Progress In Electromagnetics Research Letters, Vol. 48, 39–43, 2014

A Compact Triple-Mode Bandpass HMSIW Filter

Zicheng Wang*, **Tao Yang, and Jun Dong**

Abstract—A simple method for designing a triple-mode bandpass filter is presented in this paper. Triple-mode is achieved by using half-mode substrate integrated waveguide (HMSIW) cavity. Three perturbation metal vias were introduced for shifting resonant modes. The resonant frequencies of these modes can be adjusted by the location and the diameter of perturbation vias properly. In order to improve the out-of-band rejection, the CPW-to-SIW transition was added. A triple-mode HMSIW filter with the center frequency of 13 GHz was designed and fabricated. The measured fractional bandwidth is 35% with a transmission zero located at 20.4 GHz. Good agreement is observed between simulation and measurement.

1. INTRODUCTION

In recent years, bandpass filters have been explosively developed as a key component of modern communication and sensor systems. In order to make the filters more compact, additional modes should be generated by the traditional resonator. Triple-mode filter which hold three resonances in one structure is one kind of multi-mode filters that has been studied. This kind of filters achieves high performance in response selectivity while keeping the size compact. Generally speaking, traditional waveguide triple-mode filters are difficult to integrate with planar circuit and to fabricate [1]. Afterwards, some compact microstrip triple-mode filters were proposed [2]. The planar structure is easily integrable with planar technology, while it has higher conductor loss and lower power capability.

The substrated integrated waveguide (SIW) and half-mode substrate integrated waveguide (HMSIW) have been proved to have high Q-factor, high power capability and low cost [3, 4]. Different methods were investigated to design SIW bandpass filter, such as inverter-coupled resonator [5], combined with the concept of defected ground structures (DGS) [6]. In [7] a dualband bandpass SIW filter using perturbation vias were proposed. However, the size of SIW cavity can still be half reduced by using the HMISW resonator which has a similar field distribution. This structure has been exploited to design bandpass filters in recent years [8–10], while seldom have any papers been reported in realizing triple-mode filters using a single HMSIW resonator.

In this article, an easy way to design a triple-mode bandpass HSIW filter has been investigated. Three simple perturbation vias were used in a HMSIW cavity for mode shifting. Two modes shifted to the other resonant mode by modifying the diameters and position of two perturbation vias, and the other via had a similar function to tune the mode frequency. A CPW-to-SIW transition was introduced to improve the out-of-band performance. At the end, a design example is given to demonstrate the presented structure. A triple-mode bandpass filter is designed and fabricated using HMSIW cavity, and the results agree well with the simulated one.

Received 8 June 2014, Accepted 29 July 2014, Scheduled 13 August 2014

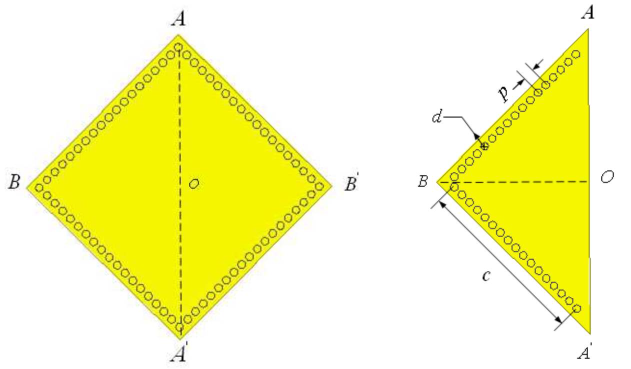
* Corresponding author: Zicheng Wang (602170090@qq.com).

The authors are with the University of Electronic Science and Technology of China (UESTC), Chengdu, Sichuan 610054, China.

2. FILTER DESIGN

2.1. HMSIW Resonator

Figure 1 shows the structure evolution of the square SIW and HMSIW cavity. The HMSIW resonator is realized by cutting the square SIW along the diagonal of the cavity. The open side of the HMSIW is approximately equivalent to magnetic wall, and the array of metallic via-holes approximates the electric boundary. The space between the metallic vias is p, and the diameter of the via is d. These two parameters are always set to the condition of $d/p \geq 0.5$ and $d/\lambda_0 \leq 0.1$ [11]. HMSIW keeps similar propagation characteristics to that of the traditional SIW resonator while the size of the structure reduces nearly 50% [4].



(a) (b)

Figure 1. Evolution of the (a) square SIW and (b) HMSIW cavity.

