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HIGH SELECTIVITY BROADBAND BANDPASS FILTER WITH DUAL-MODE FOLDED-T-TYPE RESONATOR

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Abstract—In this letter, a compact and high selectivity broadband bandpass filter (BPF) is proposed using the dual-mode folded-T-type resonator and the short stub loaded parallel-coupling feed structure. The resonator can generate one even-mode and one odd-mode in the desired band. Two resonant frequencies can be adjusted easily to satisfy the bandwidth of the BPF. A parallel-coupling feed structure with a cross coupling has been applied to generate two transmission zeros in the lower and upper stopband. Furthermore, the loaded short stub can create two transmission zeros near the upper cut-off frequency and in the upper stopband. Simultaneity, the transmission zero in the lower stopband moves towards the cut-off frequency. One filter prototype with the fractional bandwidth 57% is fabricated for experimental verification of the predicted results. The size for the resonator is only $0.156\lambda_g \times 0.303\lambda_g$ in which λ_g is the guided wavelength of $50\,\Omega$ microstrip at the center frequency.

1. INTRODUCTION

Broadband BPFs with compact size and high performance are highly demanded in many wireless communication systems [1]. The planar microstrip BPF has attractive features such as easier design, easier manufacture, lower cost, smaller size and lower radiation loss. In the past, a variety of microstrip planar broadband BPFs with improved electrical and/or geometrical features has been investigated [2–12]. Dual-mode resonators are attractive because the number of resonators required for a given degree of the filter is reduced by half, resulting in a compact filter configuration [3]. As is well known, the dual-mode

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planar microstrip resonators are introduced for designing a compact filters [3–12]. Several types of dual-mode resonators with perturbation element have been investigated, including EBG-based resonator [4], ring resonator [5], square-ring resonator [6], multi-arc resonators [7]. Subsequently, the dual-mode resonators whose odd- and even-modes do not couple have been given in [8]. The open stubs can suppress the high harmonic resonant modes; therefore, a compact BPF using the open stub loaded dual-mode resonator in [9, 10] is presented with wide upper stopband performance. Nevertheless, the lower stopband suppression is as important as the higher one. A dual-mode open loop resonator with perturbation element in [11] is applied to design a compact filter with two transmission zeros on each side of the passband and the filter exhibits a desirable stopband response where the first spurious passband naturally occurs at $3f_0$. Furthermore, a broadband BPF with the fractional bandwidth 45% in [12] is designed with a dual-mode resonator composed of single stub at the center plane and two sections of transmission lines. However, the selectivity of the filter needs to be improved.

In this letter, a compact and high selectivity broadband BPF with the fractional bandwidth 57%, as shown in Figure 1, is proposed using the dual-mode folded-T-type resonator and the short stub loaded parallel-coupling feed structure. The even-mode resonant frequency can be flexibly controlled by the middle microstrip line, whereas the odd-mode one is fixed. Four transmission zeros are generated near the cut-off frequencies and in the stopband by the short stub loaded parallel-coupling feed structure. The good agreement between the simulated and measured results demonstrates our proposed structure.

2. DUAL-MODE BROADBAND FILTER

As shown in Figure 1, The dual-mode folded-T-type resonator formed by two microstrip lines is very compact in size, due to the folded

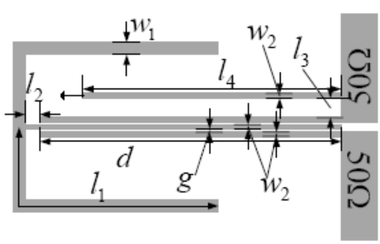

Figure 1. Schematic of the dual-mode broadband filter.

microstrip line instead of the linear one [13]. Since the resonator is symmetrical to the centre plane, the odd-even-mode method can be implemented. Voltage (current) vanishes in the centre plane, leading to the approximate transmission line circuit models represented in Figures 2(a) and (b). θ_1 and θ_2 refer to the electrical lengths of the sections with lengths l_1 and $l_2 + d$, respectively. Y_1 and Y_2 separately refer to characteristic admittances of the widths w_1 and $w_2/2$.

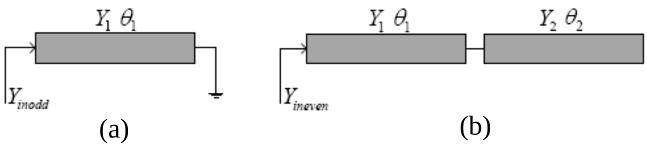

Figure 2. (a) Odd-mode equivalent circuit. (b) Even-mode equivalent circuit.

From the conditions $Y_{\text{inodd}} = 0$ and $Y_{\text{ineven}} = 0$, the odd- and even-mode resonant frequencies f_{odd} and f_{even} can be extracted [11]:

$$\cot\theta_1 = 0 \tag{1}$$

$$Y_1 \tan\theta_1 + Y_2 \tan\theta_2 = 0 \tag{2}$$

From the formula (1), the odd-mode resonant frequencies can be expressed as:

$$f_{\text{odd}} = \frac{(2n+1)c}{4l_1\sqrt{\varepsilon_e}} \tag{3}$$

where c is the speed of light and ε_e is effective permittivity.

The resonant frequencies of even excitation exclusively depend on the middle microstrip line. We may choose the parameters of the low impedance line and the substrate: $l_1 = 11.5$ mm, $w_1 = 0.5$ mm, $h = 0.508$ mm and $\varepsilon = 2.2$. Resonant-mode frequencies varied the length $l_2 + d$ of the middle microstrip line with fixed $w_2 = 0.2$ mm are interpreted in Figure 3. As the length $l_2 + d$ increases, merely even-mode resonant frequencies move towards the lower frequency. There are two resonant-mode frequencies in the range of 0.1–9.5 GHz: $f_{m1} = 4.505$ GHz and $f_{m2} = 5.027$ GHz, where the length l_2+d is equal to 13.1 mm.

