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MINIATURIZED DUAL-MODE SUBSTRATE INTEGRATED WAVEGUIDE (SIW) BAND-PASS FILTERS LOADED BY DOUBLE/SINGLE T-SHAPED STRUCTURES

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Abstract—A new class of miniaturized dual-mode substrate integrated waveguide (SIW) band-pass filters is proposed, which are loaded by double/single T-shaped structures. By introducing a double T-shaped structure in original dual-mode SIW band-pass filter, the resonant frequency is lowered from 9.46 GHz to 8.91 GHz due to the longer effective length. The introduced single T-shaped structure performs an even lower resonant frequency of 6.88 GHz for the same reason. Compared with dual-mode band-pass filters in references, the proposed dual-mode SIW band-pass filters with double/single T-shaped structures have the advantages such as compact size (like microstrip dual-mode filters) and high Q factors (like SIW dual-mode filters). The proposed filters are fabricated and measured, and the experimental results are in good agreement with simulated ones.

1. INTRODUCTION

There is a great demand of band-pass filters with compact size, low insertion loss, easy manufacture and low-cost. Filters implemented in standard waveguide technology exhibit high performance, but they are bulky, heavy and expensive. On the other hand, microstrip filters present low cost, but low Q-factors and high radiation losses. Recently, substrate integrated waveguide (SIW) has provided a very attractive platform to the novel designed filters with excellent characteristics of low-cost, low-profile, high Q factors and highly integrated waveguide [1–3]. It is synthesized on a planar substrate with linear periodic arrays of metallic vias by standard printed circuit board

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(PCB) or low-temperature co-fired ceramic (LTCC) [4]. However, the sizes of current SIW filters are larger than their microstrip or CPW counterparts.

In many papers, plenty of compact planar band-pass filters using dual-mode resonators have been proposed. In order to realize a band-pass filter, two degenerate modes of a dual-mode resonator are excited and coupled to each other by orthogonal feed lines and variety forms of perturbations [5–7]. Because of degenerate modes, the dual-mode resonators can be used as a doubly tuned resonant circuit, thus the number of filters for a given degree is reduced by half [8–10]. Dual-mode filters based on microstrip square-loop structures [11, 12] have lower Q factors than those based on SIW. At the same time, dual-mode filters based on SIW cavity [13, 14] have larger sizes than those based on microstrip square-loop structures, which are compact due to their longer effective lengths.

In this paper, a new class of dual-mode SIW band-pass filters loaded by double/single T-shaped structures is proposed with compact sizes and high Q factors. A comparative study is carried out to exhibit the resonance behaviors of original dual-mode structure and two proposed structures. Compared with dual-mode filters in [11–14], compact sizes as microstrip filters and high unloaded Q factors as SIW filters are achieved in the proposed filters with double/single T-shaped structures. Two dual-mode SIW band-pass filters are then designed with suitable adjustment of T-shaped branch lengths by parameter analysis. Finally, two miniaturized dual-mode SIW band-pass filters are fabricated to provide experimental verification on predicted results.

2. FILTER DESIGN AND ANALYSIS

Figure 1 shows configurations of the double/single T-shaped dual-mode SIW band-pass filters. The double T-shaped dual-mode SIW band-pass filter shown in Figure 1(a) consists of a square slotted dual-mode patch SIW filter with two T-shape branches. As shown in Figure 1(b), the single T-shaped dual-mode SIW filter has only one T-shaped branch which is introduced for further miniaturization. Following the physical parameters listed in Table 1, these two filters are formed on cheap substrate of Rogers RT/duriod 5880 (tm) with dielectric constant of $\varepsilon_r = 2.2$, loss tangent $\delta = 0.0009$ and $h = 0.508\,\text{mm}$. Frequency responses of the proposed filters are numerically simulated by Ansoft HFSS 11.

The coupling scheme of double/single T-shaped dual-mode SIW band-pass filters is shown in Figure 2. When the input and output feed-lines are introduced, two orthogonal modes TE_{102} and TE_{201}

will be excited. Simultaneously, the coupling scheme among source, load, resonator 1 and 2 is realized properly, where TE_{102} and TE_{201} modes in the dual-mode SIW cavity correspond to resonators 1 and 2, respectively.

