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COMPACT DUAL-MODE DGS RESONATORS AND FILTERS

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Abstract—A novel and compact dual-mode defected ground structure (DGS) resonator is presented. Distinct characteristics of the proposed resonator are investigated. Using this type of resonator, a bandpass filter with the center frequency of 2.38 GHz and the fractional bandwidth of 6.7% is simulated and fabricated. The results show that this filter not only has an inherent transmission zero near the passband, but also has a very wide upper stopband with rejection better than 20 dB up to about 12 GHz.

1. INTRODUCTION

Modern communication systems require bandpass filters with low insertion loss, high selectivity as well as compact size. Dual-mode resonators attract much attention recently because they can reduce the number of resonators required for a same degree filter by half. Dual-mode resonators with two degenerate modes are usually in the forms of a square patch [1], a circular disk [2] or a circular ring [3]. However, they have disadvantages in the resonator size. For example, $S_{patch} \approx (\lambda_g/2)^2$, $S_{disk} \approx (1.84\lambda_g/\pi)^2$, $S_{ring} \approx (\lambda_g/\pi)^2$, where λ_g is the guided wavelength of central frequency [4]. A lot of structures have been investigated to reduce the size of the dual-mode resonators, such as cross-slotted patch [5], square ring [4], meandering ring [6], multi-arc ring [7], capacitive loaded ring [8, 9] and stub-loaded ring [10]. But still, the sizes of the resonators in modern communication systems are fairly large.

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Meanwhile, dual-mode resonators with two non-degenerate modes, such as the open-stub loaded dual-mode resonators [11] and the short-stub loaded dual-mode resonators [12], attract more attentions, since they are much smaller in size, and have the advantages in design flexibility and inherent zero. The open-stub loaded resonator has a size of about $\lambda_g/8$ by $\lambda_g/8$ [11], and the short-stub loaded resonator may be designed to be much more compact [12]. Nevertheless, feed structures of the circuits using dual-mode resonators, such as bandpass filters with source-load coupling [13, 14] and dual-band filters [15, 16], cannot be designed flexibly. Therefore, dual-mode resonators with flexible feeding schemes are highly desired. DGS resonators, on the other hand, have advantages in design flexibility and have been used in the design of bandpass filters [17, 19], multi-band bandpass filters [20, 21], lowpass filters [22, 23] and bandstop filters [24] successfully. However, they are only single-mode resonators, which result in a large circuit size.

In this paper, a novel dual-mode DGS resonator is proposed. It has two non-degenerate modes and an inherent transmission zero. This type of resonator has a compact size similar to the open-stub loaded dual-mode resonator [11]. Because of its defected ground structure, the feed structure can be designed very flexibly. Based on this type of resonator, a bandpass filter is designed and fabricated. It not only has a compact size and an inherent transmission zero near the passband, but also has a very wide upper stopband to improve the selectivity.

2. DUAL-MODE DGS RESONATOR

The proposed resonator is shown in Fig. 1(b). The bottom metal regions are depicted in gray. The resonator is developed from a square open-loop DGS resonator [17], which is a folded slot etched on the ground plane. It occupies a square area with sides of L_1; the slot width is W_1 and the length of the shorted slot stub is L_4, as shown in Fig. 1(a). Two slots with dimensional parameters of W_2, L_2 and W_3, L_3 are etched in the inner square patch of the open-loop DGS resonator to form a dual-mode DGS resonator. It could be considered as a combination of two separate resonators. Such as when $W_3 = 0\,\text{mm}$, the dual-mode DGS resonator becomes an open-loop DGS resonator with a slot (W_2, L_2), as shown in Fig. 1(c); and when $L_4 = L_1/2$, the inner patch forms a stepped impedance open-loop resonator in the ground, as shown in Fig. 1(d).

