A Novel Dual-Mode Bandpass Filter Based on a Defected Waveguide Resonator

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A novel dual-mode bandpass filter (BPF) using a dual spiral-shaped defected ground waveguide (DGW) resonator is proposed in this letter. The dual-mode characteristic of this filter is achieved by loading a defected T-shaped stub at the midline of the spiral-shaped DGW resonator. Also, non-orthogonal input and output feed-lines are adopted in the filter. Based on the compact DGW structure, a dual-mode BPF with central frequency of 1.5 GHz for the global positioning system is designed, fabricated, and measured. Measured results agree well with the predicted response and verify the proposed methodology.

Keywords: Defected ground waveguide, dual-mode, bandpass filter, global positioning system (GPS).

I. Introduction

Microstrip filters have been widely used in wireless communication systems. To meet the demand of wireless communication systems for compact size and high-performance filters, there has been a growing interest in dual-mode filters. The planar dual-mode resonator was first presented by Wolff [1]. Then, several types of dual-mode microstrip resonators have been reported, such as the circular ring, meander loop, circular patch, triangle patch, and hexagonal ring [2]-[6], and so on. On the other hand, several

techniques are applied to excite the two degenerate modes of the resonator, including corner cut, attached patch, and slots. In [7], two spur-lines are symmetrically attached to the ring resonator to obtain the dual-mode characteristics. Recently, microwave bandpass filter (BPF) circuits are popularly designed on the ground plane, such as slotline with defected ground structure (DGS) stubs [8], defected resonator [9], defected stepped impedance resonator [10], and so on. However, dual-mode characteristics of some defected structures are rarely mentioned for circuit synthesis. In our previous work [11], a dual-mode defected ground waveguide (DGW) resonator is introduced. It provides a simple way for realizing dual-mode filter by fully utilizing the printed circuit board. Compared to the traditional DGS resonator with bandstop characteristics, this DGW resonator can provide bandpass characteristics in some special frequency bands.

In this letter, a novel dual-mode BPF based on DGW resonator is proposed. The input and output ports are arranged in-line. There is a defected T-shaped open-stub located at the center of the uniform impedance resonator. The T-shaped loading stub is folded to a spiral shape for the size reduction of the circuit. The dual-mode characteristic is obtained by changing the length of the stub. Also, the even-odd mode analysis for this resonant circuit is given. Finally, based on the proposed structure, a dual-mode BPF with central frequency of 1.5 GHz for global positioning system (GPS) application is designed and fabricated to verify the proposed procedure.

II. Dual-Mode DGW Resonator

Figure 1 shows the schematic view of the proposed dual-mode BPF using DGW resonator. Figure 1(a) indicates the top view of the filter, where non-orthogonal input and output

Fig. 1. Layout of proposed dual-mode DGW filter: (a) top view and (b) bottom view.

Fig. 2. (a) Simplified open-loop DGW resonator with stub-loaded and (b) its transmission characteristic versus length l of loading stub.

Fig. 3. Equivalent circuit model for proposed resonator: (a) odd mode and (b) even mode.

microstrip feed lines are adopted. Figure 1(b) shows its bottom view, where a novel stub-loaded DGW resonator is applied to realize the dual-mode characteristic. This spiral DGW resonator consists of two spirals connected in series. Compared to the traditional open-loop resonator, this spiral-shaped structure is a more compact and efficient utilization of a limited area.

The dual-mode characteristic is realized by loading a defected T-shaped stub at the center of the dual spiral-shaped DGW resonator. A simplified open-loop DGW resonator is used to analyze its dual-mode characteristic, as shown in Fig. 2(a). There is an open stub loaded inside the center of the uniform impedance DGW resonator. The stub has the same width with the open-loop resonator and its length is l. Weak coupling is applied in the simulation to decrease the influence of input and output lines to the resonator. Figure 2(b) shows the resonant characteristic of the resonator against the length of the stub l. When no loading stub, that is to say l=0, the second resonant frequency (even mode) is about twice of the fundamental mode (odd mode) of the DGW resonator. When increasing the length of the loading stub, the second resonant mode of the resonator moves toward the fundamental mode. The dual-mode characteristic can be obtained by changing the length of the loading stub. A substrate with a relative dielectric constant of ε_r=4.5 and a thickness of h=0.8 mm is used in the simulation.