The current density patterns of three dual-mode SIW resonators named resonators (a)–(c) are shown in Figure 3. An orthogonal input/output (I/O) feed line has been used in original dual-mode SIW resonator, on the surface of which double T-shaped structure [15] is etched to increase effective length, thus decreasing the resonant

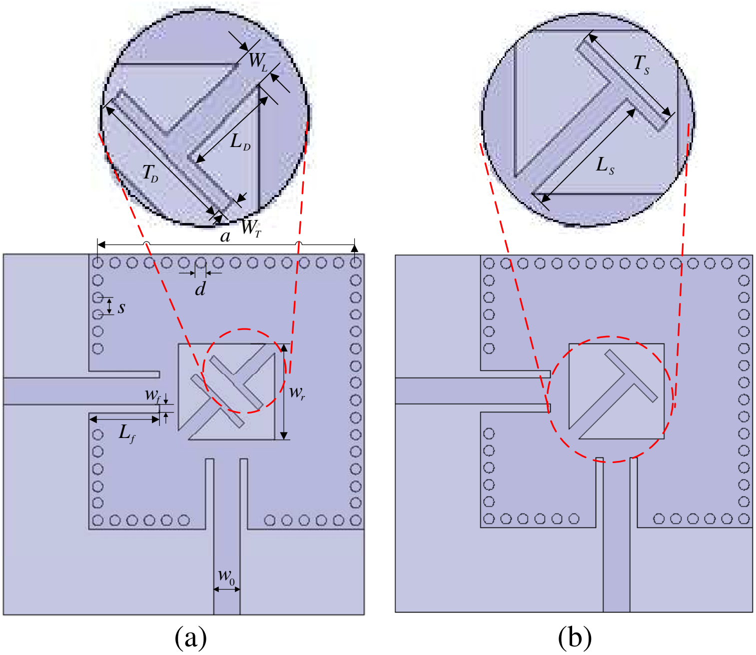


Figure 1. Configurations of the proposed dual-mode SIW band-pass filters with (a) double T-shaped/(b) single T-shaped structures.

Table 1. Physical parameters of proposed dual-mode SIW filters (unit: mm).

Symbol	Value	Symbol	Value	Symbol	Value	Symbol	Value
a	15	s	1	d	0.6	L_f	3.6
W_f	0.45	W_L	0.8	L_D	3	W_T	0.4
T_D	4	W_r	5.6	L_S	5	T_S	3.4

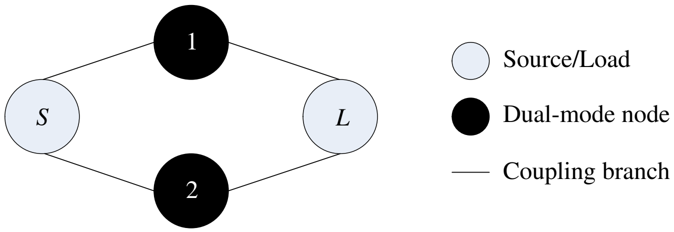


Figure 2. Coupling scheme of double/single T-shaped dual-mode SIW band-pass filters.

