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A NOVEL DUAL-MODE BANDPASS FILTER USING STUB-LOADED DEFECTED GROUND OPEN-LOOP RESONATOR

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Abstract—A novel dual-mode bandpass filter (BPF) using stub-loaded defected ground open-loop resonator is proposed in this article. Defected arrow-shaped stub is loaded to a defected ground open-loop resonator, and two non-degenerate modes are excited for dual-mode characteristics. Based on even- and odd-mode theory, dual-mode characteristics of the resonator is analyzed. Design equations for the defected-ground resonator are investigated. A two-pole dual-mode bandpass filter operating at 2.4 GHz with fractional bandwidth of 7.97% is designed, fabricated, and measured. Good agreement between simulated and measured results verifies the validity of this design methodology.

1. INTRODUCTION

Compact, high performance microwave bandpass filters (BPFs) are widely used in wireless communication systems. Dual-mode resonators are attractive because each dual-mode resonator can be used as a doubly tuned resonant circuit. Therefore, the number of resonators required for a given degree of filter is reduced by half, and the size of the filter decreases. The dual-mode microstrip bandpass filters was firstly proposed using a dual-mode ring resonator by Wolff [1]. Two degenerate modes of the resonator are excited and coupled to each other by orthogonal feed lines. To date, various types of microstrip filters have been proposed, including circular ring [1, 2], square loop [3], and square patch [4]. Dual-mode BPFs have been designed using stepped-impedance resonator in [5, 6]. In [7], dual-mode filter is realized by using a pentagon loop defected ground resonator. Recently,

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dual-mode characteristic is achieved by loading a stub to the center of a resonator [8, 9]. And dual-mode bandpass filter (BPF) using stub-loaded defected ground open-loop resonators is proposed in [10]. The loaded stub is used to excite non-degenerate modes for dual-mode characteristics.

In this paper, a novel dual-mode bandpass filter (BPF) using $\lambda/2$ defected ground open-loop resonator is proposed. The filter is compact because it is about half of traditional filter using open-loop resonator. A defected arrow-shaped stub is loaded to the center of a defected ground open-loop resonator to excite an additional non-degenerate mode. Consequently, dual-mode characteristics are obtained in one resonator. Furthermore, the mechanism of the proposed dual-mode resonator filter is investigated in detail by using even- and odd-mode analysis. Finally, this proposed filter is verified by simulation and measurements.

2. ANALYSIS OF DEFECTED GROUND OPEN-LOOP RESONATOR

The Configuration of the proposed defected ground dual-mode BPF is illustrated in Figure 1. The filter consists of two layers, i.e., the top microstrip layer (MSL) and the bottom defected ground layer (DGL).

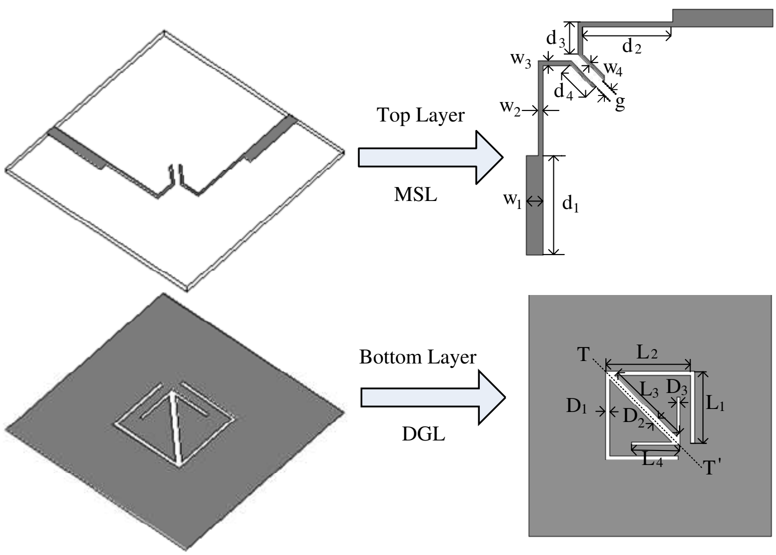

Figure 1. Configuration of the defected ground open-loop filter.

