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Compact Inline Triplet SIW Filter with Embedded Short-Ended Strip Line

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Abstract—A compact triplet inline substrate integrated waveguide (SIW) bandpass filter is presented with sharp lower skirt and deep lower-stopband performance. The filter is composed of two SIW rectangular cavities and an embedded short-ended strip line on the top surface of two adjacent SIW cavities. A transmission zero can be generated by the cross coupling near the lower passband edge, which allows the filter implementation in inline with sharp lower skirt. Deep lower stopband performance is inherited from SIW. To validate the concept, a filter prototype with fractional bandwidth (FBW) of 4% at 5.75 GHz is designed, fabricated and measured. Good agreement can be obtained between the measured and simulated results.

1. INTRODUCTION

Modern wireless communication systems are in constant need of filters with high performance and compact size. By introducing cross coupling between nonadjacent resonators, the generalized Chebyshev filters with finite transmission zeros gain considerable attention since they exhibit highly selective responses [1]. However, compared with their cross-coupled counterparts, the inline filters have many advantages for some specific applications [2, 3]. In the last decade, it has demonstrated that mixed couplings allow the filter to generate one or more transmission zeros in an inline topology [3, 5, 6]. Moreover, the SIW passive components have some advantages, including low loss, high Q-factor, and easy integration with other planar circuits [4]. Recently, the inline SIW filters with mixed coupling have been presented by embedding short-ended strip line [5] or etching slotlines with different shapes on the top face [6] between two adjacent SIW cavities which can introduce the electric coupling. However, the transmission zero is inherently associated with the spurious passband generated by the embedded strip line or etched slotline. Although there is no increase in circuit size, the filter exhibits poor stopband response due to the spurious passband. Once the transmission zero is allocated on the low side of passband, the spurious passband appears in lower stopband.

In this paper, as shown in Fig. 1(a), the short-ended strip line embedded on the top surface of two adjacent SIW cavities is used as a resonator rather than introducing electric coupling as usual [5, 6]. Furthermore, the dominant resonant frequency generated by the short-ended strip line can be adjusted and works together with the resonant frequencies of two SIW cavities to form a third-pole filter. The number of resonators required for a given degree is reduced, leading to a inline filter configuration with compact size. A transmission zero near the lower passband edge is generated by the cross coupling. Deep lower stopband performance is inherited from SIW. Finally, a third-order filter prototype is designed with sharp lower skirt and deep lower stopband, and good agreement can be obtained between experimental and simulated results. The filter is fabricated on an RT/Duriod 5880 substrate with a thickness of 0.508 mm, loss tangent of 0.0009, and relative dielectric constant of 2.2.

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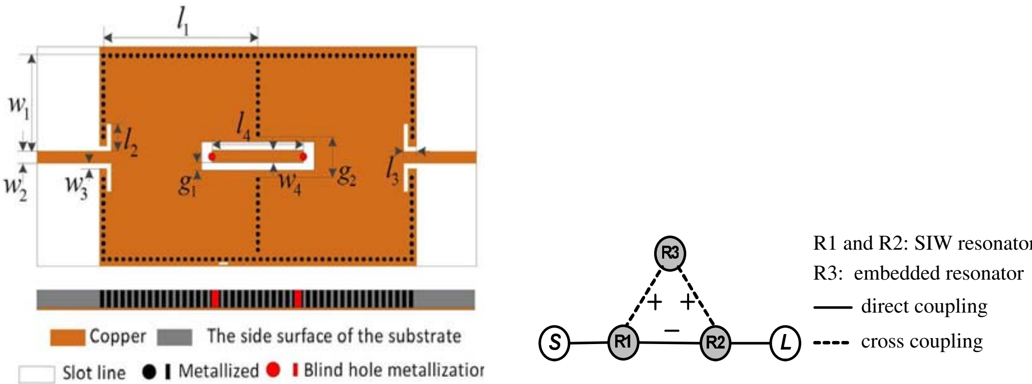
2. FILTER DESIGN

