Progress In Electromagnetics Research Letters, Vol. 65, 75–79, 2017

Design of Compact Wideband QMSIW Band-Pass Filter with Improved Stopband

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Abstract—A compact wideband quarter mode substrate integrated waveguide (QMSIW) band-pass filter with wide stopband performance is presented in this paper. Compared with conventional SIW cavity, the QMSIW cavity occupies only one fourth of the size. A meandered H-shaped slot is etched on the cavity to change the current direction for size reduction. In order to prove the validity, a compact fourth-order band-pass filter with wide stopband is fabricated on a single-layer Rogers RT/Duroid 5880 substrate. The measured in-band insertion loss is only 1.02 dB including the loss caused by two connectors, and the stopband attenuation in the frequency band from 4.02 GHz to 12.63 GHz is better than 25 dB. The whole size of the filter is only $20.6 \times 26.8 \times 0.254\,\text{mm}^3$.

1. INTRODUCTION

With the rapid development of wireless communication systems, it is urgent to increase demand for high selectivity microwave filters with compact size, low cost, high power capability, etc. Substrate integrated waveguide (SIW) is an artificial waveguide structure which has attracted much attention to design low-cost and highly integrated waveguide filters for its high quality and easy connection with other planar transmission lines [1–6]. However, for lower microwave frequencies application, SIW is still too large. Considering the symmetrical field distribution of SIW cavity, quarter mode substrate integrated waveguide (QMSIW) is proposed for size reduction by approximately 75% [7]. Wide stopband performance should be provided for filters especially when the transmit band is far away from the receive band. Several techniques have been developed to improve the stopband performance, such as transmission zeros [8] and cascading other suppression structures [9]. These techniques suffer from physical realization or larger volume.

In this paper, a compact fourth-order band-pass filter with wide stopband response is proposed. A meandered H-shaped slot is etched on the QMSIW cavity. The dominant resonant mode of the proposed resonator is TE_{101} mode. The proposed band-pass filter is analyzed and designed using full-wave EM simulator software (Ansoft HFSS). To validate the design and analysis, the filter prototype is fabricated on Rogers RT/Duroid 5880 substrate and the measured results verify the performance of the proposed filter.

2. FILTER DESIGN

2.1. QMSIW Cavity Resonator

The QMSIW cavity is generated by bisecting the conventional SIW cavity along both horizontal and vertical direction. The electric field distribution in conventional SIW and QMSIW cavity at the dominant TE_{101} mode is shown in Fig. 1. The overall size of QMSIW is approximately one fourth

Received 3 November 2016, Accepted 24 December 2016, Scheduled 13 January 2017
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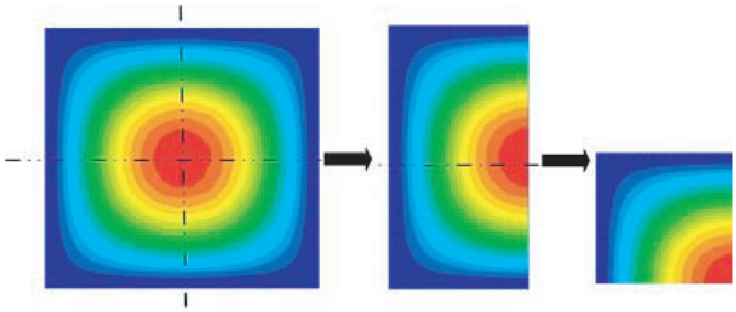

Figure 1. Electric field distribution of full-mode SIW, HMSIW and QMSIW cavities.

of the original SIW cavity while keeping the same resonant frequency. According to the formulas given by [9], the resonant frequency of the dominant mode TE_{101} mode can be calculated. The size of the cavity is adjusted to suitable cut off frequency.

$$f = \frac{c_0}{2\pi\sqrt{\varepsilon_r \mu_r}}\sqrt{\left(\frac{\pi}{a_{eff}}\right)^2 + \left(\frac{\pi}{l_{eff}}\right)^2} \tag{1}$$

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

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

2.2. Design Procedure

As illustrated in Fig. 2, the filter is composed of four QMSIW square resonant cavities, where asymmetric input/output feed line structure is adopted. The 50 Ω microstrip lines are directly connected to the QMSIW cavity at the input/output ports. External quality factor Q is controlled by adjusting the taper position, and the tapped line position for the required Q is determined from Fig. 3. Taking the in-band insertion loss into account, four cavities are sufficient to meet the requirement of selectivity [10]. The coupling coefficient between two QMSIW cavities can be tuned by regulating the post-wall iris, which is specified in [11].