For the purpose of demonstration, frequency response simulation of the resonators with a weak couple was carried out using the full-wave simulator ANSOFT HFSS. The simulated results are shown in Fig. 2. It can be observed that, the slot (W_2, L_2) helps to lower the

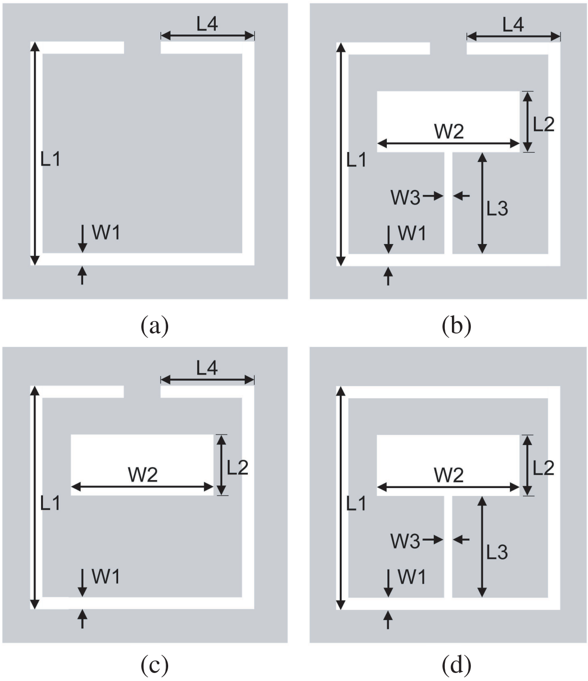

Figure 1. Different types of resonators: (a) open-loop DGS resonator, (b) dual-mode DGS resonator, (c) open-loop DGS resonator with a slot (W_2, L_2), (d) open-loop resonator in the ground. The parameters are: $L_1 = 13\,\text{mm}$, $L_2 = 3\,\text{mm}$, $L_3 = 5\,\text{mm}$, $L_4 = 6\,\text{mm}$, $W_1 = 0.4\,\text{mm}$, $W_2 = 10.2\,\text{mm}$, $W_3 = 0.2\,\text{mm}$. The substrate with relative permittivity of 2.55, thickness of 0.8 mm is used.

resonant frequency of the open-loop DGS resonator, and the resonant frequencies of the dual-mode DGS resonator are combination of the resonant frequencies of the resonators shown in Fig. 1(c) and Fig. 1(d). And these two modes almost have no effect with each other. Thus, the two modes are two non-degenerate modes. Also, like the open loaded open-loop dual-mode resonators [11], a transmission zero is generated by this type of resonator. The transmission zero is inherent and always located at a finite frequency since the coupling strength between the external feeding network and the two modes are different [25].

Eigen mode property of the dual-mode DGS resonator has also been studied by the Eigen mode simulator of ANSOFT HFSS. Electric field vectors of two modes are shown in Fig. 3. Fig. 3(a) presents the electric field patterns at the lower resonant frequency and shows

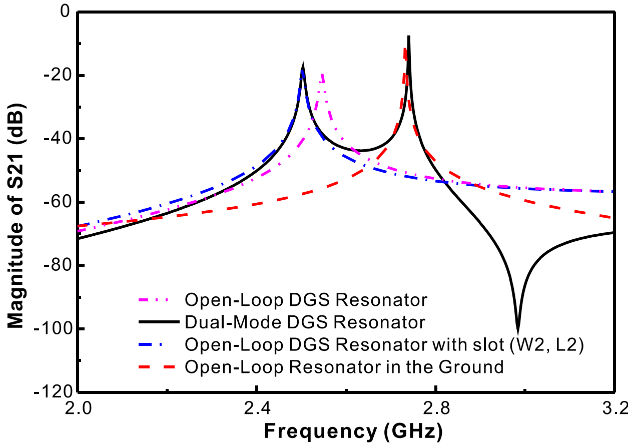

Figure 2. Resonant properties of different types of resonators.

