Novel Compact Bandpass Filter Based on Folded Half Mode Substrate Integrated Waveguide Cavities

Ke Gong · Wei Hong · Jixin Chen · Hongjun Tang · Debin Hou · Yan Zhang

Abstract

This paper proposed a novel compact bandpass filter with folded half mode substrate integrated waveguide (FHMSIW) cavities using two-layer printed circuit board(PCB) process. The area of the FHMSIW filter is reduced by nearly 50 % and 75 % compared with half mode substrate integrated waveguide(HMSIW) filter and substrate integrated waveguide(SIW) filter, respectively. A four-pole Chebyshev FHMSIW bandpass filter at C-band has been designed, simulated and fabricated. Measured results are presented and found to agree with the full-wave simulated results by using Ansoft HFSS. The filter shows good performance and compact size.

Key words : Bandpass Filter(BPF), Compact Size, Folded Half Mode Substrate Integrated Waveguide(FHMSIW), Half Mode Substrate Integrated Waveguide(HMSIW), Substrate Integrated Waveguide(SIW).

Ⅰ. Introduction

High-performance small-size microwave filters with low insertion loss, easy fabrication and potential integration with planar circuits are finding increasing application in modern communication systems. Recently, substrate integrated waveguide(SIW) structure, which is synthesized in a planar substrate with arrays of metallic vias by the standard PCB or LTCC fabrication process, has provided a useful technology to design such filters and other components for microwave and millimeter wave applications[1]~[3].

However, the physical dimension of SIW blocks may be too large for certain applications, especially for lower microwave frequency band. To overcome such drawbacks, a new guided wave structure called half mode substrate integrated waveguide(HMSIW) was proposed[4] and seriously studied[5]. The HMSIW could be realized by cutting the SIW along the center symmetrical plane which can be considered as an equivalent magnetic wall when the SIW is operated with the dominant mode. HMSIW shows the similar propagation characteristics to that of SIW with nearly half reduction in size, thus HMSIW technique is attractive for high-density integration of microwave and millimeter wave components and systems. Some kinds of HMSIW components including filters with size reduction have been proposed and studied[6].

On the other hand, substrate integrated folded waveguide(SIFW) was proposed in [7] and [8] to obtain size reduction with bandpass filter applications. Folded substrate integrated waveguide(FSIW) structure was studied and employed to design some filters with compact size[9]. Recently, folded half mode substrate integrated waveguide(FHMSIW) was proposed and used to implement a 3-dB coupler which shows good performance and compact size[10].

In this paper, a new type of bandpass filter with compact size based on FHMSIW cavities has been proposed. A prototype of four-pole Chebyshev FHMSIW bandpass filter at C-band has been designed, simulated and fabricated. The measured results which show good agreement with the simulated ones are provided.

Ⅱ. Filter Structure and Design

Fig. 1 shows the configuration of the proposed four-pole FHMSIW Chebyshev filter. The filter was fabricated on two-layer Taconic TLY-5 substrate with dielectric constant ε_{r1}=2.2 and loss tan δ=0.0009. Both of the layers have a height of 0.508 mm. The layer of Taconic TPG-30 material is used as bonding layer to combine the two layers of substrate, which is 0.12 mm thick with dielectric constant ε_{r2}=3.0 and loss tan δ =0.0038. Metallic vias are used to synthesize the equivalent waveguide sidewalls. The diameter and the center-to-center space of the vias are much smaller than the operating wavelength. The I- and L-shaped slots opened respectively on the top and middle copper layers near the vias are used to create folded HMSIW cavities. One

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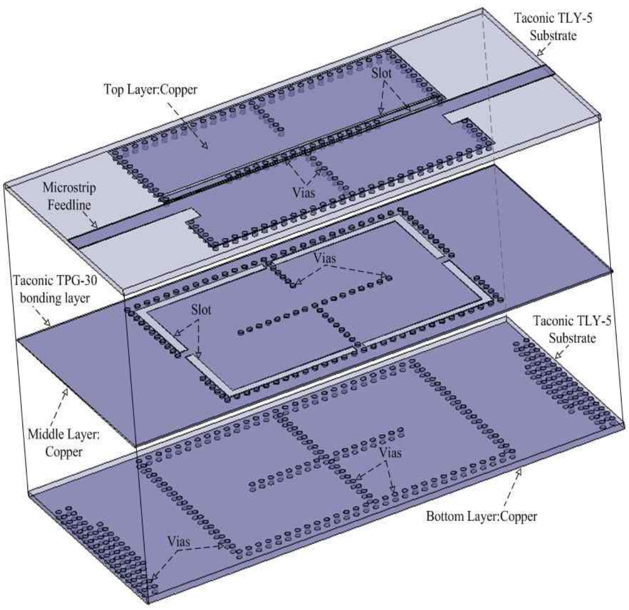