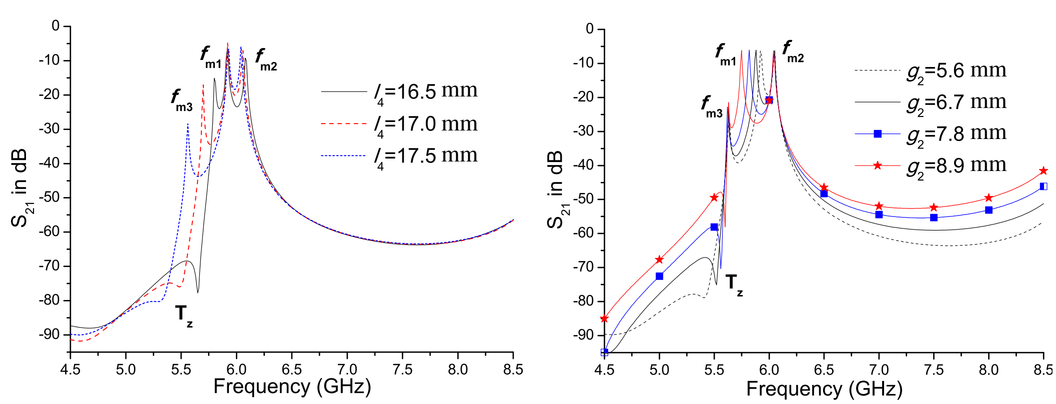
As illustrated in Fig. 1(a), the proposed bandpass filter is made up of two SIW rectangular cavities (length: l_1 and width: $w_2 + 2w_1$) and an embedded short-ended strip line (length: l_4, width: w_4 and gap: g_1) on the top surface of two adjacent SIW cavities with $50\,\Omega$ coplanar waveguide (CPW) (length: l_1+l_2, width: w_3). In [5, 6], the embedded strip line or etched slotline mainly introduces electric coupling to build the mixed coupling. From another point of view, the embedded slotline can be considered as a non-resonant node (NRN) [7]. The attenuation pole can be generated by the cross coupling through the NRN. In this paper, the embedded short-ended strip line is used as a half wavelength resonator, and the coupling scheme is illustrated in Fig. 1(b). The main coupling between two SIW resonators is magnetic coupling (negative), whereas the cross coupling between SIW resonator and embedded short-ended microstrip resonator is electric coupling (positive) [5, 6]. The resonant frequency f_{m3}, as shown in Fig. 2(a), is adjusted and works together with f_{m1} and f_{m2} created by the SIW cavities to form a third-pole filter. The formation reason of T_z on the right side of f_{m3} is interpreted as the cross coupling [8].

The specifications of the third-order filter are 4% FBW at 5.75 GHz with -13 dB return loss, and one transmission zero will be introduced at 5.63 GHz. With the filter specification and topology



(a) (b)

Figure 1. (a) Schematic, and (b) coupling scheme of the inline triplet SIW bandpass filter. ($l_1 = 22.8$ mm, $l_2 = 3.5$ mm, $l_3 = 1.3$ mm, $l_4 = 17.25$ mm, $g_1 = 0.25$ mm, $g_2 = 5.6$ mm, $w_1 = 12.5$ mm, $w_2 = 1.588$ mm, $w_3 = 0.3$ mm, $w_4 = 1.5$ mm).



(a) (b)

Figure 2. The insertion losses of the filter with varied l_4 and g_2 in the weak coupling case: (a) varied l_4 with fixed $g_2 = 5.6$ mm, (b) varied g_2 with fixed $l_4 = 17.25$ mm.

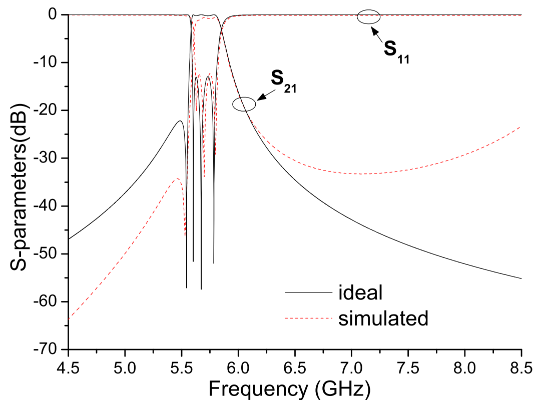


Figure 3. The ideal filter responses for the topology in Fig. 1(b) and corresponding simulated results.

defined, the normalized coupling matrix has been obtained by Eq. (1), and the ideal filter response for the topology is shown in Fig. 3.

