Design of a Dual-Band Dual-Mode Substrate Integrated Waveguide Filter with Symmetric Transmission Zeros

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***Abstract*- In this paper, a dual-band dual-mode substrate integrated waveguide (SIW) filter with symmetric transmission zeros is presented. The filter is comprised of three-cavity dual-mode resonators with inductive inter-resonator couplings. Each cavity has a pair of orthogonal waveguide resonator modes (TE_{102} and TE_{201}) capable of producing two transmission poles and one transmission zero. The proposed filter is implemented using SIW technology featuring compact size, low cost, high Q, and high power-capacity. Examples of three-cavity dual-mode SIW filters featuring bandpass and dual-band frequency characteristics realized *via* EM simulations are presented.**

Keywords - Dual-band filter, Dual-mode resonator, Symmetric transmission zeros, Substrate integrated waveguide (SIW).

I. INTRODUCTION

Rapid development of modern wireless systems has resulted in an increasing demand for telecommunication systems that function over multiple frequency bands. For example, global system for mobile communications (GSM) cellular terminals operate globally at 900 and 1800 MHz, and wireless local area networks (WLAN) such as IEEE 802.11b/g are required to operate simultaneously at 2.4 and 5.5 GHz. Consequently, interest has grown in re-designing filters to exhibit dual-band frequency characteristics with advanced functionality that meets the stringent requirements on modern systems such as small size, minimal insertion loss, and high selectivity. Filters comprising dual-mode resonators are good candidates, and they are especially good if the filter realization is supported by substrate integrated waveguide (SIW) technology [1]. SIW enables the realization of low profile and low cost planar filters while maintaining high performance of conventional rectangular waveguides. Moreover, SIW dual-mode bandpass filters exhibit high skirt selectivity and symmetric transmission zeros [2]. In dual-mode filters, the number of resonators required for a given filter can be reduced by half, resulting in a compact filter configuration. Each dual-mode cavity resonator is capable of generating two transmission poles and a single transmission zero. This is due to the input and output coupling to both TE_{102} and TE_{201} modes [3].

To date, existing literature has focused on developing dual-mode SIW filters exhibiting bandpass characteristics [4-7]; however, no works concerning dual-band dual-mode SIW filters, especially with inductive inter-resonator couplings, have been carried out.

The objective of this paper is to demonstrate that the dual-mode bandpass filter configuration is capable of realizing a dual-mode dual-band filter based on the use of simple inductive discontinuities in an SIW environment. This is achieved by moving one of the bandpass transmission zeros inside the passband. It will be shown that the proposed filter possesses the desirable feature of compactness while achieving an excellent frequency performance.

II. FILTER IMPLEMENTATIONS

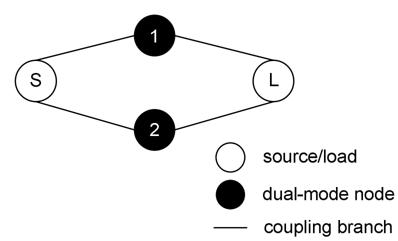
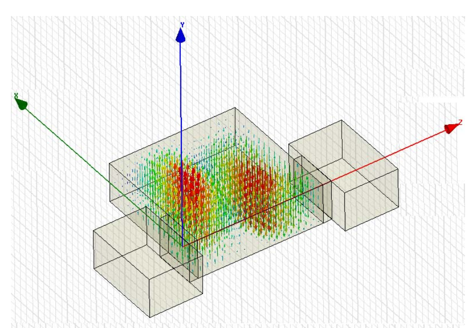


Fig.1. Coupling topology of a dual-mode SIW cavity.



(a)

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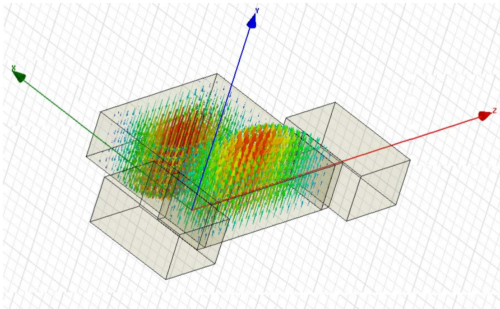


(b)

Fig.2 (a) Electric field distribution of TE_{102} mode and (b) Electric field distribution of TE_{201} mode.