Fig. 1. Structure of the proposed FHMSIW filter in a two-layer configuration.

might notice that the folded cavity has a similar quality factor as that of the unfolded one if only the width of the slot is not less than the height of the substrate[11]. The filter is composed of cascaded FHMSIW cavities, which are magnetically coupled with the adjacent cavities, and the filter is excited by microstrip lines.

The proposed filters can be implemented using the coupled-resonator filter design procedures based on the coupling coefficients and the external quality factor. The design parameters associated with the specifications may be expressed as[12]:

$$Q_{ei} = Q_{eo} = \frac{g_0 g_1}{FBW}, \quad k_{j,j+1} = \frac{FBW}{\Omega_C \sqrt{g_i g_{i+1}}} \tag{1}$$

where Q_{ei} and Q_{eo} are the external quality factors of the resonators at the input and output, $k_{j,j+1}$ is the coupling coefficients between the adjacent resonators, FBW is the fractional bandwidth, Ω_c and $g_j(j=0,\cdots,n+1)$ are the low-pass prototype parameters.

After determining the required coupling coefficients and external quality factors, the relationship between the coupling coefficients and physical structures of designed filter should be established. The inter-resonator coupling coefficients can be extracted by using full-wave simulation with HFSS as follows[12]:

$$k = \frac{f_u^2 - f_l^2}{f_u^2 + f_l^2} \tag{2}$$

where f_u and f_l stand for the upper and lower resonating frequency of the resonators, respectively. The larger the window is, the stronger the coupling and the wider the separation of the two resonant peaks.

To determine the external quality factor, full-wave simulation with HFSS is executed on a dominant mode FHMSIW cavity resonator with 50-Ω microstrip lines as its input and output. The desired external quality factor can be achieved by adjusting the length of the coupling slot with a fixed coupling slot width of 1.8 mm. The external quality factor Q_e can be characterized by the following formula[12]:

$$Q_e = \frac{2 f_0}{\Delta f_{-3\text{dB}}} \tag{3}$$

where f_0 and $\Delta f_{-3\text{dB}}$ represent the resonating frequency and the 3-dB bandwidth of the input or output resonator, respectively.

Finally, using the initial values of the design variables about the entire filter shown in Fig. 1, numerical analysis and optimization with HFSS can be carry out to realize the desired frequency response.

Ⅲ. Simulation and Experimental Results

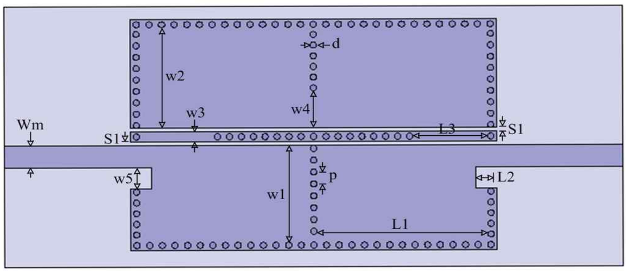
To verify the performance of the proposed FHMSIW filter, a four-pole bandpass filter with Chebyshev response at C-band is designed, fabricated and measured. The specification of the filter is 10 % fractional bandwidth centered at 5.55 GHz with 0.2 dB passband ripple. From [12], the corresponding Q_e and k are found to be

$$k = \begin{bmatrix} 0 & 0.077 & 0 & 0 \\ 0.077 & 0 & 0.063 & 0 \\ 0 & 0.063 & 0 & 0.077 \\ 0 & 0 & 0.077 & 0 \end{bmatrix}$$