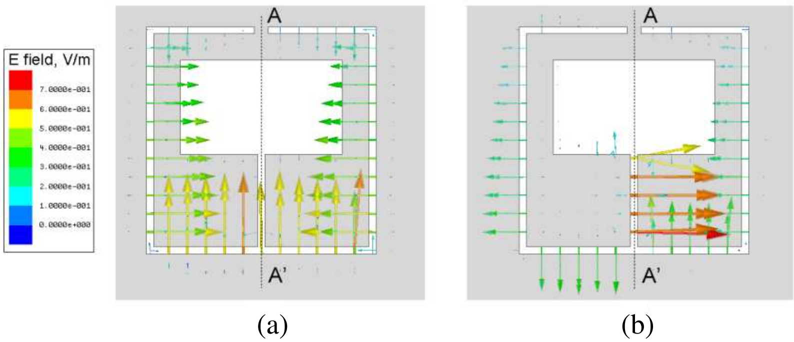

Figure 3. Simulated electric field patterns for dual-mode DGS resonator: (a) even-mode, (b) odd-mode.

a symmetric property along the symmetry line A-A'. Thus, it is an even-mode, and it corresponds to the resonance of the open-loop DGS resonator with a slot (W_2, L_2). Also, at the higher resonant frequency, an odd mode can be observed from Fig. 3(b). It corresponds to the resonance of the stepped impedance open-loop resonator formed by the inner patch with two slots.

The resonant frequencies of the two modes could be controlled separately. As shown in Fig. 4(a), the resonant frequency of the odd-mode can be adjusted by changing L_2 while keeping other dimensional parameters fixed; the resonant frequency of the even-mode keeps

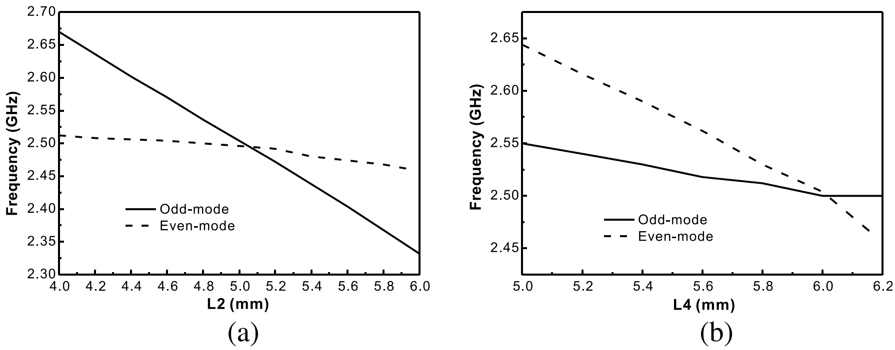

Figure 4. (a) Simulated resonant frequencies of the resoantor against L_2, (b) simulated resonat frequencies of the resonator against L_4.

basically unchanged at the same time. Moreover, the resonant frequency of the even-mode can be adjusted by changing L_4 while keeping other dimensional parameters fixed, meanwhile, the resonant frequency of the odd-mode slightly changed because of the layout of the stepped impedance open-loop resonator has been slightly changed, as shown in Fig. 4(b). Similar to the open-stub loaded dual-mode resonator, the position of the inherent transmission zero could be controlled to locate at the lower or higher side of the two modes while the resonant frequency of the odd-mode is lower or higher than that of the even-mode.

3. DUAL-MODE BANDPASS FILTER

Based on the resonator proposed above, a bandpass filter with the center frequency of 2.38 GHz and the fractional bandwidth of 6.7% has been designed and fabricated. The layout of this filter is shown in Fig. 5. The top metallic layer is depicted in black. Two open microstrip stubs are used as feed lines. Photograph of the proposed filter is shown in Fig. 6.

The substrate with relative permittivity of 2.55, thickness of 0.8 mm is used. The circuit parameters are: $L_1 = 13$ mm, $L_2 = 5$ mm, $L_3 = 5.3$ mm, $L_4 = 6.1$ mm, $L_5 = 13$ mm, $W_0 = 2.2$ mm, $W_1 = 0.4$ mm, $W_2 = 9$ mm, $W_3 = 0.4$ mm, $W_4 = 1$ mm, $S = 0$ mm. The simulated results obtained by ANSOFT HFSS and measured ones obtained by the network analyzer RS ZVM are shown in Fig. 7.