Fig. 1 depicts the coupling scheme of the 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). The electric field distributions of the orthogonal modes are shown in Fig. 2. In a dual-mode resonator, the condition that both modes resonate at the same frequency [3] in a rectangular cavity with a, b, and l sides is given by

$$(\frac{m\pi}{a})^2 + (\frac{n\pi}{l})^2 - (\frac{p\pi}{a})^2 - (\frac{q\pi}{l})^2 = 0\,. \qquad (1)$$

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

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

where (m, n) and (p, q) refer to the first and second mode respectively. It is assumed that the dimension b (*i.e.* cavity height) is equal to zero, since the proposed filter is realized using planar SIW technology. In this paper, we illustrate two SIW filter design examples.

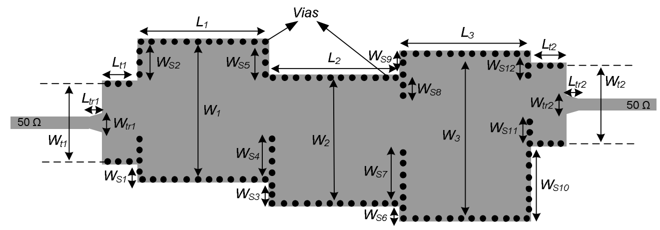
A. Three-Cavity Bandpass Dual-Mode SIW Filter

Fig. 3(a) illustrates the physical structure of a three-cavity bandpass dual-mode SIW filter with 50 Ω microstrip feed-lines. As depicted, a linear taper for transition between the 50 Ω microstrip line and the SIW is used for the input/output feed-lines [1]. The structure is supported by a 0.508 mm thick Rogers RT/duroid 5880 [8] substrate with a dielectric constant of 2.2 and a loss tangent of 0.0009.

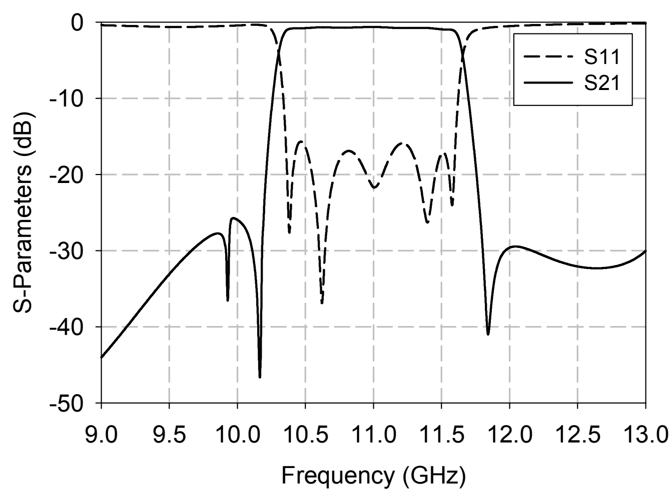
Full-wave EM simulations were performed using HFSS [9] leading to the optimal dimensions (Table I) of the dual-mode bandpass filter.

The source and load couplings, as well as the inter-resonator couplings, were adjusted to achieve the best electrical performance resulting in the simulated electrical performances shown in Fig. 3(b). The evaluated response has a passband center frequency at 11 GHz with a 10% fractional bandwidth. Three transmission zeros are introduced. Two transmission zeros are located on the passband's lower side at 9.9 GHz and 10.2 GHz while the third transmission zero is located on the upper side at 11.8 GHz. Each cavity is responsible for generating one transmission zero due to the different phase shifting between the two orthogonal modes in the cavity.

Note that the position of the transmission zeros can be moved to the passband's left- or right-side by changing the cavity's length-to-width ratio [3].



(a)



(b)

Fig.3. (a) Top view configuration of the three-cavity bandpass dual-mode SIW filter and (b) its simulated frequency characteristics.

TABLE I. DIMENSIONS OF THE BANDPASS DUAL-MODE SIW FILTER WITH VIA DIAMETER = 0.5 MM AND SPACING BETWEEN ADJACENT VIAS = 1.5 MM.

Symbol	Value (mm)	Symbol	Value (mm)
L_1	17.5	W_{tr2}	1.8
L_2	18	W_{S1}	3.7
L_3	18.6	W_{S2}	8.4
L_{t1}	6	W_{S3}	1.7
L_{tr1}	2.8	W_{S4}	8.6
L_{t2}	6	W_{S5}	8
L_{tr2}	2.8	W_{S6}	0.75
W_1	25.2	W_{S7}	10
W_2	18.8	W_{S8}	3.6
W_3	22.6	W_{S9}	2.7
W_{t1}	13.6	W_{S10}	8.9
W_{tr1}	1.8	W_{S11}	3
W_{t2}	13.2	W_{S12}	2.8