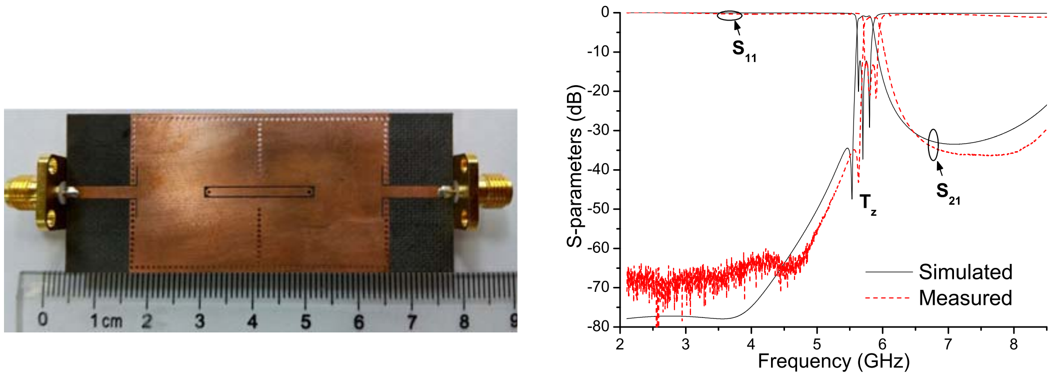
$$M = \begin{bmatrix} 0 & -0.8896 & 0 & 0 & 0 \\ -0.8896 & -0.0994 & -0.6936 & 0.5206 & 0 \\ 0 & -0.6936 & 0.5832 & 0.6936 & 0 \\ 0 & 0.5206 & 0.6936 & -0.0994 & -0.8896 \\ 0 & 0 & 0 & -0.8896 & 0 \end{bmatrix} \tag{1}$$

For the filter with 4% FBW at 5.75 GHz, $Q_{e1} = Q_{e2} = 31.6$. The sizes of the SIW cavity and 50 Ω feed line are determined as: $w_1 = 12.5$ mm, $w_2 = 1.588$ mm, $l_1 = 22.8$ mm. The circuit dimensions of the filter can be determined by applying the coupling coefficient method to meet the specifications. The external coupling with CPW feeding is controlled by l_2 and l_3 (fixed $w_3 = 0.3$ mm). The sizes of the CPW feeding are obtained by using Ansoft HFSS 13.0: $l_2 = 3.4$ mm, $l_3 = 1.3$ mm. However, it is difficult to independently and accurately extract the coupling coefficient between two resonators, because the microstrip resonator is dependent on two SIW cavities and simultaneously has a great impact on the coupling between two cavities.

In the weak coupling case, the insertion loss with varied g_2 is simulated by Ansoft HFSS and illustrated in Fig. 2(b). It can be found that the gap g_2 of inductive window only controls the second resonant frequency f_{m1}. As g_2 decreases, the inductive coupling will be strengthened. However, the total coupling between two SIW cavities is electric coupling and will be weakened [5, 6]. Hence, the coupling coefficient becomes smaller, and f_{m1} will shift towards f_{m3}. Meanwhile, the transmission zero T_z shifts towards the lower frequency. Thus, f_{m1}, f_{m2}, f_{m3} and T_z can be adjusted to satisfy the design specification by simply varying the parameters l_4 and g_2. Finally, the design parameters are optimized and given in Fig. 1(a). The simulated S-parameters are compared with the ideal results and shown in Fig. 3. The poor agreement in the upper stopband is due to the spurious passband generated by the SIW resonator.

3. EXPERIMENTAL RESULTS

The third-order SIW filter with 4% at 5.75 GHz is fabricated on an RT/Duroid 5880 substrate. A photograph of the filter is shown in Fig. 4(a). The performance is measured by the Agilent network analyzer N5230C. The measured frequency responses are illustrated in Fig. 4(b) and show good agreements with the simulated results. The slight shift in the center frequency may be attributed to mismatching tolerances. The measured insertion loss of 3 dB is in the range from 5.73 to 5.93 GHz ($\text{FBW}_{5.75\,\text{GHz}} \approx 3.45\%$), and its measured return loss is less than −10.5 dB. The measured transmission zero T_z is located at 5.63 GHz with an attenuation level less than −43 dB, resulting in sharp lower skirt. The measured lower stopband is extended to 5.64 GHz with an insertion loss less than −35 dB, and the measured upper stopband is less than −30 dB in the range of 6.45–8.47 GHz.



(a) (b)

Figure 4. (a) Photograph, and (b) simulated and measured S-parameters of the inline triplet SIW bandpass filter.

4. CONCLUSIONS

In this paper, a novel inline triplet SIW filter has been proposed with compact size, sharp lower skirt and deep lower stopband performance by embedding short-ended strip line on the top surface of two adjacent SIW cavities. A filter prototype with 4% FBW at 5.75 GHz is designed, fabricated and measured. Good agreement between the simulated and measured results demonstrates the validity of our proposed structure.

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