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Design of Compact SIW Bandpass Filter with High Selectivity

Yudan Wu[1, *], Yingjie Yu[2], Ping Su[1], Xiang Zhang[1], Licong Wang[1], and Shuaishuai Wang[1]

Abstract—In this paper, a method of designing a SIW (Substrate Integrated Waveguide) bandpass filter with high selectivity is proposed. Four resonant cavities of the proposed filter are arranged in straight line. The microstrip gradient line is directly fed into the cavities. Two U-shaped slots are etched on the top face of each cavity which will result in the resonant modes reduced and the high modes of SIW cavity pushed far away from the dominant resonant mode. Thus, the filter will have both the features of compact size and wide stopband. The center frequency of the filter is designed at 5.2 GHz. The measured results are highly matched with the simulated ones.

1. INTRODUCTION

Microwave filter plays a key role in modern wireless communication system for its capability of suppressing the noises and interferences in the electromagnetic scenarios. Small size, low insertion loss, high out of band selectivity, wide stopband are constantly called for filters.

In recent years, much attention has been paid to SIW filter for its low loss, high power capability, and easy connection with other planar circuits. However, the physical dimension of traditional SIW filter is relatively larger than the microstrip filter for it can not be folded. Thus, many academics have made efforts on HMSIW (Half Mode Substrate Integrated Waveguide) filter and QMSIW (Quarter Mode Substrate Integrated Waveguide) filter [1–4]. There are a part of filters are miniaturised by loading slots on the surface of the SIW cavity [5–7]. Furthermore, the second harmonic of filter always appears close to the dominate mode which will worsen the rejection of stopband. Several methods have been applied to solve this problem. Cross coupling between nonadjacent resonators enables the phase flipped in different paths and results in transmission zeros. Transmission zeros are introduced and located at the proper situation to suppress the spurious passband [8–12]. In [13] and [14], the wide stopband is generated by cascading low pass filter. In [15], the harmonic TE_{102}/TE_{201} modes are eliminated by the orthogonal port. However, those filters discussed before do not have both compact size and good out-of-band rejection.

A fourth order SIW filter with compact size and high selectivity out of band is proposed in this paper. The compact size of the filter is reduced by approximately 75% compared to traditional filters except the feed lines and connectors. The filter is centered at 5.2 GHz, and the out of band rejection is more than 35 dB at 4.8 GHz and 5.6 GHz.

2. SIW CAVITY ANALYSIS

As shown in Fig. 1(a), the resonant frequency of a traditional SIW filter is decided by a_{eff} and l_{eff} according to the formulas given by [16]:

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* Corresponding author: Yudan Wu (627196565@qq.com).
[1] Shanghai Radio Equipment Research Institute, Minhang, Shanghai 201109, China. [2] Shanghai Electro-mechanical Engineering Institute, Minhang, Shanghai 201109, China.

$$f = \frac{c_0}{2\pi\sqrt{\varepsilon_r \mu_r}} \sqrt{\left(\frac{\pi}{a_{eff}}\right)^2 + \left(\frac{\pi}{l_{eff}}\right)^2}$$

$$a_{eff} = a - \frac{d^2}{0.95p}, \quad l_{eff} = l - \frac{d^2}{0.95p}$$

where a and l are the width and length of the SIW cavity, respectively. d represents the diameter of the metallic vias, and p represents the distance between the centers of two adjacent vias. ε_r and μ_r are the relative dielectric constant and permeability, respectively.

This paper proposes a new SIW cavity with two U-shaped slots etched on the top face of cavity, as shown in Fig. 1(b).

Field analysis has been done to explore the electromagnetic characteristic of the proposed resonator.

