Dual-Mode Substrate Integrated Waveguide (SIW) Bandpass Filters with an Improved Upper Stopband Performance

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***Abstract*—Dual-mode substrate integrated waveguide (SIW) filters with improved upper stopband attenuation is presented. The filter is comprised of TE_{102} and TE_{201} modes waveguide resonator. The proposed filters are implemented using substrate integrated waveguide (SIW) technology featuring compact size, low cost, and high power-capacity. A simple solution for improving the upper stopband performance while maintaining compact size realization is provided. The stopband improvement is achieved by using defected ground structure (DGS) which is etched on the ground plane of the SIW cavity. Compared to previous-reported SIW filters with improved stopband achieved by lowpass cleanup filters, the proposed approach provides a relatively compact realization while reducing the complexity of the overall structure. Simulation examples of single- and double-cavity dual-mode SIW filters are realized using EM simulations for demonstrating the underlying principle.**

I. Introduction

Substrate integrated waveguide (SIW) technology [1] has been an attractive subject over the past several years. SIW enables the realization of low profile and low cost planar filters while maintaining high performance of conventional rectangular waveguides. Most efforts have been focused on implementing SIW filters to operate in the dominant TE_{10} mode [2, 3] and few works concerned about SIW dual-mode filters. In dual-mode bandpass filters, the number of resonators required for a given filter can be reduced by half, resulting in a compact filter configuration. Moreover, dual-mode SIW filters exhibit high skirt selectivity and symmetric transmission zeros [4]. The early works on SIW dual-mode filters are focused on realizing dual-mode frequency characteristics in single and multi-layer configurations [5, 6]. However, SIW dual-mode filters suffer from limited upper stopband attenuation thus will require to be cascaded by a lowpass cleanup filter [7]. To this end, lowpass filter (LPF) with wide stopband may be implemented using defected ground structure (DGS) which is realized by etching off a defected pattern from the backside metallic ground plane and has periodic structures, provides rejection of certain harmonics and/or allows the realization of compact size components [8].

The objective of this paper is to present an SIW dual-mode filters with an improved upper stopband performance suitable for narrowband applications. It will be shown that the proposed filters possess the desirable feature of compactness while achieving excellent upper stopband attenuation by the application of DGS.

II. Filter Implementations

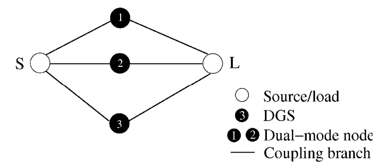


Fig.1. Coupling topology of the proposed filter.

Fig. 1 depicts the coupling scheme of the DGS dual-mode SIW filter which consists of two orthogonal resonant modes (TE_{102} and TE_{201}) in an SIW cavity (node 1 and node 2) and the cascaded LPF with wide stopband generated using DGS (node 3). It will be shown that the DGS occupies the area of the SIW cavity; hence, compact realization is achieved.

In dual-mode resonator, the condition that both modes resonate at the same frequency in a rectangular cavity with *a*, *b*, and *l* sides is given by

$$\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{l}\right)^2 - \left(\frac{p\pi}{a}\right)^2 - \left(\frac{q\pi}{l}\right)^2 = 0 \quad (1)$$

Consequently, the initial dimension ratio between the length (*l*) and the width (*a*) of the resonator can be calculated using the following equation

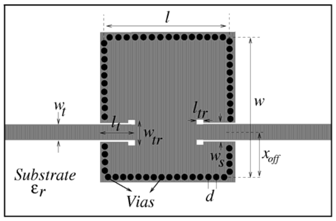
$$\frac{a}{l} = \sqrt{\frac{m^2 - p^2}{q^2 - n^2}} \quad (2)$$

where (*m*, *n*) and (*p*, *q*) refer to the first and second mode respectively. We assumed that the dimension *b* (*i.e.* cavity height) is equal to zero, since the proposed filters realized using planar SIW technology. Two examples will now be illustrated.

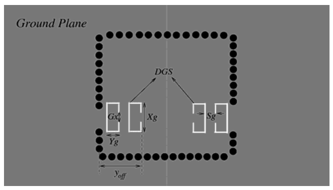
A. Single-cavity dual-mode SIW filter

Fig. 2 illustrates the physical structure of a single-cavity dual-mode SIW filter with DGS. The structure is supported by a 0.508 mm thick Rogers RT/duroid 5880 substrate with a dielectric constant of 2.2 and a loss tangent of 0.0009. Full-wave EM simulations were performed using *ANSYS* HFSS leading to the following optimal dimensions of the proposed filter: l=20.1mm, w=19.8mm, w_t=1.6mm, w_s=1.8mm, l_t=4.5mm, l_{tr}=0.6mm, w_{tr}=2.8mm, x_{off}=6.5mm, d=2mm, G_x=0.7mm, Y_g=2.1mm, X_g=2.7mm, S_g=0.3mm, Y_{off}=3.8mm. As depicted in Fig. 2, slot coupling is used for the input/output feed-lines. SIW filters with slot coupling have better stopband performance since less energy can be transferred by the higher order modes.