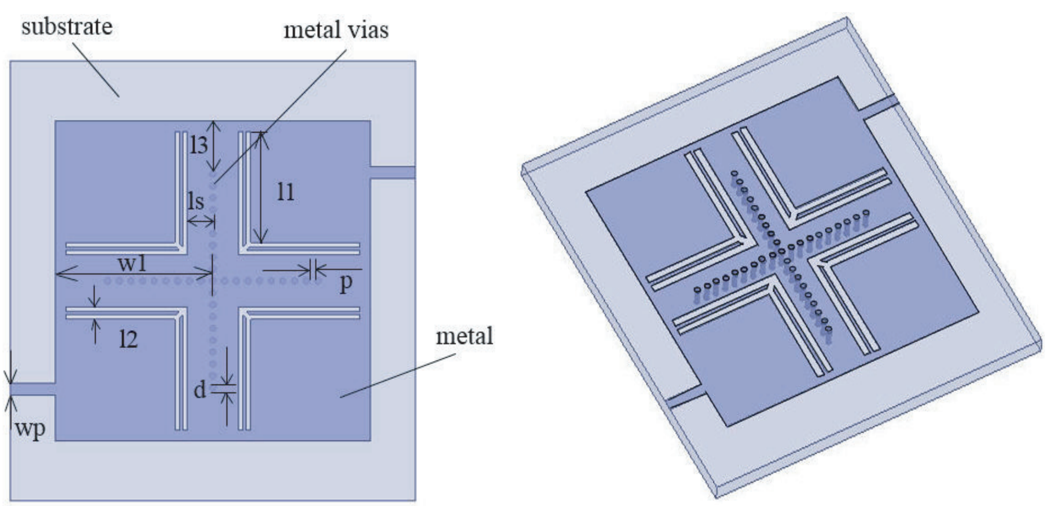

Figure 2. Configuration of the proposed QMSIW filter (Top view & 3-D graph).

It is found that the wide stopband performance is created by etching H-shaped slots on the cavity. The length of the slots $l1$ is used to control both center frequency and bandwidth of the proposed filter, as shown in Fig. 4. Spurious resonant modes may occur in the stopband with the improper parameter value. Additionally, as demonstrated in Fig. 5, the position of the slot also has effect on the bandwidth except center frequency. Compromise should be made to balance both bandwidth and stopband performance when choosing the parameters values.

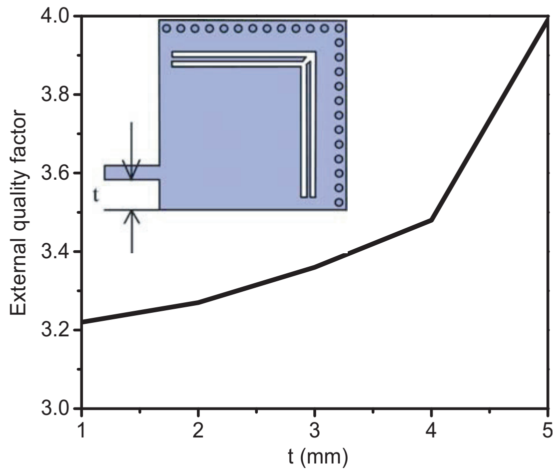

Figure 3. External quality factor as a function of tapper position.

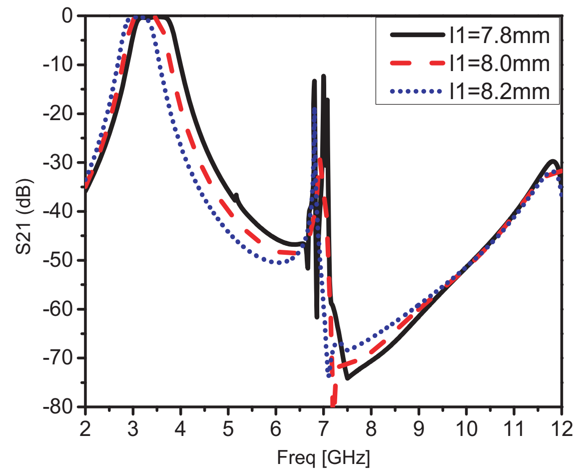

Figure 4. Frequency responses of filter with various $l1$ values.

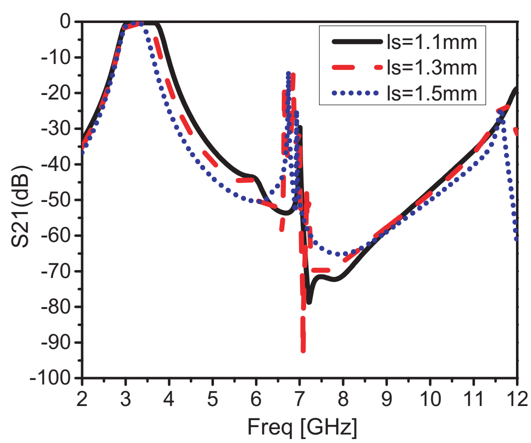

Figure 5. Frequency responses of filter under different values of ls.