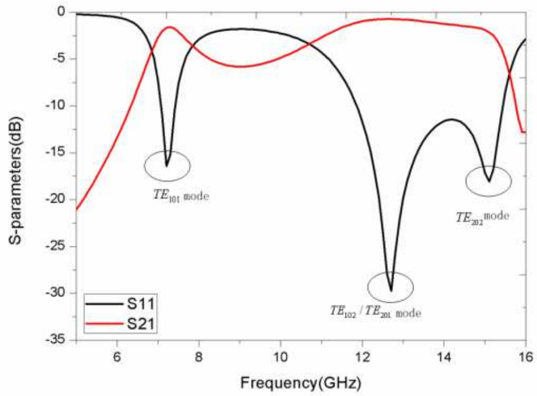


Figure 2. Simulated S-parameter of the HMSIW resonator.

The resonant frequencies of the resonant modes of a square SIW cavity are calculated as the following formula

$$f_{m0n} = \frac{c_0}{2\sqrt{\varepsilon_r}} \sqrt{\left(\frac{m}{c_{eff}}\right)^2 + \left(\frac{n}{c_{eff}}\right)^2} \tag{1}$$

where c_0 is the speed of light in free space and C_{eff} the equivalent width of rectangle cavity.

$$c_{eff} = c - \frac{d^2}{0.95p} \tag{2}$$

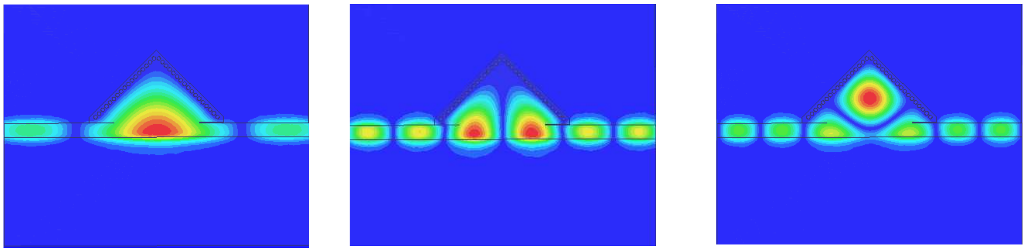
C is the width of SIW cavity, d the diameter of SIW via-holes, and p the space between two vias. As the size of the HMSIW is determined, the central frequency of the filter is basically settled.

2.2. Triple-Mode Filter Design

Figure 2 depicts the resonant frequencies of the HMSIW resonator. The resonant frequencies for the HMSIW are at 7.5 GHz, 13 GHz and 15 GHz, and the corresponding modes are TE_{101}, $\mathrm{TE}_{201}/\mathrm{TE}_{102}$ and TE_{202}, indicated in Figure 2 within the curve. In order to demonstrate the differences among these resonant modes clearly, the electric field distributions at different resonant modes of the HMSIW resonator are shown in Figure 3.

Figure 4 shows the studied HMSIW cavity with three metallic perturbation vias. One of the metallic vias is located at the symmetry axis of the HMSIW cavity with a diameter r and the other two located at the blue gap of the mode TE_{202} shown in Figure 3(c) with a diameter R.

One of the perturbation vias located at the symmetry axis of the HMSIW cavity has little effect on the $\mathrm{TE}_{201}/\mathrm{TE}_{102}$ mode since the electric field is weak at that location, while it affects the resonant modes TE_{101} and TE_{202} as the perturbation via approximates the electric wall. The size of the cavity



(a) (b) (c)

Figure 3. Electric field distribution of (a) TE_{101} mode, (b) $\mathrm{TE}_{201}/\mathrm{TE}_{102}$ mode, (c) TE_{202} mode.

