A Compact Substrate Integrated Waveguide Band-pass Filter

2 authors:

Changjun Liu
Sichuan University

Kama Huang
Sichuan University

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Changjun Liu and Kama Huang
School of Electronics and Information Engineering, Sichuan University, Chengdu 610064, China

Abstract— A substrate integrated waveguide (SIW) filter with compact size compared to traditional SIW filters are presented in this work. A band-pass filter for general purpose is designed at 5.8 GHz with relative bandwidths of 5%. The fabricated filter is on F4B-2 substrate and about $0.5\lambda_g$ by $1\lambda_g$, which is about 50% of a conventional SIW dual-mode band-pass filter. Simulation and measurements agree well over a frequency band of 3–10 GHz. The empirical design formulae are presented as well.

1. INTRODUCTION

Substrate integrated waveguides (SIWs) have many advantages over microstrip lines, such as high Q-factor, small size, light weight, and easy to integrate. Since SIWs have been proposed in 1998 [1], SIWs have found many applications in various microwave circuits [2]. A lot of conventional passive microwave components and devices, such as antennas [3], directional couplers [4], diplexers [5], and phase shifters [6] have been successfully realized with SIWs.

SIW filters have also been investigated by many researchers. Some of these filters [7–12] make use of quasi-waveguide cavity resonant modes formed by metallic vias. SIWs are integrated to reduce its size, weight, and cost. Meanwhile, they greatly enhance manufacturing repeatability and reliability [12].

Most of them have very high center frequencies [9, 12] e.g., 20 GHz or higher. Even when the resonance is of high-order modes, the overall size of a SIW filter keeps compact enough to work with other components and exhibits good performances. However, a SIW filter is not acceptable, when the center frequency goes down to several GHz and, even, in low-order modes, such as TE_{201} and TE_{102}. It limits the applications of SIW filters at low frequency part. But the SIW is a born high-pass filter due to its waveguide characteristics. If a stop band higher than its cut-off frequency is introduced, a band-pass filter is presented.

This work is focused on a compact SIW band-pass filter. We present a method to design and realize compact SIW band-pass filter, in which a hole on the top metallic surface of the SIW filter is applied for mode regulation. A SIW band-pass filter at 5.8 GHz with a fractional bandwidth of 5% is demonstrated. The measured results of the fabricated SIW filter agree well to simulations. The size of the proposed SIW filter is roughly about half of a traditional dual-mode SIW filter, e.g., with TE_{201} and TE_{102} modes.

2. PRINCIPLES

A SIW is a type of dielectric-filled waveguide which is synthesized in a planar substrate with linear arrays of metallic vias. Those vias are used to realize metal edge walls. Its basic structure is similar to a microstrip structure, which is easy to fabricate. It works in TE or TM modes, instead of the quasi-TEM mode of a microstrip line. Thus, some components are usually required at both input and output of a SIW band-pass filter. Planar structures, such as microstrip lines and coplanar waveguides (CPWs), may be integrated to SIWs as various transitions. An entire system based on SIWs is compact, and convenient to connect to other parts.

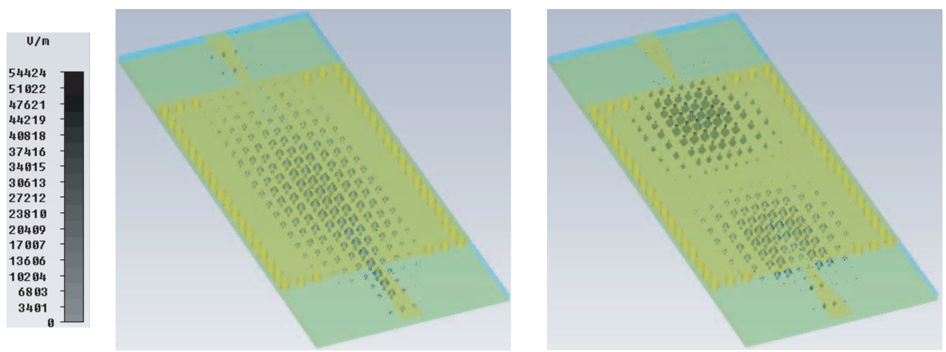
A section of SIW at given boundary conditions is equivalent to a cavity resonator. The resonant frequencies are

$$f_{m0n} = \frac{c}{2\sqrt{\varepsilon_{eff}}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2} \tag{1}$$

where ε_{eff} is the effective permittivity, m and n are non-negative integers, and a and b are effective length along x and z directions, c is the speed of light in free space, respectively. The resonant frequencies are corresponding to different electromagnetic field distributions and modes.