The dimensions of the filter can be obtained after optimization as following: $l1 = 8$ mm, $l2 = 0.8$ mm, $l3 = 3$ mm, $ls = 1.3$ mm, $w1 = 10.4$ mm, $wp = 0.78$ mm, $d = 0.4$ mm, $p = 0.77$ mm. A comparison of band-pass filters ([8–10]) to the proposed filter is shown in Table 1. In [8], narrow band filter with poor performance is obtained, and its circuit size is larger than the proposed one. In [9], the design has a compact size with high selectivity and wide stopband. However, its RL (N/A) is not good enough. Compared with the BPF in [10], the proposed wideband BPF not only has more compact size, but also reveals wide stopband. In general, it can be seen that the proposed filter has a good performance of small size, wide band, good insertion loss, return loss and its excellent stopband performance (25 dB suppression from 4.02 GHz to 12.63 GHz, $3.88f_0$).

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

	f_0 (GHz)	BW (%)	IL (dB)	RL (dB)	Stopband (25 dB)	Size (λg^3)
[8]	5.57	7.44	2	18.1	$1.38f_0$	$0.420 \times 0.420 \times 0.009$
[9]	1.455	39.2	1	N/A	$5.15f_0$	$0.336 \times 0.308 \times 0.007$
[10]	20	10	0.9	20	$1.575f_0$	$0.706 \times 1.260 \times 0.034$
This work	3.25	21.2	1.02	17	$3.88f_0$	$0.225 \times 0.293 \times 0.003$

3. FABRICATION AND EXPERIMENT

Following the design procedure, a compact wideband QMSIW band-pass filter is designed, fabricated and measured. This whole work is based on full wave software Ansoft HFSS. A 0.254 mm thick Rogers 5880 with relative permittivity of 2.2 and dielectric loss tangent of 0.0009 is used in this paper. The fabricated filters were measured using Agilent 8722ES network analyzer. The photograph of the fabricated filter is shown in Fig. 6. The measured and simulated results are displayed in Fig. 7, showing its overall size of $0.225 \times 0.293 \times 0.0027\lambda g^3$. The measured center frequency f_0 is 3.25 GHz with 3-dB bandwidth of 21.2%. The insertion loss at the center frequency is 1.02 dB, and the return loss is better than 17 dB. More than 25-dB suppression levels are realized from 4.02 GHz to 12.63 GHz ($3.88f_0$). Good agreement between the theoretical and measured results verifies the proposed idea.

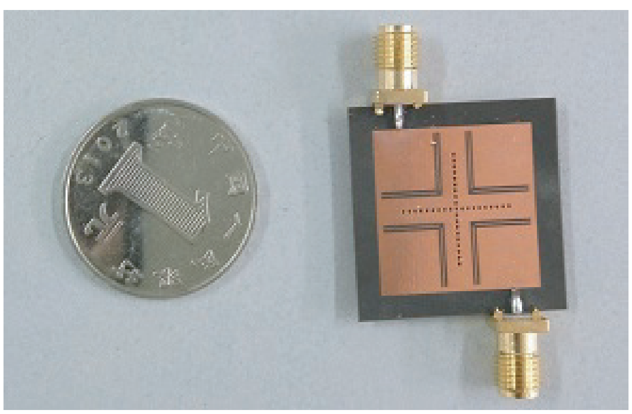

Figure 6. Photograph of the fabricated filter.

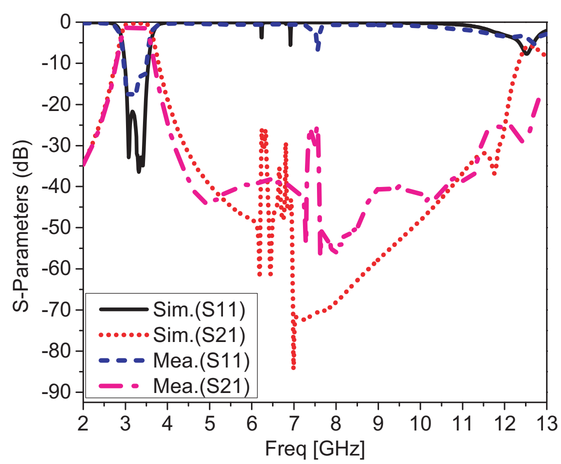

Figure 7. Photograph of the fabricated filter with measured and simulated results.

Compared with the simulated result, a slight deviation for bandwidth and return loss can be observed. It is conjectured that the decrease of bandwidth may be caused by the low machining precision of ls which has been discussed in Fig. 4, and the unsatisfactory return loss may be attributed to slight impedance mismatch between the feeding section and the SMA connectors caused by manual welding and the effective conductivity of fabricated filters which is less than that of the simulation.

4. CONCLUSION

This paper presents a compact bandpass filter with wide stopband performance using QMSIW cavity. The filter is centered at 3.275 GHz with an insertion loss of < 1.02 dB, bandwidth of 21.2%, which could be used for WiMax application. Its volume is $20.6 \times 26.8 \times 0.254\,mm^3$. The wide stopband performance of 25 dB suppression is realized from 4.02 GHz to 12.63 GHz, about $3.88f_0$. These excellent performances ensure that it is competitive for application in microwave communication systems.

ACKNOWLEDGMENT

This work is supported by the National High-tech Research Development Plan (863 Plan) (2015AA016201).

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