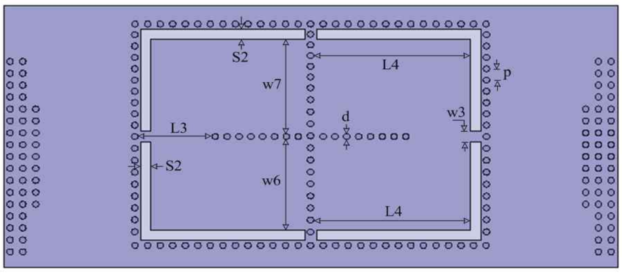
$$Q_{ei} = Q_{eo} = 13.028$$

The filter is simulated by using Ansoft HFSS. The dimensions of the filter are shown in Fig. 2 and its geometric parameters are collected in Table 1. The SIW and HMSIW filters with identical specification along with the FHMSIW filter were designed and fabricated using the same two-layer substrate and multilayer PCB process. Fig. 3 (a) presents the photograph of the fabricated FHMSIW filter and Fig. 3 (b) shows the photograph of the fabricated SIW, HMSIW and FHMSIW filters. From Fig. 3 (b), we can clearly observe the size reduction by using the FHMSIW cavities in filter design. The proposed filter was measured with the Agilent E8363B vector network analyzer and Anritsu 3680V test fixture whose effects have been removed by calibration.

The simulated and measured results of the FHMSIW



(a) Top layer of the FHMSIW filter

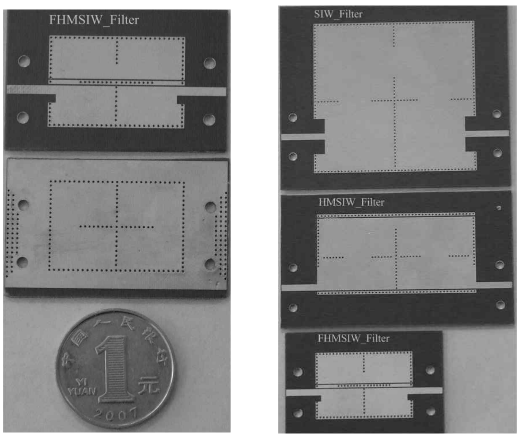


(b) Middle layer of the FHMSIW filter

Fig. 2. Dimensions of the proposed FHMSIW filter.

Table 1. Geometric parameters of the proposed filter

Symbol	Quality(mm)	Symbol	Quality(mm)
w_1	8.15	L_1	13.25
w_2	8.45	L_2	1.4
w_3	0.9	L_3	6.3
w_4	3.35	L_4	12.25
w_5	1.8	S_1	0.3
w_6	7.65	S_2	0.8
w_7	7.95	d	0.5
W_m	1.87	p	1.0



(a) (b)

Fig. 3. (a) Photograph of the fabricated FHMSIW filter and (b) Photograph of the fabricated SIW, HMSIW and FHMSIW filters.

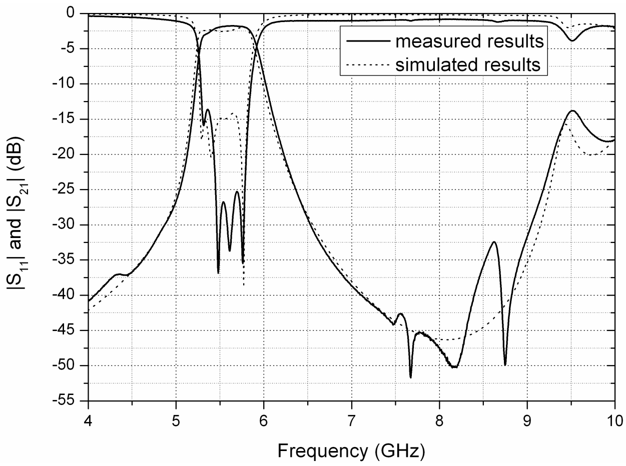


Fig. 4. *S*-parameters of the proposed FHMSIW filter.

filter are shown in Fig. 4. Good agreement is observed between the measured and simulated responses. Measured results show that the insertion loss at the mid-band is about 1.7 dB. The return loss of the filter is lower than −13 dB. The measured results include the influence of a pair of SMA connectors. The results show that the FHMSIW technique is suitable for the implementation of filters with compact size.

Ⅳ. Conclusion

In this paper, a new type of bandpass filter with compact size has been successfully development using folded half mode substrate integrated waveguide technology. The area of the FHMSIW filter is reduced by nearly 50 % and 75 % compared with half mode substrate integrated waveguide filter and substrate integrated waveguide filter, respectively. A four-pole bandpass filter with Chebyshev response at C-band is designed and fabricated using a two-layer substrate and multilayer PCB process. The measured results show good performance and in agreement with the simulated results.

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