On the top layer, two hook-shaped microstrip feed lines are utilized to achieve the desired coupling between resonator and microstrip feed lines. On the bottom layer, a defected ground open-loop resonator is etched on the backside metallic ground plane. Different from traditional open-loop resonators, this open-loop resonator is opened at a symmetrical corner. The schematic view of the defected ground open-loop resonator is given in Figure 2. A defected ground arrow-shaped stub is loaded to the center of the defected ground open-loop resonator to excite non-degenerate modes for dual-mode characteristics. The first mode (odd mode) is determined the defected ground open-loop resonator itself, while the second mode (even mode) is related to the defected arrow-shaped stub. Because of the symmetric structure, even-mode and odd-mode analysis can be used to explain its resonant characteristics. The equivalent circuits of the defected ground open-loop resonator for even-mode and odd-mode are shown in Figure 3.

For even mode excitation, the symmetry plane TT' of the dual-mode resonator as shown in Figure 2 is considered as a magnetic wall and its equivalent circuit is given in Figure 3(a). The defected ground resonator works like a half wave-length resonator, and its resonant condition can be described by

$$Z_2'^2 \tan\theta_3 \tan\theta_4 - Z_2' Z_3 + Z_1 Z_2' \tan\theta_0 \tan\theta_4 + Z_1 Z_3 \tan\theta_0 \tan\theta_3 = 0 \quad (1)$$

where $\theta_0 = \theta_1 + \theta_2 = \beta(L_1 + L_2)$ and Z_1 are the electrical length and characteristic impedance of the defected ground open-loop resonator respectively. $\theta_3 = \beta L_3$, $\theta_4 = \beta L_4$, and Z_2', Z_3 are the electrical length and characteristic impedance of the loaded defected stub after it is cut by the symmetry plane TT', respectively. Resonant frequency of

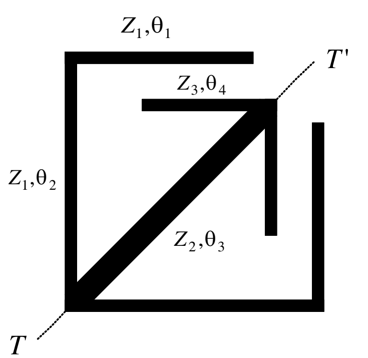

Figure 2. Schematic view of the proposed dual-mode defected ground resonator.

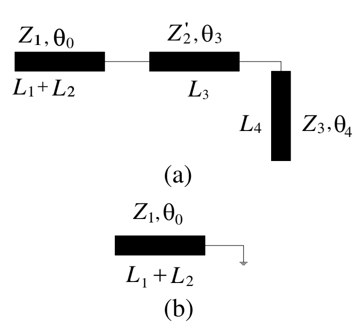

Figure 3. Equivalent circuit at (a) even mode, and (b) odd mode.

the even-mode is determined by both the defected ground open-loop resonator and the defected arrow-shaped stub.

For odd mode excitation, the symmetry plane TT' is considered as an electrical wall and its equivalent circuit is shown in Figure 3(b). The defected ground open-loop resonator works like a quarter wavelength uniform impedance resonator at odd-mode resonant frequency. The resonant condition is described as

$$\theta_0 = \theta_1 + \theta_2 = \frac{\pi}{2} \tag{2}$$

Obviously, the resonant frequency of the odd-mode is only determined by the length of defected ground open-loop resonator.

3. ANALYSIS OF TRANSMISSION ZEROS

There are two transmission zeros in the stopband of the filter. Assume that the frequencies of the transmission zeroes in the lower and upper stopbands are f_{zero1} and f_{zero2}, respectively. The position of transmission zeros against d_4 with $L_4 = 6$ mm is shown in Figure 4(a). When d_4 increases from 1 to 6 mm, f_{zero1} decreases from 1.68 GHz to 1.25 GHz, while f_{zero2} is fixed at 2.7 GHz. Figure 4(b) shows the position of transmission zeros against L_4 with $d_4 = 2.8$ mm. When L_4 increases from 4 to 7 mm, f_{zero2} decreases from 3.2 GHz to 2.5 GHz, while f_{zero1} is fixed at 1.5 GHz. Clearly, the transmission zero in the lower stopband is produced by the source-load coupling, and the transmission zero in the upper stopband is produced by the defected ground open-loop resonator itself.

