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Design of a Miniaturized SIW Filters by Using DGS in WLAN Frequency Band

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Abstract

Substrate integrated waveguide (SIW) filers are good candidates to substitute for bulky and expensive metallic waveguide filters. Many methods are used in order to develop the specific filter responses. One of them is using defected ground structures (DGS) in SIW filters to generate desired transmission zeros, which cannot be used in waveguide filters. In this paper, an elliptical third order bandpass SIW filter is designed in WLAN frequency band using the DGS technique. It is also shown that the proposed technique reduces the filter size while providing good filtering response. The central frequency and fractional bandwidth of the filter is 2.4 GHz and 16.2%, respectively.

Keywords: Substrate integrated waveguide, SIW, Filter, WLAN.

1.INTRODUCTION

In recent years, a new type of transmission line, called substrate integrated waveguide (SIW), has been proposed for microwave and millimeter wave frequencies. This printed structure was introduced in 1998 as a planar waveguide [1]. Actually, a rectangular waveguide can be constructed in a flat shape compatible with the PCB technique.

SIW is a flat waveguide that can be integrated with any flat manufacturing or processing technique including PCB and LTCC technologies in a dielectric substrate.

This waveguide structure can be constructed with a pair of intermittent metal arrays that act as a metal wall. these two pairs of VIA arrays play the role of sidewalls of a rectangular waveguide, but the difference is that part of the propagating fields may leak out through VIA columns. These VIAs connect the upper and lower metal walls and there is a distinct space between these two pairs of arrays and enclose electromagnetic waves. This type of waveguide does not have

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the disadvantages of microstrip structures (high losses, low power, etc.) and metal waveguides (bulky and costly). In addition, it has almost advantages of both these structures such as print capability, specific modes and fields inside. In general, the main advantages of this type of transmission lines are high quality, easy and cost-effective construction, and easy connection to other flat structures, including microstrip structures. This type of transmission lines is an appropriate alternative for use in the millimeter wave communication systems. In fact, SIW is a compromise between the quality factor, the power handling capability, the dimensions, the cost, and the integrity of the devices.

According to the SIW characteristics, various devices have been built in the microwave and millimeter wave frequency bands. These devices include passive antennas, active antennas, power amplifiers, oscillators, couplers, power dividers, filters, and etc. One of the most important applications of this technology is filters fabrication where many researches have been done. Although, SIW filters are smaller than the metallic waveguide filters, but their communication specifications are slightly weaker than the metallic type. However, in comparison with microstrip filters, SIW has greater power handling, lower dimension, and less insertion loss.

First, in 2003, an SIW filter was designed [2] and then many researchers worked in this field and several methods to overcome drawbacks like improving bandwidth, and decreasing dimensions were presented.

In many applications, it is necessary to eliminate a specific frequency in the desired frequency band (separated by a filter in other frequencies) or to sharpen the bandpass filter within a given range. This can be done by creating a transmission zero in the filter response. There are several methods to create a transmission zero in the filter response. One of these methods in printed filters is the use of defected ground structures (DGS). In this method, a portion of the copper layer is removed under certain patterns which causes resonating behavior. DGS implementing in a filter structure improves the quality factor, increases the power handling and decreases dimensions of the filter. An example of this method used in a microstrip filter design [3] which created a bandgap in the filter response. In 2005, this technique was also used in SIW filters [4] for the first time. There are other examples of using DGS in SIW filters that improve the filtering characteristics as well.

In this paper a novel band-pass WLAN filter is designed using coupling matrix. Then the DGS structures is used to create desired transmission zeros. As the basic structure of the proposed filter is based on the filter introduced in [5], so the bandwidth, sharpness and dimension are compared with the achieved results in reference [5]. Furthermore, the behavior of this simple structure is also compared to other design in this filed.

2. DESIGN SIW FILTER WITH DGS

The filters structure and coupling schematic are shown in Figs. 1 and 2.

The structure of this filter is almost the same as the structure of article [5] and includes a SIW resonator, two DGS resonators, and two

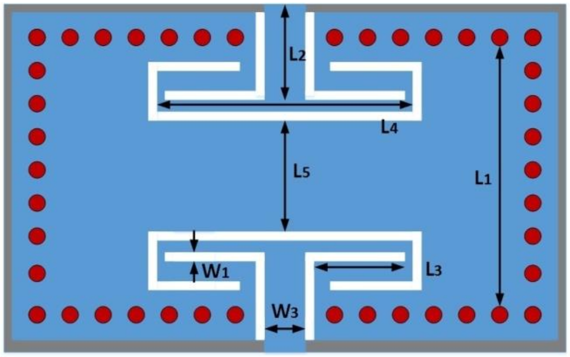


Fig. 1. Top view of filter.

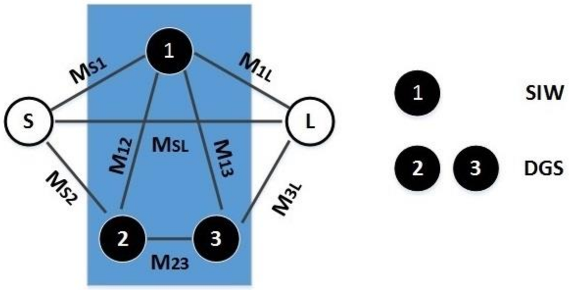


Fig. 2. Schematic of filters coupling structure [5].

CPW feed lines. However, unlike paper [5], for easy to fabrication, both DGS resonators and CPW feed lines are etched on the top layer of the filter. As shown in Fig. 2, the SIW resonator with number 1 and the DGS resonators with numbers 2 and 3 have been named respectively.