In many dual mode filter design, sizes in x- and y-direction are almost the same, so the orders of resonance modes are the same [11]. As for SIW, resonance modes of f_{101} and f_{102} are shown in Fig. 1. It's the first time that we have introduced a circular hole etched on the top metal layer of the SIW filter to perturb the electromagnetic field distributions of these two modes and form a filter as shown in Fig. 3. With the increment of R_c, resonance frequencies of f_{101} and f_{102} get close to each other gradually. When coupling those two modes, the cavity is resonant at dual mode. Moreover, the introduced circular hole reduces the size of the resonator by enhance the path length of currents.

A valid method is to use a section of Conductor Backed Coplanar Waveguide (CBCPW) as a transition to connect a SIW to a microstrip line. The gaps of the CBCPW transition work as chokes at a given frequency, when the gap length is about quarterwavelength, as shown in Fig. 2. It is clear that there is a short circuit formed at the end of the CBCPW from the simulated current distribution and, then, leads to a strong reflection from the choke. The CBCPW transition may used as a band-stop structure in the SIW filter with the introduced extra transmission zero, of which the frequency is dependent on the length of the CBCPW transition. It is a compact design without occupy extra space. Thus, CBCPW transitions are introduced in the proposed SIW band-pass filter design to improve its performance.



(a) f_{101} (4.95 GHz) (b) f_{102} (6.28 GHz)

Figure 1: Simulated electric field distributions of resonance modes.

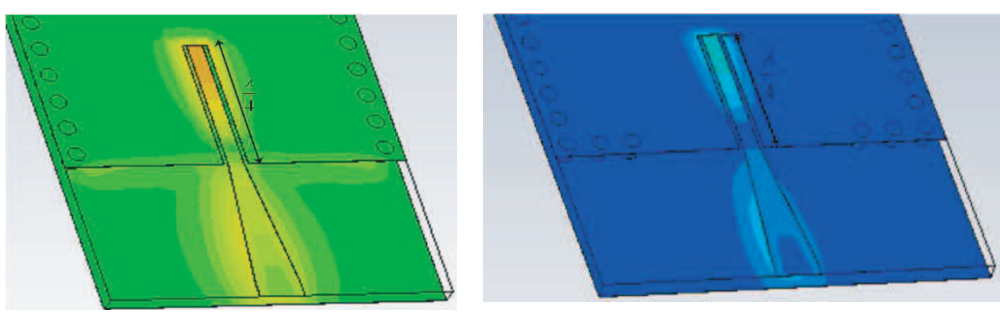


Figure 2: Current distribution of a CBCPW with a choke structure.

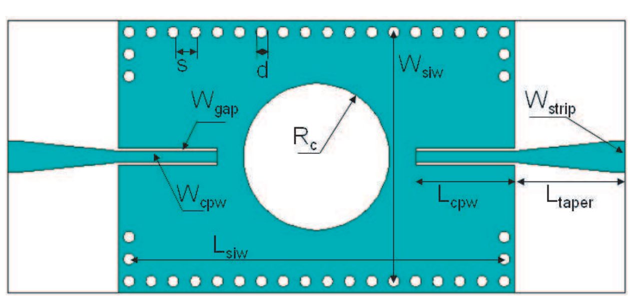


Figure 3: General filter.

3. SIW BAND-PASS FILTER

The SIW band-pass filter works in dual-mode with a circular hole etched on top metal layer and two CBCPW sections, as shown in Fig. 3. We first design the SIW filter prototype with roughly estimated parameters at the center frequency f_0. Then, we use CST to simulate and optimize the filter prototype. Finally, we give the following empirical formulae to help the design of the proposed SIW band-pass filter whose relative bandwidth of about 5% (The thickness of the substrate is 1 mm.):

$$W_{\mathrm{SIW}} = \frac{0.58c}{f_0\sqrt{\varepsilon_r}} \tag{2}$$

$$L_{\mathrm{SIW}} = 1.895 * W_{SIW} \pm 2d \tag{3}$$

$$L_{\mathrm{CPW}} = 0.46 \cdot W_{SIW} \tag{4}$$

$$R_c = 0.26 \cdot W_{SIW} \tag{5}$$

where c is the light speed in free space, ε_r is the relative permittivity of the substrate, d is the diameter of vars. As shown in Fig. 3, metallic vias are added at corners of the SIW to reduce its insertion loss, achieve a sharper skirt and a wider stop-band. Since these vias reduce the equivalent width of the SIW, W_{SIW} should increase to maintain the resonance frequency f_0 unchanged. Parameter values of the filter are given in Table 1. Larger R_c helps to get narrower pass band and steeper skirt, but leads to higher insertion loss.