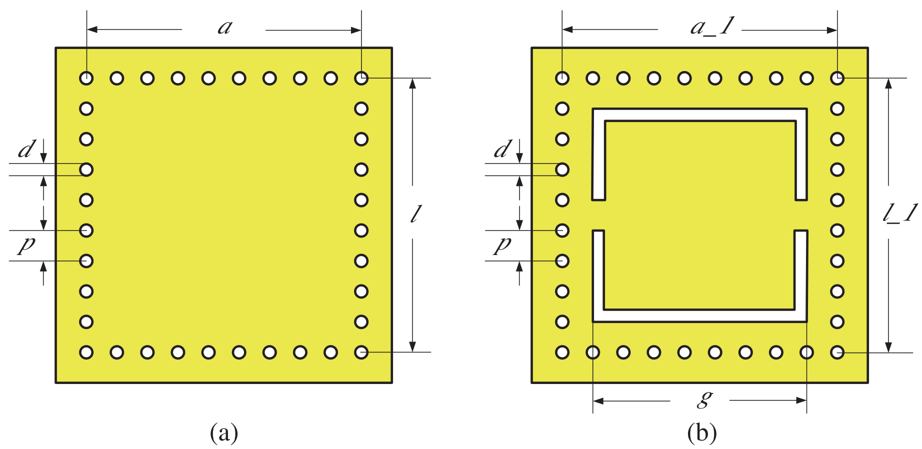

Figure 1. Configuration of traditional SIW cavity and the proposed SIW cavity. (a) The traditional SIW cavity. (b) The proposed SIW cavity.