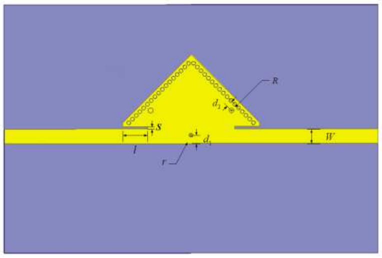
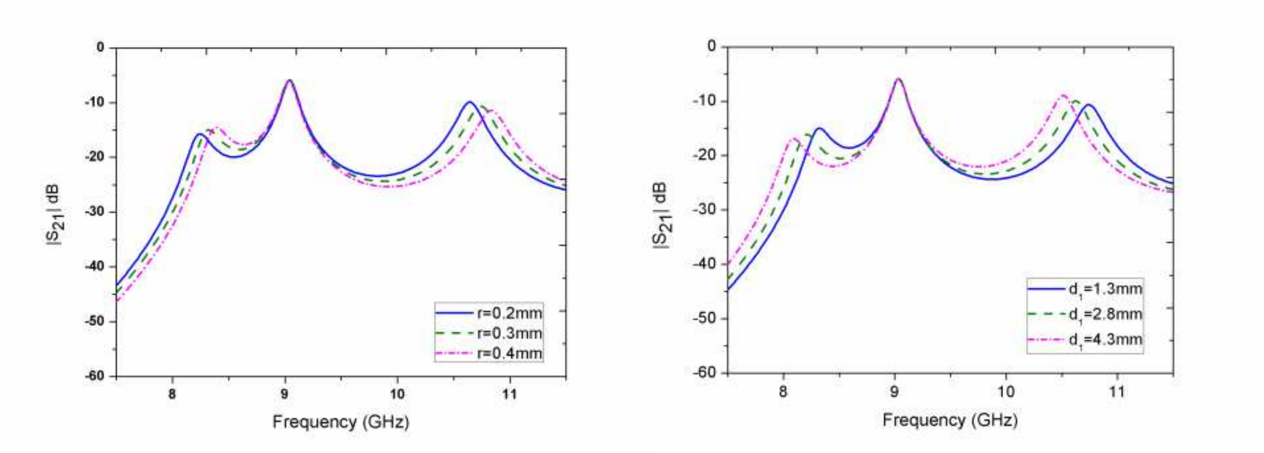


Figure 4. Configuration of the HMSIW resonator.



(a) (b)

Figure 5. Simulated S_{21} with different perturbation vias, (a) radius R, (b) position d_1.

will be equal to a decrement of the resonant mode TE_{101} and an increment of TE_{202} mode as d_1 increases. By employing this characteristic, the lower and higher modes will be under control. Since the resonant frequency of the SIW cavity is given in Equation (1), the variation of the cavity size will lead to a movement of the resonant frequency.

Similar to parameter d_1, the increase of parameter r will tune the resonant frequencies of TE_{101} and TE_{202} modes while having little effect on the frequency of $\mathrm{TE}_{102}/\mathrm{TE}_{201}$ modes. Figure 5 plots the simulated S-parameters by changing parameters d_1 and r of the perturbation vias.

In order to tune the resonant frequency of TE_{101} mode to the desired frequency, we add two more perturbation vias located in the gap of mode TE_{202}. The change of diameter R or position d_2 will have a notable impact on the TE_{101} and $\mathrm{TE}_{201}/\mathrm{TE}_{102}$ modes while the TE_{202} mode keeps unchanged.

As a conclusion, these three vias located at the particular position can shift TE_{101} and TE_{202} mode resonant frequencies or TE_{101} and $\mathrm{TE}_{201}/\mathrm{TE}_{102}$ mode resonant frequencies, whereas the other resonant frequency will keep unchanged.

3. EXPERIMENT RESULTS

A triple-mode bandpass filter has been designed and fabricated following the previous analysis. The substrate used for the bandpass filter is Rogers RT/Duroid 5880 with a relative permittivity of 2.2 and thickness of 0.787 mm. As depicted in Figure 6, the dimensions of the filter are $l = 4$ mm, $s = 0.4$ mm, $w = 2.34$ mm, $R = 0.8$ mm, $r = 0.6$ mm, $d_1 = 1.34$ mm, $d_2 = 1$ mm. Figure 6 shows a photograph of the fabricated filter.

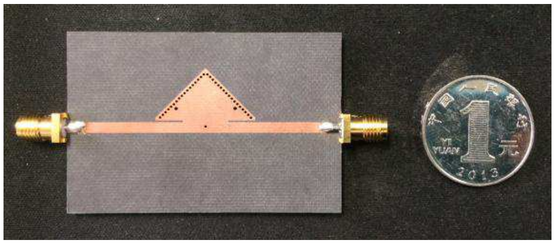


Figure 6. Photograph of the fabricated filter.

The simulated and measured results of the proposed filter are shown in Figure 7. It is obvious that the central frequency is about 13 GHz. The measured insertion loss is about 2.5 dB, and the measured return loss is lower than 10 dB. Some discrepancies between the simulated and measured ones are mainly attributed to the fabrication inaccuracy and extra SMA connector loss. In addition, there is a transmission zero located at 20.4 GHz due to the introduction of the CPW-to-SIW transition, which brings in the source-load coupling. The additional transmission zero improves the out-of-band rejection of the designed filter [12].