Table 1: Parameters of the filter with matched port configuration, Unit: mm.

s	d	W_{gap}	W_{CPW}	L_{taper}	L_{CPW}	R_c	W_{SIW}	L_{SIW}	W_{strip}
2.0	1.0	0.3	0.5	10.0	9.0	6.8	22.2	34.0	2.8

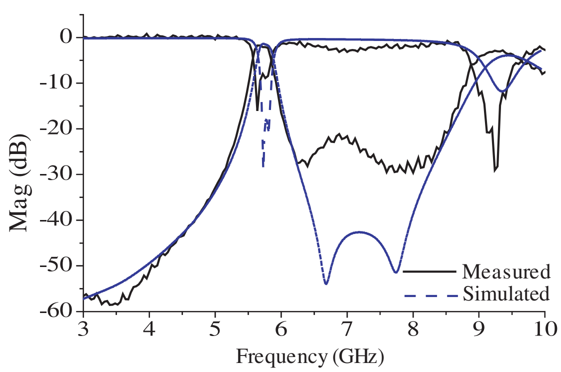
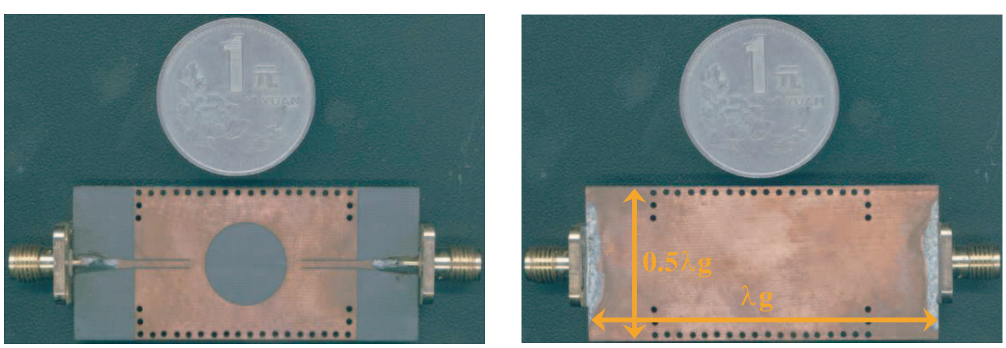


Figure 4: Simulated and measured results of the general filter.



(a) (b)

Figure 5: Front and back view of the general filter. (a) Front view, (b) back view.

Responses of full-wave simulation and measurement are shown in Fig. 4. The center frequency is 5.8 GHz and the 3-dB bandwidth is 280 MHz, which is about 5% of the center frequency. The measured return lose is better than 9 dB and the insertion is 1.8 dB in pass band. The fabricated filter is shown in Fig. 5.

There are three drawbacks of this band-pass filter, although it has a quite good performance. A) The frequency response at the cut-off frequency is not steep enough. B) The first parasitic pass band is too close, which limits the applications of the proposed band-pass filter. C) The return loss in pass band is too small.

4. CONCLUSION

In this research, a novel SIW filter is investigated and the empirical design formulae are presented. Filters are fabricated on an F4B-2 substrate, whose dielectric constant is 2.65 and dielectric loss tangent is 0.001. Although there is a little frequency shift by approximately 0.8%, measured results are in good agreement with simulated ones, which suggest that the proposed filters present attractive performances, especially the high selective filter. It's a difficulty for traditional SIW filters to get rid of parasite pass bands caused by lower- or higher-order modes [11], while the parasite pass band has been depressed effectively in this paper. The size of the filter is about half of a traditional dual mode SIW filter that make use of TE_{102} and TE_{201}, as discussed in [11]. It is expected to find applications in communication systems, especially for frequencies in C-band.

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