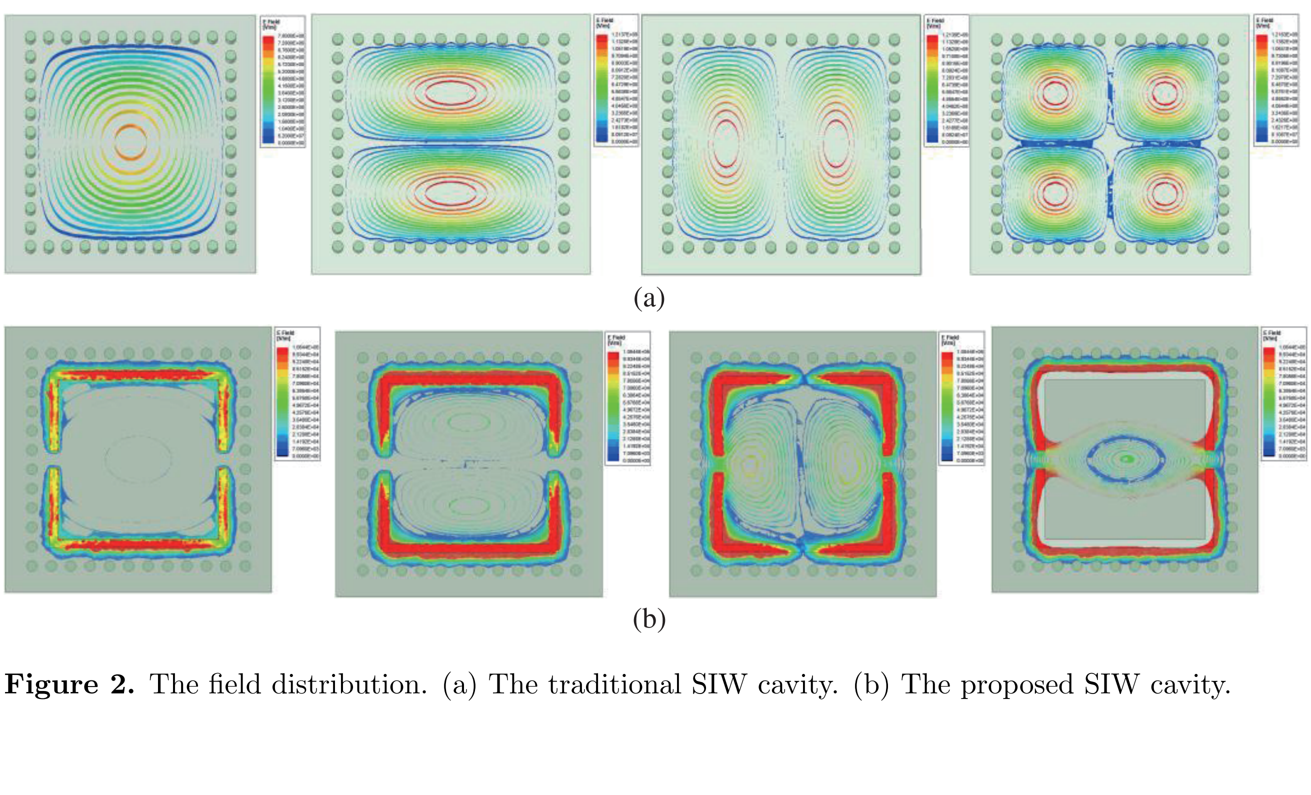

Figure 2. The field distribution. (a) The traditional SIW cavity. (b) The proposed SIW cavity.

The comparison between field distributions in traditional SIW cavity and the proposed SIW cavity is shown in Fig. 2. It should be noted that the dominant resonant mode, second resonant mode, and third resonant mode field distributions between traditional SIW cavity and the proposed SIW cavity are similar but not exactly the same.

As shown in Fig. 3, the performances of the primary four resonant modes (TE_{101}, TE_{201}, TE_{102}, TE_{202}) in traditional SIW cavity and the proposed SIW cavity are listed when they pick the same size: $a = a\_1 = 12$ mm. It is suggested that the U-shaped slots will not utterly change the resonant modes while the resonant frequencies will be decreased owing to the capacitive effect. Thus, the size of the proposed SIW cavity is far smaller than traditional SIW cavity when they resonate at the same frequency. In addition, the higher modes (TE_{201}, TE_{102}, etc.) will be pushed away from the dominant resonant mode: the 2nd resonant frequency (TE_{201}) in traditional SIW cavity is about $1.54f_1$ (TE_{101}) while it is about $2.07f_1$ (TE_{101}) in the proposed SIW cavity when $l = l\_1 = 10$ mm. Especially, the 3rd resonant mode (TE_{102}) has been moved obviously because the U-shaped slots shorten the guide wavelength. Therefore, the filter will have both the features of wide stopband and compact size which uses the proposed cavity.

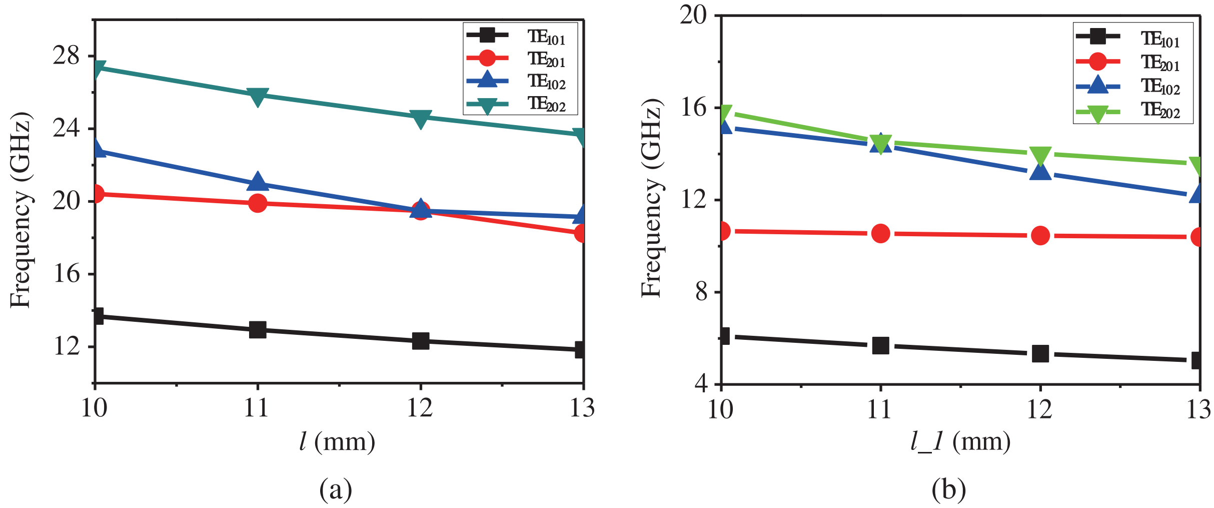

Figure 3. The performance of resonant modes. (a) Modes in traditional SIW cavity. (b) Modes in the proposed SIW cavity.