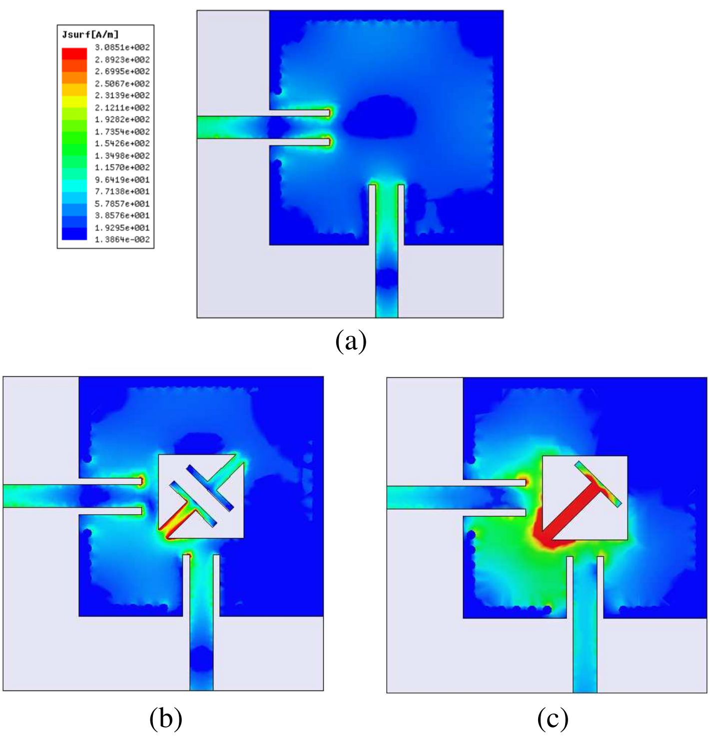


Figure 3. Current density patterns of three dual-mode SIW resonators. (a) Original filter at 9.46 GHz, (b) filter loaded by double T-shaped structure at 8.91 GHz, and (c) filter loaded by single T-shaped structure at 6.88 GHz.

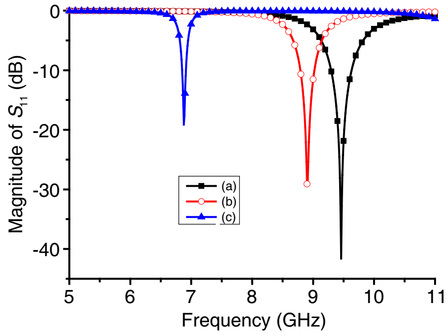


Figure 4. Simulated S_{11} parameters for three resonators in Figure 2. (a) Original filter, (b) filter loaded by double T-shaped structure, and (c) filter loaded by single T-shaped structure.

frequency. The current density pattern of resonator (b) illustrates that the down left T-shaped branch has a stronger impact on the resonator than the top right one. Therefore resonator (c) in Figure 3 with single T-shaped structure is supposed to further reduce the resonant frequency or miniaturize the overall size of the resonator.

Figure 4 shows simulated magnitudes of S_{11} for three resonators in Figure 3 and validates the analysis above. The resonant frequency of resonator (a) is 9.46 GHz with an area of 21 mm × 21 mm. As the double T-shaped structure ($L_D = 3$ mm and $T_D = 4$ mm) is centrally loaded on resonator (a), the resonant frequency of resonant (b) is reduced to 8.91 GHz with the same size. The single T-shaped resonator ($L_S = 5$ mm and $T_S = 3.4$ mm), i.e., resonator (c), which has the same size with resonator (a) and (b), exhibits an even more lower resonant frequency of 6.88 GHz. The decreased resonant frequencies lead up to miniaturization of the band-pass filters eventually. The dimensions of original SIW resonator with the same resonant frequencies of double/single T-shaped resonators are 22 mm × 22 mm and 27 mm × 27 mm, respectively. The proposed double/single T-shaped loaded filter reduced the occupied areas up to 8.9% and 39.5% respectively, compared with original dual-mode SIW filter. Therefore, the proposed double/single T-shaped structures, especially the single T-shaped structure, can miniaturize the size of dual-mode SIW band-pass filter effectively.

The characteristics of proposed double/single T-shaped dual-mode SIW band-pass filters are sensitive to the lengths of T-shape branches, which are marked as L_D, T_D, L_S and T_S in Figure 1, while the widths of T-shaped branches have small influence on the proposed filters.