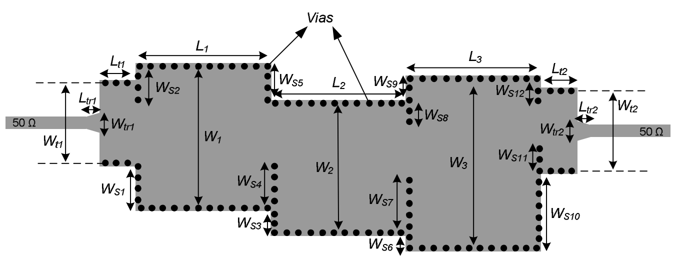
B. Three-Cavity Dual-Band Dual-Mode SIW Filter

Based on the successful implementation of the three-cavity bandpass filter, a three-cavity dual-band filter was implemented following similar steps. Here, the position of the transmission zero responsible for creating the dual-band characteristics has been adjusted by changing the offset in the input and the output couplings.

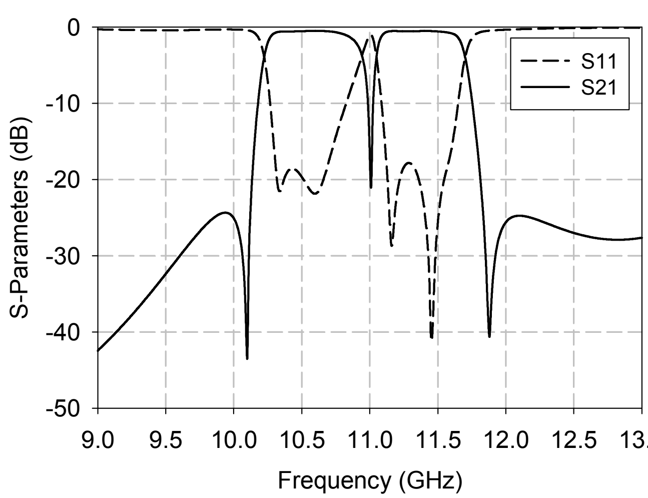
The physical structure of the proposed dual-band dual-mode SIW filter is shown in Fig. 4(a). Full-wave EM simulations were performed leading to the optimal dimensions of the proposed filter as in Table II.

The simulated frequency performance shown in Fig. 4(b) clearly exhibits dual-band frequency characteristics and further establishes the validity of the proposed approach. The dual-band frequency response has a lower passband center frequency at 10.6 GHz with a 4% fractional bandwidth and an upper passband center frequency at 11.4 GHz with a 5% fractional bandwidth. Two symmetric transmission zeros are located on the passband's lower and upper sides, and the transmission zero that was located at 9.9 GHz in the previous design is now located at 11 GHz.

It is worth mentioning that the level and bandwidth of the in-band notch, i.e. the third transmission zero, could be further improved by increasing filter order until it provides enough isolation between two adjacent bands.



(a)



(b)

Fig.4. (a) Top view configuration of the proposed three-cavity dual-band dual-mode SIW filter and (b) its simulated frequency characteristics.

TABLE II. DIMENSIONS OF THE PROPOSED DUAL-BAND DUAL-MODE SIW FILTER WITH VIA DIAMETER = 0.5 MM AND SPACING BETWEEN ADJACENT VIAS = 1.5 MM.

Symbol	Value (mm)	Symbol	Value (mm)
L_1	17.5	W_{tr2}	1.8
L_2	19.7	W_{S1}	4.8
L_3	17.9	W_{S2}	6.9
L_{t1}	5.75	W_{S3}	2.5
L_{tr1}	2.8	W_{S4}	8.1
L_{t2}	6	W_{S5}	4.8
L_{tr2}	2.8	W_{S6}	0.9
W_1	21.4	W_{S7}	8.6
W_2	19	W_{S8}	2.8
W_3	23.4	W_{S9}	2.9
W_{t1}	12.8	W_{S10}	8.6
W_{tr1}	1.8	W_{S11}	2.9
W_{t2}	12.8	W_{S12}	2.35

III. CONCLUSIONS

In this paper, an SIW filter with dual-mode dual-band frequency characteristics and symmetric transmission zeros has been successfully realized. Dual-band response can be achieved by moving one of the dual-mode bandpass filter transmission zeros toward its passband. The filter is comprised of three SIW cavities with pairs of orthogonal modes while the inter-resonator couplings are realized using simple inductive discontinuities. SIW technology is used for better device and system integration.

ACKNOWLEDGMENT

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