To explain the above-mentioned resonant characteristic of the resonator, its equivalent circuit model is set up. The resonator can b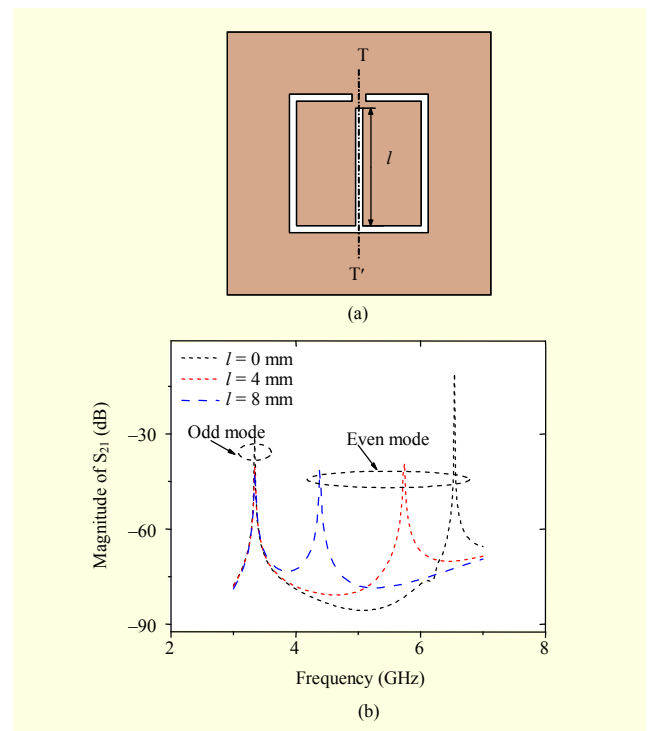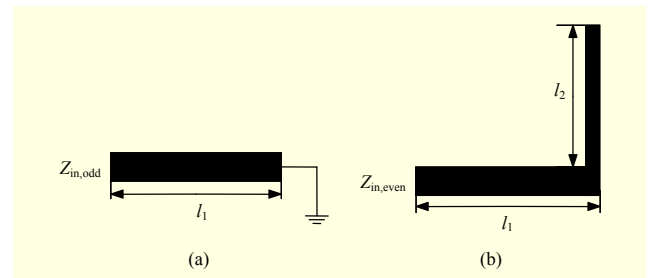e analyzed in terms of even and odd mode theory with respect to the symmetrical plane T-T′, as shown in Fig. 2(a). The odd modes occur when the symmetrical plane TT′ behaves as an electrical wall, as shown in Fig. 3(a). The resonator can be modeled as a quarter-wavelength short-circuited transmission line. Its resonant frequency is determined by

$$f_{\text{odd}} = \frac{(2n-1)c}{l_1\sqrt{\varepsilon_{\text{eff}}}}, \qquad (1)$$

where n=1, 2, 3,…, c is the velocity of light in the free-space and ε_{eff} denotes the effective dielectric constant of the slot line. The resonant frequency of the odd modes of the resonator is mainly determined by the length of the open-loop resonator $2l_1$.

On the other hand, the even modes occur when the

symmetrical plane TT′ behaves as a magnetic wall. The resonator can be modeled as a half-wavelength open-circuited transmission line. Its resonant frequency is determined by

$$f_{\text{even}} = \frac{nc}{(l_1 + l_2)\sqrt{\varepsilon_{\text{eff}}}}, \tag{2}$$

where $n=1, 2, 3,\ldots$, c is the velocity of light in the free-space and ε_{eff} denotes the effective dielectric constant of the slot line. Resonant frequency of even modes of the resonator is mainly determined by the length of the open-loop resonator and the loading stub. Keeping l_1 stable and increasing the length l_2 of the loading stub, the fundamental mode remains unchanged while the second resonant mode f_{even} of the resonator will move towards the fundamental mode. Thus, a dual-mode characteristic can be achieved by tuning the length of the loading stub.

III. Simulation and Measurement

To confirm the above-mentioned analysis, a BPF with central frequency of 1.5 GHz for GPS application is designed using the proposed DGW structure. To improve the slow-wave effect for miniaturation, the defected open-loop resonator is folded as a spiral shape, and the defected loaded stub is also folded to a spiral T-shaped stub, as shown in Fig. 1. The substrate used in this design has a relative dielectric constant of ε_r=4.5 and a thickness of h=0.8 mm. Dimensional parameters of the filter are optimized and shown as follows: L_1=11.2 mm, L_2=6.7 mm, L_3=1.3 mm, L_4=3.2 mm, L_5=5.9 mm, W_1=0.4 mm, and W_2=0.5 mm.