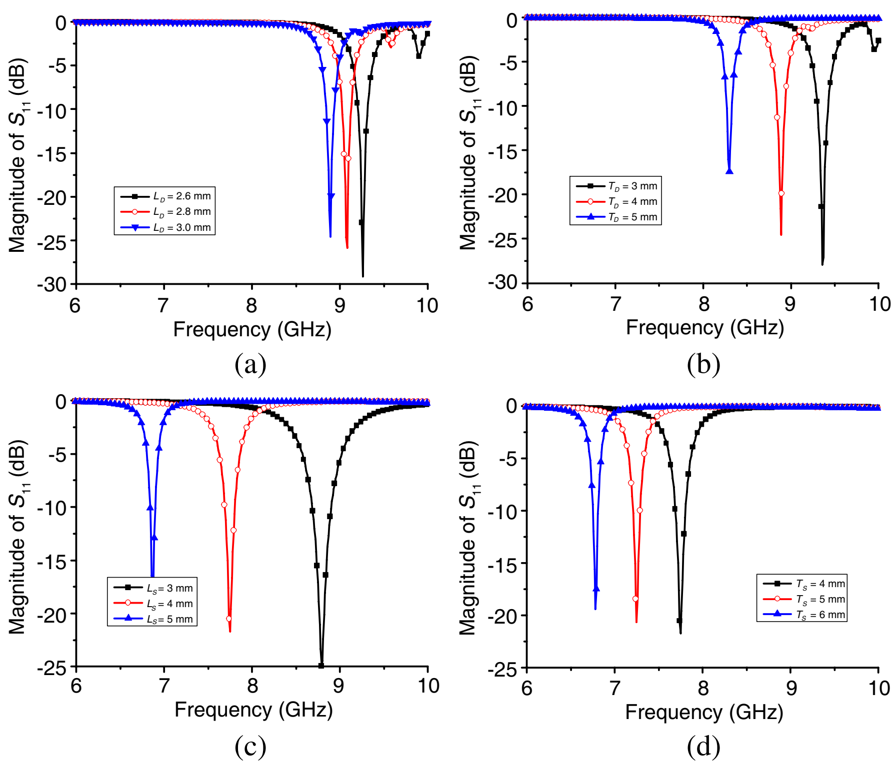


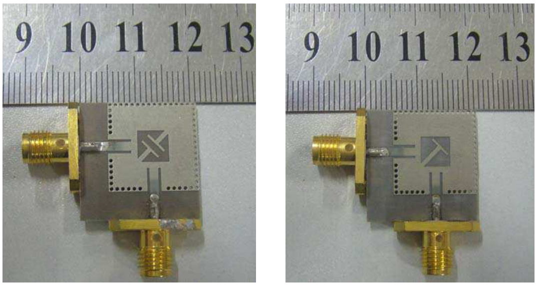
Figure 5. Simulated S_{11} parameters for different values of (a) L_D ($T_D = 4\,\text{mm}$), (b) T_D ($L_D = 3\,\text{mm}$) in double T-shaped structure and (c) L_S ($T_S = 4\,\text{mm}$), (d) T_S ($L_S = 4\,\text{mm}$) in single T-shaped structure.

Figure 5 shows simulated response of these two proposed filters with respect to L_D, T_D, L_S and T_S. The S_{11} parameters are plotted in Figures 5(a) and (b) for different values of L_D and T_D of double T-shaped dual-mode SIW band-pass filter, while Figures 5(c) and (d) indicated that L_S and T_S of the single T-shaped dual-mode SIW band-pass filter have significant effect on the performance of simulated response. As shown in Figure 5, the resonant frequencies decrease as the lengths of T branches increase. The choice of single/double T-shaped parameters as $L_D = 3\,\text{mm}$, $T_D = 4\,\text{mm}$, $L_S = 5\,\text{mm}$ and $T_S = 3.4\,\text{mm}$ is a compromise between compact size and layout. Figure 5 also illustrates that with the same area, the single T-shaped structure has a lower resonant frequency than the double one.

For comparison, the center frequency, 3 dB fractional bandwidth, normalized circuit size (NCS), minimum insertion loss of simulation,

Table 2. Performance comparisons among published SIW filters and the proposed filters.

