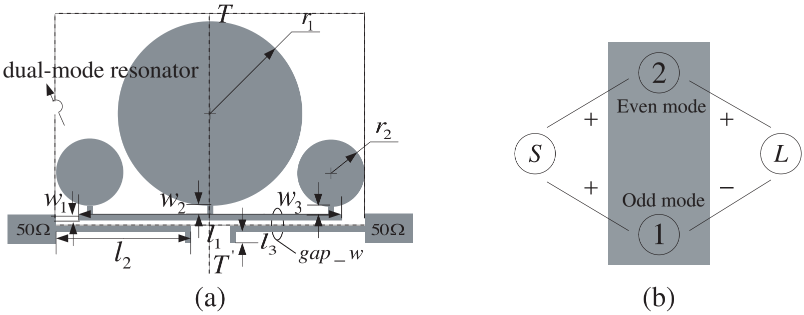


Figure 1. Schematic and coupling scheme of the proposed dual-mode BPF. (a) Schematic and (b) coupling scheme.

upper-stopband, respectively. The BPF is designed and fabricated, and the measured results show excellently agreement with the simulated ones.

2. PROPOSED DUAL-MODE RESONATOR AND BPF

The proposed dual-mode resonator is formed by attaching a disc-shaped open stub (r_1) and circular open stubs (r_2) in pairs to a high impedance microstrip line (l_1, w_1). Since the resonator is symmetrical to the T-T' plane, the odd-mode and even-mode method can be employed to analyze it [10, 11]. Voltage (current) vanishes in the disc-shaped open stub, leading to the approximate transmission line circuit models represented in Figures 2(a) and (b). It can be observed from the Figure 2 that odd-mode resonance frequencies are merely correlated to the circular open stubs in pairs and high impedance microstrip line, whereas those of even excitation are exclusively determined by the disc-shaped open stub.

The open stub-loaded resonator is coupled to 50 Ω input/output feeding lines through weakly capacitive coupling line length (l_2) of 0.5 mm in order to investigate its resonant behaviour. Figure 3(a) interprets the simulated S_{21}-magnitude of the resonator circuit under the weak coupling case with $l_3 = 0$ mm, $gap = 0.1$ mm and varied r_1. As radius r_1 of disc-shaped open stub varying from 1.25 mm to 1.65 mm, the operating even-mode (f_{m2}) and two high harmonic resonance modes (h_{m1}, h_{m2}) tend to shift downwards in the range of 0.1–24 GHz, whereas the operating odd-mode (f_{m1}) keep almost unchanged. Since the symmetrical plane of the resonator is a virtually

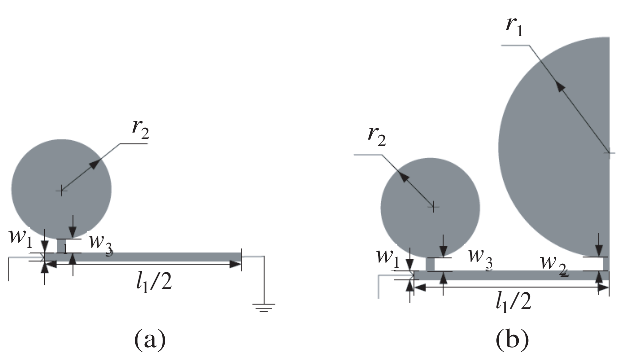
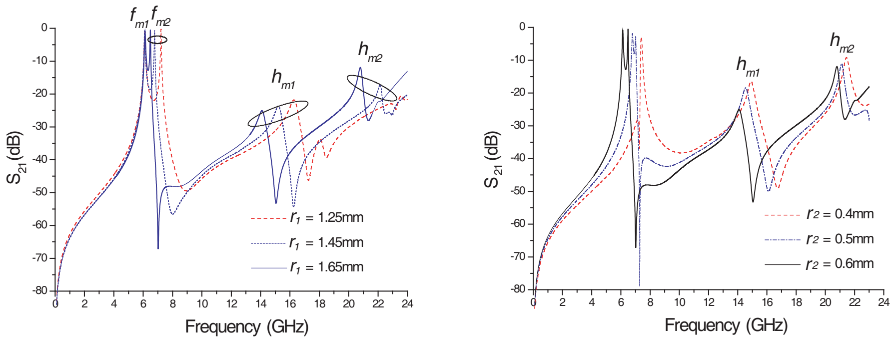


Figure 2. (a) Odd-mode equivalent circuit, and (b) even-mode equivalent circuit.