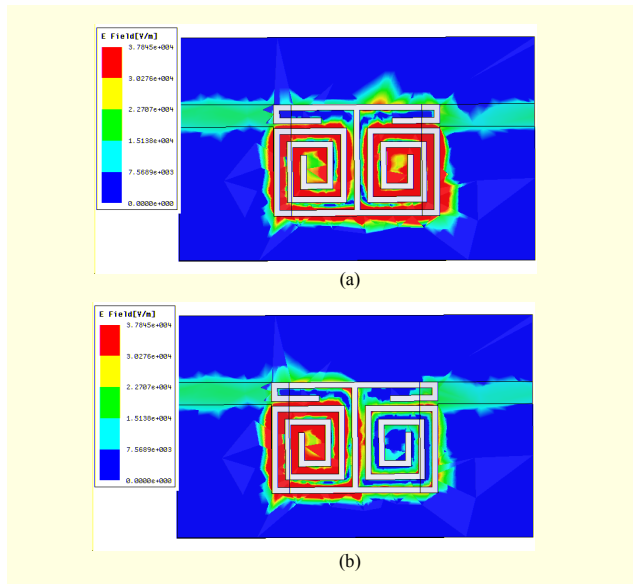The proposed filter was simulated, fabricated, and measured.

Fig. 4. Current density distribution over dual-mode filter layout at mode resonances: (a) 1.51 GHz and (b) 1.54 GHz.

Current density distributions of this designed dual-mode filter are shown in Fig. 4. Figure 4(a) shows current distribution of the odd mode, which mainly covers the whole DGW resonator. Figure 4(b) shows current distribution of even mode, which mainly covers left half of the DGW resonator. Photographs of the fabricated proposed filter are shown in Fig. 5, where it occupies only about $0.10\lambda_g \times 0.07\lambda_g$. The fabricated filter is measured using vector network analyzer HP8722ES. When performing the measurement, the circuit is incorporated in a metallic shielding box. To decrease the effect of the shielding box on the filter, the circuit is suspended on the middle layer of the box. The height of the circuit and the length between the top layer of the filter and the cover are about $\lambda/2$ [12]. A comparison between the simulated and measured results are shown in Fig. 6, where the dashed line indicates the simulated results using HFSS 10.0 and the solid line indicates the
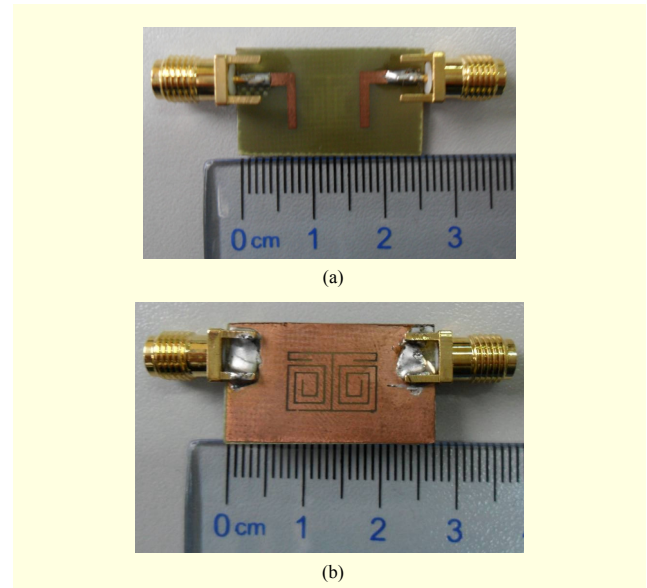

Fig. 5. Photographs of proposed filter: (a) top view and (b) bottom view.
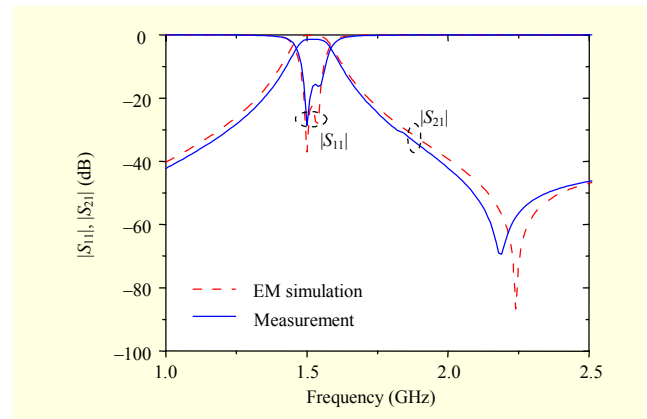

Fig. 6. Comparison between simulated and measured results.

measured results. Measured results agree well with the simulated response and verify the proposed procedure. Interestingly, there is a transmission zero at about 2.2 GHz with −60 dB attenuation, which greatly improved the stopband characteristic of the filter. Measured insertion loss in the passband of the filter is less than 1.5 dB, and the return loss in the passband is larger than −16 dB.

IV. Conclusion

In this letter, a novel compact dual-mode BPF using DGW was proposed for GPS application. The dual-mode characteristic is achieved by introducing a tuning T-shaped stub inside the spiral open-loop ring resonator. The input and output ports are arranged in-line that is convenient to interconnect with other components. The filter is very compact and occupies only about $0.10\lambda_g \times 0.07\lambda_g$. The transmission zero is produced and greatly improved the selectivity and stopband suppression. Good agreement between the simulated and measured results demonstrates the proposed filter design.

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