As shown in Fig. 7(a), the measured center frequency is at 2.4 GHz, the measured 3 dB fractional bandwidth is about 7.5%, and

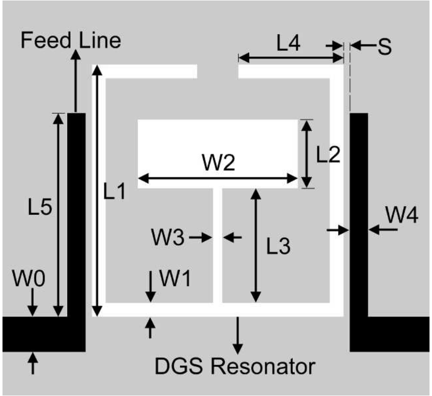

Figure 5. Layout of the proposed bandpass filter.

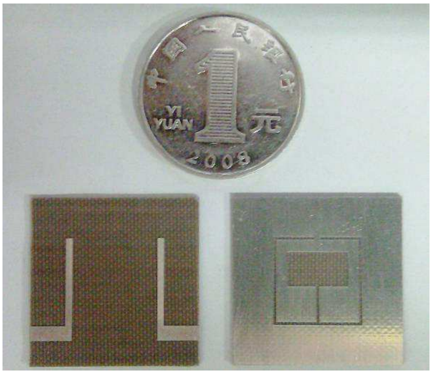

Figure 6. Photograph of the fabricated bandpass filter.

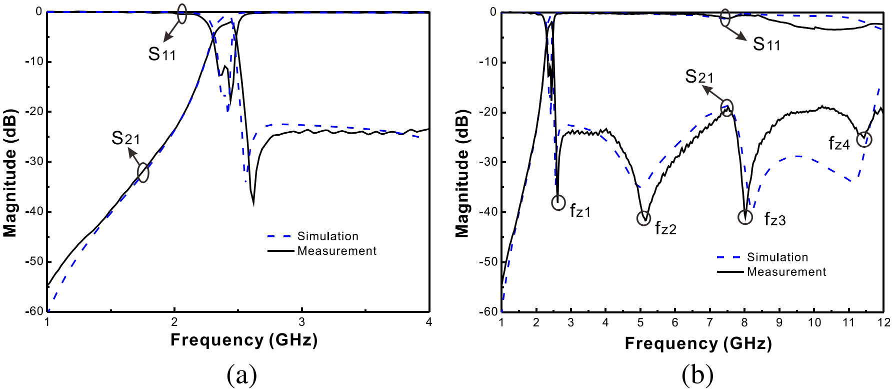

Figure 7. Simulated and measured results of the proposed filter: (a) narrowband response, (b) wideband response.

the minimal insertion loss is 2.01 dB. There is an inherent transmission zero at 2.6 GHz (f_{z1}). Moreover, three more transmission zeros (f_{z2}, f_{z3}, f_{z4}) are generated by this type of filter, as shown in Fig. 7(b). The transmission zeros f_{z2}, f_{z3} and f_{z4} correspond to the resonance of the input microstrip stub [18]. Therefore, a very wide upper stopband with rejection better than 20 dB up to about 12 GHz is realized. The simulated and measured results agree well, and the discrepancy is mainly caused by the tolerance of the fabrication process.

4. CONCLUSION

A novel and compact dual-mode DGS resonator is presented, and its two operating modes of the resonator have been investigated by full-wave analysis. A bandpass filter based on the resonator is designed and fabricated. The whole filter has a size around 15 × 15 mm ($0.175\lambda_g \times 0.175\lambda_g$ in which λ_g is the guided wavelength of 50 Ω microstrip at 2.4 GHz). The test results agree well with the simulated ones. It is shown that this type of filter not only has an inherent transmission zero, but also has a very wide stopband to improve the selectivity.

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