3. FILTER DESIGN

Figure 4 illustrates the schematics of the proposed fourth order filter. To simplify the designation, a linear-type topology is adopted. A gradient line is employed between feed line and SIW cavity for matching. In this case, the center frequency is designed at 5.2 GHz. The passband of the proposed SIW filter is set from 5.15 GHz to 5.25 GHz. Taking machining accuracy and common difference into account, the expansion of bandwidth is considered. Thus, the real passband is designed more than 0.2 GHz.

The corresponding normalized coupling matrix for the proposed filter is listed as follows:

$$M = \begin{bmatrix} 0 & 0.043 & 0 & 0 \\ 0.043 & 0 & 0.031 & 0 \\ 0 & 0.031 & 0 & 0.043 \\ 0 & 0 & 0.043 & 0 \end{bmatrix} \quad (1)$$

The dominant frequency is apparently decided by both length and width of the cavity. The external quality factor Q_e is calculated as 17.9. In the simulation model, external quality factor can be tuned by the window between the microstrip line and first/last cavity which is named as win_p. The coupling coefficient can be adjusted by changing the size of the window between two corresponding resonators, such as $win12$ and $win23$.

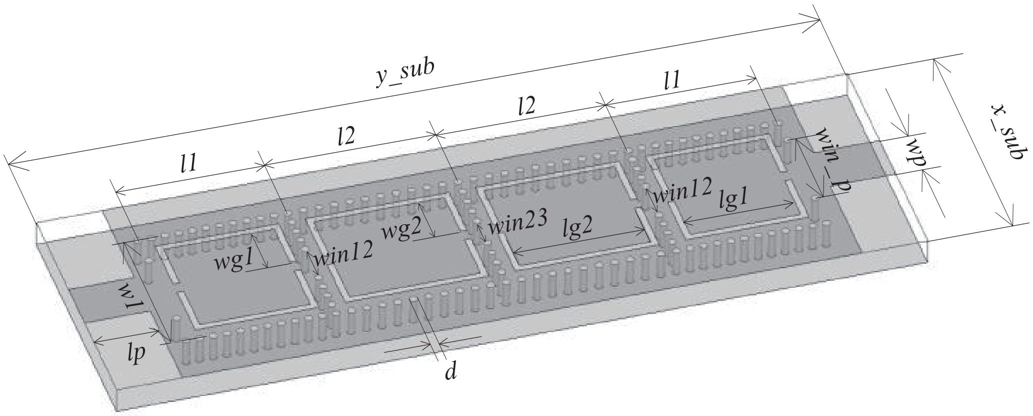

Figure 4. Configuration of the proposed filter.

A comparison of bandpass filters [10–12] to the proposed filter is shown in Table 1. It can be seen that the proposed filter has a good performance of small size, wide stopband, good insertion loss, and excellent stopband performance (25 dB suppression from 5.8 GHz to 15.2 GHz).

Table 1. Comparison between the proposed filter and the references.

Ref.	f_0 (GHz)	3 dB BW (%)	IL (dB)	Stopband	Size (λ_0^2)
[10] filter II	13.2	4.54	1.5	$1.13f_0$ (20 dB)	/
[11]	14.87	1.68	3.6	/	2.1
[12]	8.25	1.1	3.3	/	2.04
This work	5.2	3.85	2.9	$1.8f_0$ (25 dB)	0.52

4. FABRICATION AND EXPERIMENT

The proposed SIW filter is fabricated on a Rogers 5008 substrate with a thickness of $h = 0.787$ mm and a relative dielectric constant of 2.2. The diameter of the via hole is set the same as the regular size to simplify both the simulation and fabrication. Besides, the horizontal sizes of the four resonators are the same, and resonator 1 and resonator 4 share the same vertical size, meanwhile resonator 2 and resonator 3 also share the same vertical size. The optimized dimensions of the filter are listed as follows: $x\_sub = 20$ mm, $y\_sub = 62$ mm, $l1 = 11.4$ mm, $l2 = 13$ mm, $w1 = 12$ mm, $win12 = 3.4$ mm, $win23 = 2.6$ mm, $lg1 = 9.4$ mm, $wg1 = 4.5$ mm, $lg2 = 11$ mm, $wg2 = 4.5$ mm, $d = 1.2$ mm.