(a) (b)

Figure 3. Simulated S_{21}-magnitudes of weak coupling dual-mode resonator with $gap\_w = 0.1\,\text{mm}$, $l_1 = 4.7\,\text{mm}$, $l_2 = 0.5\,\text{mm}$, $l_3 = 0\,\text{mm}$, $w_1 = 0.1\,\text{mm}$, $w_2 = w_3 = 0.13\,\text{mm}$, (a) with fixed $r_2 = 0.6\,\text{mm}$ and varied r_1, (b) with fixed $r_1 = 1.65\,\text{mm}$ and varied r_2.

perfect electrical wall in the case of odd-mode, disc-shaped open stub at centre plane has nearly no effect on its current distribution. All the resonant modes move towards in the range of 0.1–24 GHz, as shown in Figure 3(b), while changing the radius r_2 of the circular open stubs in pairs from 0.4 mm to 0.6 mm. Thus, the circular open stubs varied r_2 can provide an additional degree of freedom to adjust the locations of the resonant frequencies in an alternative way.

Based on the aforementioned dual-mode open stub-loaded resonator, the operating even and odd resonant modes can be used to make up of a compact BPF. The input/output parallel-coupled feed line with tuning stub which is applied to obtain good match can provide sufficiently strong coupling degree to form the passband which shifts towards the lower frequency a little. The frequency response of the filter at 5.8 GHz is simulated and shown in Figure 5. As shown in Figure 1(a), a transmission zero can be created near the passband due to the main path signal counteraction, as explained in [12]. Due to even-mode f_{m2} greater than odd-mode f_{m1} in the passband, the transmission zero (f_{z1}) near the cut-off frequency would be in the upper stopband [13]. Two transmission zeros f_{z2} and f_{z4} excited by the circular open stubs in pairs are applied to suppress the high harmonic resonant frequencies h_{m1} and h_{m2}, leading to wide upper-stopband performance of the filter [14]. The transmission zero (f_{z3}) produced by input/output parallel-coupled feed line deepens the upper-stopband [15]. The substrate used here has a relative dielectric constant of 10.5 and a thickness of 0.635 mm. The filter is simulated by

HFSS and the optimized parameters are: $l_1 = 4.7\,\text{mm}$, $l_2 = 2.4\,\text{mm}$, $l_3 = 0.2\,\text{mm}$, $w_1 = 0.1\,\text{mm}$, $w_2 = w_3 = 0.13\,\text{mm}$, $r_1 = 1.65\,\text{mm}$, $r_2 = 0.6\,\text{mm}$, $gap\_w = 0.1\,\text{mm}$, respectively.

3. EXPERIMENTAL VERIFICATION

After studying the characteristic of the filter, a compact dual-mode BPF is fabricated on the RT6010 substrate through the standard PCB fabrication process, and its photograph is shown in Figure 4. The measured frequency responses of the S-magnitude are shown in Figure 5 and illustrated good agreement with simulated results. The measured 2 dB passband is within the passband 5.64–5.98 GHz, giving a fractional bandwidth of 6% at centre frequency 5.81 GHz, and its measured return loss is less than -20 dB. Meanwhile, a wide upper-stopband with the insertion loss better than -20 dB in range of 6.5 to 21 GHz is achieved.

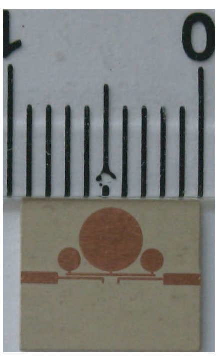


Figure 4. Photograph of the fabricated dual-mode BPF.

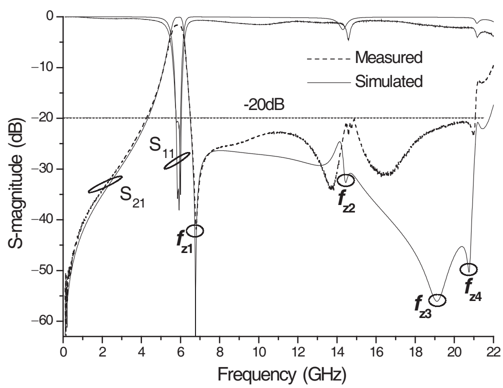


Figure 5. Simulated and measured frequency responses of the dual-mode BPF.

4. CONCLUSION

In this paper, a novel compact BPF at 5.8 GHz is proposed using the dual-mode open stub-loaded resonator. The advantageous feature of the resonator is that the operating even-mode resonance frequency can be controlled exclusively by the disc-shaped open stub. A transmission zero near the upper cut-off frequency is created to sharpen the rejection skirt due to the main path signal counteraction. Two transmission zeros are excited by the circular open stubs in pairs to suppress high harmonic resonant frequencies. Furthermore, a transmission zero produced by parallel-coupled feed line deepens the upper-stopband. The size for the resonator is only 4.7×3.4 mm ($0.29\lambda_g \times 0.21\lambda_g$ in which λ_g is the guided wavelength of $50\,\Omega$ microstrip at 5.8 GHz). The simulated results are finally verified by the experiment of the fabricated filter.

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