	Simulated center frequency (GHz)	Simulated 3 dB fractional bandwidth (%)	Normalized circuit size (NCS)	Simulated minimum insertion loss (dB)	Simulated Unloaded Q-factor
Ref. [11]	2.41	4.5	0.95×0.95	1.38	151.27
Ref. [12]	2.40	12.5	0.66×0.66	0.39	182.20
Ref. [13]	14.42	2.64	1.38×1.38	2.60	146.43
Ref. [14]	5.00	4.00	1.01×1.01	0.70	322.88
Double T-shaped	8.91	6.51	0.86×0.86	0.39	349.85
Single T-shaped	6.88	2.62	0.66×0.66	1.12	315.50



(a) (b)

Figure 6. Photograph of two fabricated dual-mode SIW band-pass filters with (a) double T shaped structure, (b) single T shaped structure.

and unloaded Q factor of the proposed filters and those in references [11–14] are listed in Table 2. In this table, the normalized circuit size (NCS) is given by:

$$\text{NCS} = \text{physical size}/\lambda_g \times \lambda_g \tag{1}$$

where λ_g is the guided wavelength of the center frequency. As seen from Table 2, the proposed filters with double/single T-shaped structures have the advantages of small NCSs as microstrip filters [11, 12] and high unloaded Q factors as SIW filters [13, 14], while retain perfect performance of bandwidth and minimum insertion loss.

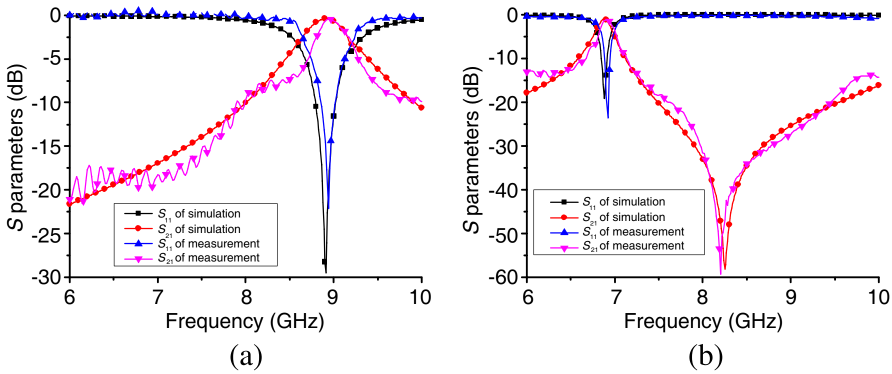


Figure 7. Simulated and measured frequency responses of two proposed dual-mode SIW band-pass filters with (a) double T-shaped structure, and (b) single T-shaped structure.

3. FILTER FABRICATION AND RESULTS

Photographs of the fabricated band-pass filters loaded by double/single T-shaped structures are shown in Figure 6. The simulated and measured S_{11} and S_{21} parameters for the proposed filters are shown in Figure 7. Good agreement can be observed between simulated and measured frequency responses of the proposed filters. The measured insertion loss at the center frequency of 8.95 GHz is −0.41 dB, as shown in Figure 7(a), while the insertion loss at the center frequency of 6.89 GHz is −1.24 dB, as shown in Figure 7(b). The fractional bandwidths are 5.41% for Figure 7(a) and 2.49% for Figure 7(b). The proposed dual-mode filters with NCS of 0.86×0.86 in the double T-shaped structure and 0.66×0.66 in the single T-shaped structure have high unloaded Q factors of 349.85 and 315.50 respectively.

4. CONCLUSION

In this paper, a new class of miniaturized dual-mode SIW band-pass filters loaded by double/single T-shaped structures is proposed. Through current density patterns of double/single T-shaped structures, the reason of miniaturization is analyzed in this paper. The resonant frequencies of the proposed structures decrease as the effective lengths increase. Compared with dual-mode band-pass filters in references, the dual-mode SIW band-pass filters with double/single T-shaped structures have the advantages of compact sizes as microstrip dual-mode filters and high Q factors as SIW dual-mode filters. The measured results validate the predicted ones well. We can conclude that the new class of double/single T-shaped structures is powerful in the exploration of size miniaturization while remains high unloaded Q factor and perfect performance.

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