The proposed bandpass filters are analyzed and designed using Ansys HFSS. The filter prototype is fabricated to validate the design and analysis. The simulated and measured results are plotted together in Fig. 5. Good agreement between them has been obtained. It should be pointed out that discrepancies can be observed although the agreement of the measured results with the simulated ones is acceptable. The measured passband is smaller than the simulated one. The insertion loss and return loss of measured results are 2 dB and are 5 dB lager than simulated ones, respectively. In addition, the stopband of the measured results has about 20 dB deterioration compared to the simulated one. It is conjectured that all of the differences between measured and simulated results may be attributed to the slight impedance mismatch between the feeding section and SMA connectors caused by manual welding and the effective conductivity of fabricated filters which is less than that of the simulation.

The filter is centered at 5.2 GHz, with a 3.85% relative bandwidth (from 5.12 GHz to 5.32 GHz). The insertion loss of the filter is about 2.9 dB when the losses caused by connectors and test environment are counted in. The stopband is about 9.7 GHz (from 5.8 to 15.2 GHz) while the suppression is more

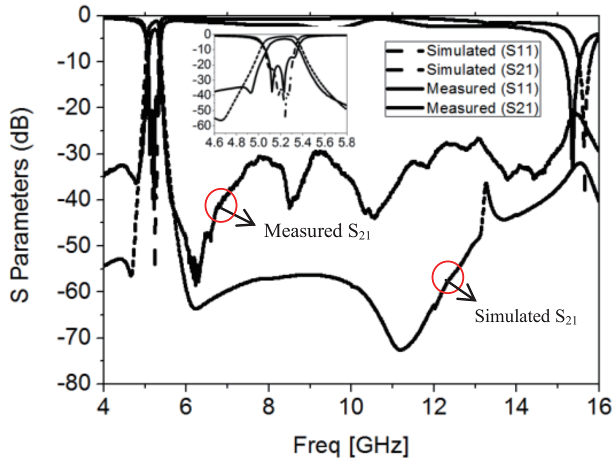

Figure 5. Simulated and measured results.

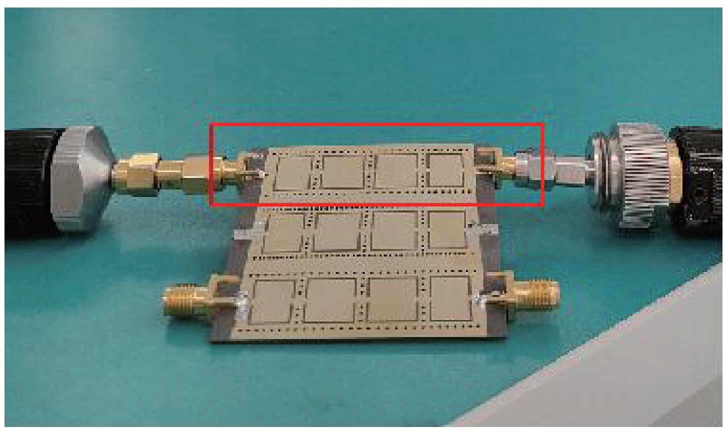

Figure 6. Photograph of fabricated filter (labeled by the red box).

than 25 dB. The nearest higher harmonic is about trice of the passband. The stopband performance of filter is even better than a single cavity which is about $2.07f_1$. Fig. 6 shows the photograph of the fabricated filter, and the filter occupies a compact size of 55 mm × 16 mm × 0.787 mm.

5. CONCLUSION

A novel fourth order SIW filter with U-shaped slots etched on the top face which exhibit compact size and wide stopband has been proposed in this paper. The measured results of the filter validate the method of designation. Both simulated and measured results suggest that the proposed filter is a candidate for the design of compact and wide stopband planar filter.

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