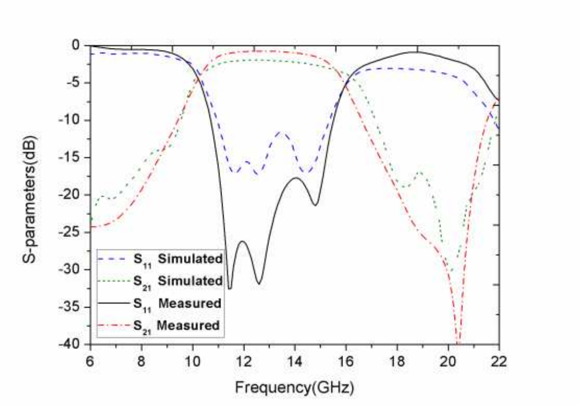


Figure 7. Simulated and measured results.

4. CONCLUSION

In this paper, an easy way to design a single-cavity HMSIW triple-mode filter has been investigated. Metallic perturbation vias are introduced to shift the resonant modes. By moving the position and changing the size of the perturbation vias, the size of the cavity will be equal to a decrement. Two of the resonant frequencies can be adjusted as the perturbation vias approximates the electric wall which will lead to a variation of the equivalent cavity size, while the other resonant frequency keeps unchanged since the electric field is weak at that particular location. By using CPW-to-SIW transition, out of band rejection performance can be further improved. A triple-mode bandpass HMSIW filter with the proposed element has been fabricated to validate the synthesis technique, and the measured result shows a good agreement with the simulated performances.

REFERENCES

1. Amari, S. and U. Rosenberg, "New in-line dual-and triple-mode cavity filters with nonresonating nodes," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 53, No. 4, 1272–1279, 2005.
2. Balalem, A., A. R. Ali, S. Amari, et al., "Realization of a microstrip triple-mode bandpass filter using a square-loop resonator," *IEEE International Microwave Symposium Digest*, 849–852, 2009.
3. Deslandes, D. and K. Wu, "Integrated microstrip and rectangular waveguide in planar form," *IEEE Microwave and Wireless Components Letters*, Vol. 11, No. 2, 68–70, 2001.
4. Liu, B., W. Hong, Y. Q. Wang, et al., "Half mode substrate integrated waveguide (HM-SIW) 3-dB coupler," *IEEE Microwave and Wireless Components Letters*, Vol. 17, No. 1, 22–24, 2007.
5. Chen, X. P., K. Wu, and Z. L. Li, "Dual-band and triple-band substrate integrated waveguide filters with Chebyshev and quasi-elliptic responses," *IEEE Transactions on Microwave Theory and Techniques,* Vol. 55, No. 12, 2569–2578, 2007.
6. Deng, K., Z. Guo, C. Li, et al., "A compact planar bandpass filter with wide out-of-band rejection implemented by substrate-integrated waveguide and complementary split-ring resonator," *Microwave and Optical Technology Letters*, Vol. 53, No. 7, 1483–1487, 2011.
7. Cheng, F., X. Q. Lin, X. X. Liu, et al., "A compact dual-band bandpass SIW filter," *Journal of Electromagnetic Waves and Applications*, Vol. 27, No. 3, 338–344, 2013.
8. Gong, K., W. Hong, H. Tang, et al., "C-band bandpass filter based on half mode substrate integrated waveguide (HMSIW) cavities," *IEEE Asia Pacific Microwave Conference, APMC 2009*, 2591–2594, 2009.
9. Zhou, S., Z. Wang, R. Xu, et al., "A novel X-band half mode substrate integrated waveguide (HMSIW) bandpass filter," *IEEE Asia Pacific Microwave Conference, APMC 2009*, 1387–1389, 2009.
10. Liu, W. and F. Liu, "A highly selective super-wide bandpass filter by cascading HMSIW with asymmetric defected ground structure," *2010 International Conference on IEEE Microwave and Millimeter Wave Technology (ICMMT)*, 77–80, 2010.
11. Cassivi, Y., L. Perregrini, P. Arcioni, et al., "Dispersion characteristics of substrate integrated rectangular waveguide," *IEEE Microwave and Wireless Components Letters*, Vol. 12, No. 9, 333–335, 2002.
12. Shen, W., W. Y. Yin, and X. W. Sun, "Compact substrate integrated waveguide (SIW) filter with defected ground structure," *IEEE Microwave and Wireless Components Letters*, Vol. 21, No. 2, 83–85, 2011.