978-1-4577-0509-0/11/$26.00



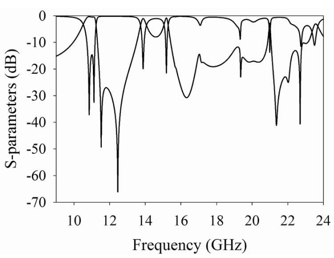
(a)



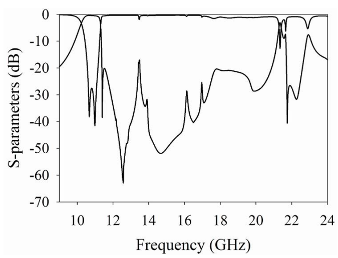
(b)

Fig.2. The physical structure of a single-cavity dual-mode bandpass filter with DGS: (a) top view; and (b) bottom view.

The source and load couplings as well as the inter-resonator couplings were adjusted for best electrical performance resulting in the simulated electrical performances shown in Figs. 3(a) without DGS and Fig. 3(b) with DGS and improved upper stopband. Both plots have passband center frequency at 11 GHz with a transmission zero located on the passband's upper side.



(a)



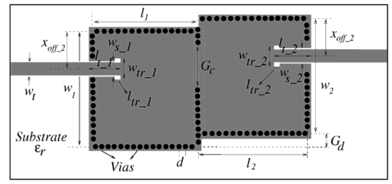
(b)

Fig.3. Simulated frequency response of the single-cavity SIW bandpass filter: (a) without DGS; and (b) with DGS.

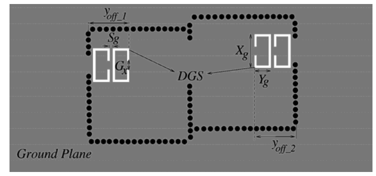
B. Double-cavity-dual-mode SIW filter

An attempt to improve the skirt selectivity led to the implementation of a double-cavity dual-mode SIW filter with DGS whose configuration is shown in Fig. 4. EM simulations were performed leading to the following optimal dimensions: l_1=20.5mm, l_2=19.8mm, w_1=20.3mm, w_2=22.25mm, w_t=1.6mm, G_c=5.6mm, G_d=0.7mm, w_{s-1}=1.8mm, w_{s-2}=1.9mm, l_{t-1}=4.7mm, l_{t-2}=5.7mm, l_{tr-1}=l_{tr-2}=1.2mm, w_{tr-1}=w_{tr-2}=3.7mm, x_{off-1}=5.9mm, x_{off-2}=7.9mm, d=2mm, G_x=0.7mm, Y_g=2.1mm, X_g=2.7mm, S_g=0.3mm, Y_{off}=3.8mm.

Fig. 5(a) shows the simulated performance of a double-cavity filter without DGS while Fig. 5(b) shows the same filter with DGS. Fig. 5(b) clearly exhibits an improved upper stopband performance and further proving the validity of the proposed design technique. Both plots have passband center frequency at 11 GHz with two transmission zeros located on the passband's lower and upper side.

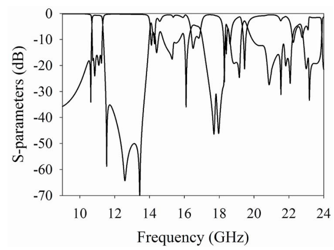


(a)

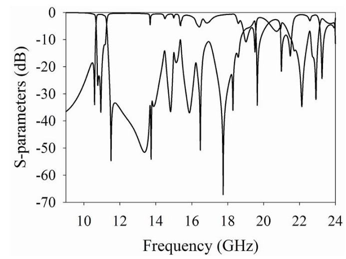


(b)

Fig.4. The physical structure of a double-cavity dual-mode SIW bandpass filter with DGS: (a) top view; and (b) bottom view.



(a)



(b)

Fig.5. Simulated frequency response of the double-cavity SIW bandpass filter: (a) without DGS; and (b) with DGS.

III. CONCLUSION

SIW dual-mode bandpass filters with an improved upper stopband performance are demonstrated. The filters are comprised of SIW cavities with two orthogonal modes and a lowpass cleanup filter generated using DGS pattern etched on the ground plane within the cavity area. The proposed filters show an excellent upper stopband improvement while filter's compact size is maintained.

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