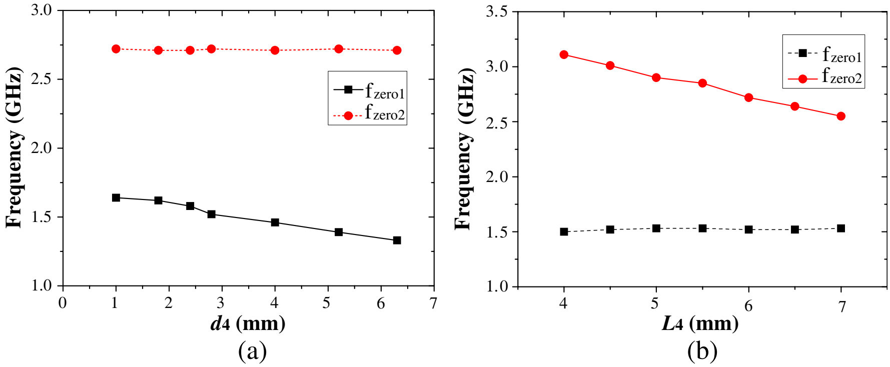

Figure 4. Transmission zero characteristic of the proposed filter (a) with $L_4 = 6$ mm and (b) with $d_4 = 2.8$ mm.

4. FILTER DESIGN AND EXPERIMENT

A dual-mode bandpass filter with central frequency of 2.4 GHz and equal ripple of 0.05 dB is designed based on the proposed resonator. The size of the defected ground open-loop resonator can be calculated by

$$\lambda_g = c/(f \times \sqrt{\varepsilon_{rD}}) \tag{3}$$

where c is the velocity of light in free space, f is the center frequency of the defected ground open-loop resonator, ε_{rD} is the effective relative permittivity of defected ground structure. A substrate with dielectric constant of $\varepsilon_r = 4.5$ and a thickness of $h = 0.8$ mm is used in the design. Obtained parameters of the filter shown in Figure 1 are $W_1 = 1.5$ mm, $W_2 = W_3 = W_4 = 0.4$ mm, $d_1 = 9.1$ mm, $d_2 = 8.2$ mm, $d_3 = 3$ mm, $d_4 = 3$ mm, $L_1 = 9$ mm, $L_2 = 10.5$ mm, $L_3 = 12$ mm, $L_4 = 6$ mm, $D_1 = 0.5$ mm, $D_2 = 1$ mm, $D_3 = 0.4$ mm, and $g = 0.8$ mm. Figure 5 shows a comparison between the measured and simulated results of the proposed filter. Dashed and solid lines indicate the simulated and measured results, respectively. Disregard the frequency shift between simulated and measured results which may be caused by the dielectric constant inaccuracy, good agreement is obtained between the measured and simulated insertion losses and return losses. The passband's return loss of the designed dual-mode filter is better than −18 dB. The simulated −18 dB bandwidth covers the frequency range from 2.29 to 2.48 GHz. Two transmission zeros at about 1.52 GHz and 2.72 GHz are clearly observed, which improve the skirt selectivity of the filter greatly. Due to the resonance of the extended feed lines, the rejection

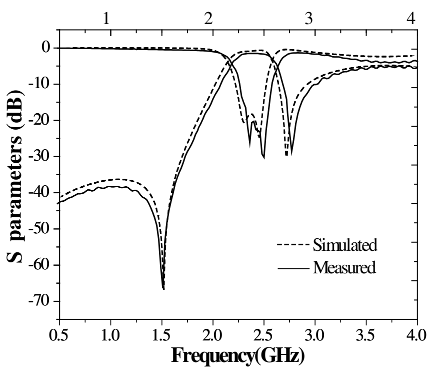

Figure 5. Simulated and measured results of the proposed filter.

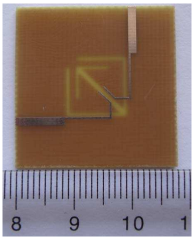

Figure 6. A photograph of the fabricated filter.

in upper stopband becomes poor. It can be improved by increasing g. A photograph of fabricated circuit is presented in Figure 6.

5. CONCLUSION

In this paper, a novel dual-mode bandpass filter (BPF) using $\lambda/2$ dual-mode open-loop defected-ground resonator is proposed. Defected arrow-shaped stub is analyzed and used to excite non-degenerate modes for dual-mode characteristics. Two transmission zeros near the transition band improve stopband characteristic of the filter. The presented filter has the advantages of simple structure, compact size and good skirt selectivity.

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