The dual-mode folded-T-type resonator coupling to the parallel-coupling feed structure with and without the loaded short stub is simulated by HFSS. The parameters of the gap and the loaded short stub are optimized and obtained: $g = 0.1$ mm, $d = 12.5$ mm, $l_3 = 1.0$ mm and $l_4 = 10.8$ mm. The simulated frequency responses are interpreted in Figure 4. It can be seen that there are four transmission

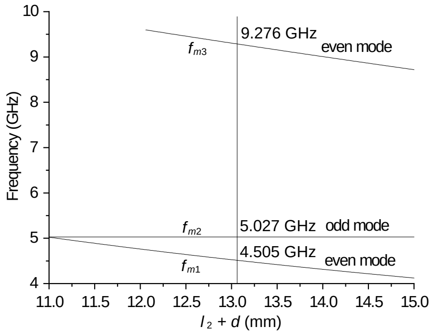

Figure 3. Even-mode resonant frequencies varied l_2+d with fixed $w_2 = 0.2\,\text{mm}$.

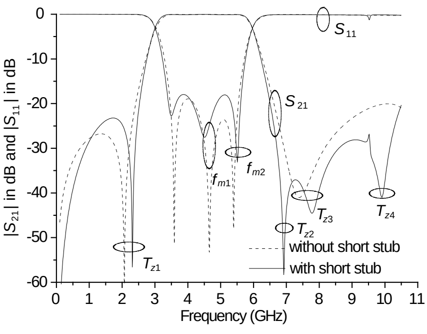

Figure 4. Simulated frequency responses of the broadband BPF with and without the loaded short stub.

zeros and three resonant frequencies (even-mode frequency f_{m1}, odd-mode one f_{m2} and the resonant frequency created by the parallel-coupling line [14]). The transmission zeros T_{z1} and T_{z3} in the lower and upper stopband are attributed to the ended-coupling between the $50\,\Omega$ input/output feed lines [11]. Compared to the simulated results of the filter with the loaded short stub, two additional transmission zeros T_{z2} and T_{z4} can be generated near the upper cut-off frequency and in the upper stopband by the loaded short stub, which improves sharp upper skirt and deep upper stopband. Simultaneity, the transmission zero T_{z1} moves towards the lower cut-off frequency.

3. EXPERIMENTAL RESULTS

To validate the above design approach, the compact and high selectivity dual-mode broadband BPF with the loaded short stub is fabricated on the RT/Duroid 5880 substrate and its photograph is shown in Figure 5. The filtering performance is measured by Agilent

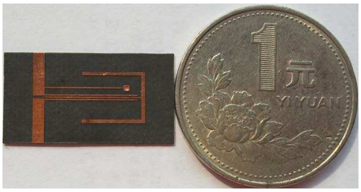

Figure 5. Photograph of the implemented broadband BPF.

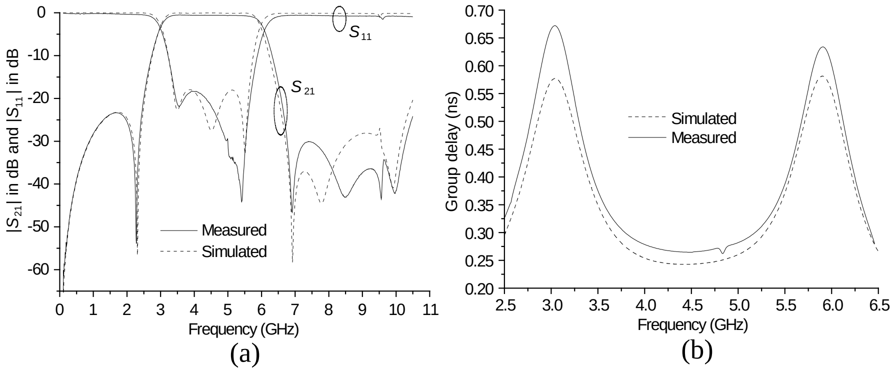

Figure 6. Simulated and measured frequency responses of the broadband BPF with high selectivity. (a) $|S_{21}|$ in dB and $|S_{11}|$ in dB. (b) Group delay.

network analyzer N5230A. The measured $|S_{11}|$ in dB and $|S_{21}|$ in dB as well as group delay are shown in Figure 6 and illustrated good agreement with simulated results. The measured 1 dB passband is in the range of 3.22 to 5.79 GHz and its measured input return loss ($|S_{11}|$ in dB) is less than -15.1 dB. Two transmission zeros T_{z1} and T_{z2} are located at 2.28 GHz and 6.91 GHz with an attenuation level of less than -47 dB, resulting in sharp roll-off. The upper stopband in experiment is extended up to 10.7 GHz with an insertion loss better than -30 dB. In addition, the measured in-band group delay is varying from 0.27 to 0.6 ns, which is quite small and flat in all the passband.

4. CONCLUSION

A compact broadband BPF with high selectivity performance is proposed using the dual-mode folded-T-type resonator and the short stub loaded parallel-coupling feed structure. Four transmission zeros are created near the cut-off frequencies and in the stopband by the feed structure, leading to high selectivity and deep upper stopband. A dual-mode broadband filter with the fractional bandwidth 57% is simulated and fabricated. The size for the resonator is only $0.156\lambda_g \times 0.303\lambda_g$ in which λ_g is the guided wavelength of $50\,\Omega$ microstrip at 4.5 GHz. The measured results agree well with the EM simulations.

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