Using this structure, we will design a passband filter at 2.4GHz with a bandwidth of 400MHz. For this purpose, we obtain the corresponding coupling matrix for the filter and then we will use the coupling matrix to realize the filter dimensions.

2.1. Filter Design Process

The generalized coupling matrix can be obtained using the gradient-based optimization method [6]. In this paper, the designed filter is elliptical 3rd order with three transmission zeros. The coupling matrix and corresponding filter response are shown in Table.1 and Fig. 3, respectively.

The distance and relation between the resonators determine the coupling coefficients. Therefore, some of the filter parameters can be obtained easily from the coupling matrix coefficients. The coupling coefficient between resonators is calculated as,

$$M_{i,j} = \pm \frac{\left(f_{1_{i,j}}^2 - f_{2_{i,j}}^2\right)}{\left(f_{1_{i,j}}^2 + f_{2_{i,j}}^2\right)} \qquad (1)$$

where $f_{1_{i,j}}$ and $f_{2_{i,j}}$ are the first and the second resonance frequencies of i and j resonators, respectively.

TABLE 1. ***Coupling matrix of filter.***

	S	**1**	**2**	**3**	**L**
S	0	0.3	-0.5	0	0.32
1	0.3	0	-0.28	-0.5	-0.3
2	-0.5	-0.28	0	0.07	0
3	0	-0.5	0.07	0	0.4
L	0.32	-0.3	0	0.4	0

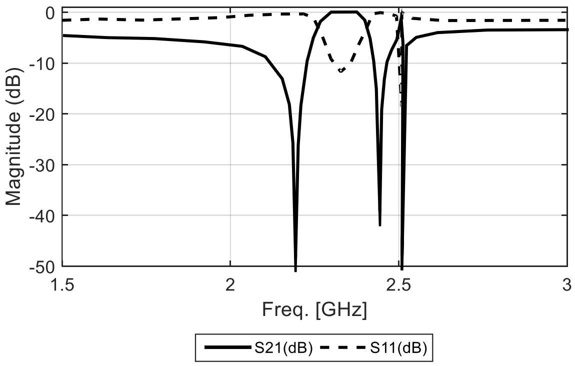
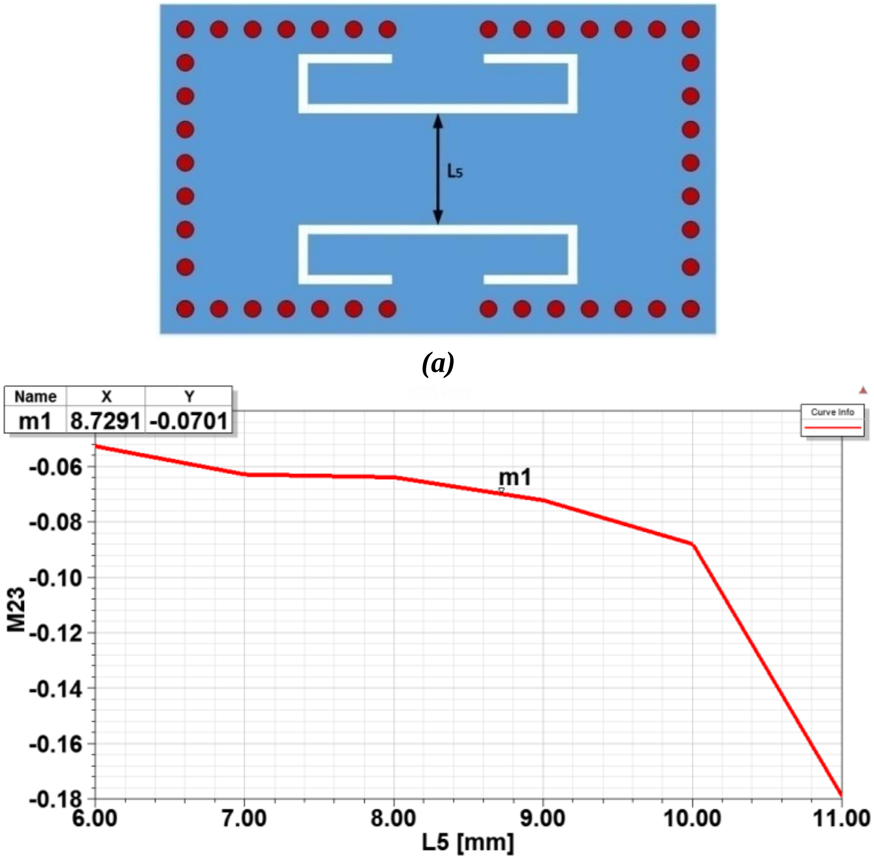


Fig. 3. Frequency response corresponding to the coupling matrix.



(a)

(b)

Fig. 4. (a) M_{23} coupling schematic and (b) M_{23} Coupling coefficient as a function of L_5.

When the resonators close each other, the resonance frequency of each of them (which was the same as the central frequency of the filter before), change from the filter's central frequency. In this case, the resonance frequency of one of them is less than the center frequency of the filter and the other is greater than the center frequency of the filter. These frequencies are named as $f_{1_{i,j}}$ and $f_{2_{i,j}}$.

The HFSS software has been used to calculate low and high resonance frequencies.

Based on the filter structure, the values of L_2, L_4 and L_5 (dimensions in Fig. 1) can be determined from M_{SL}, M_{12}, and M_{23}, respectively.

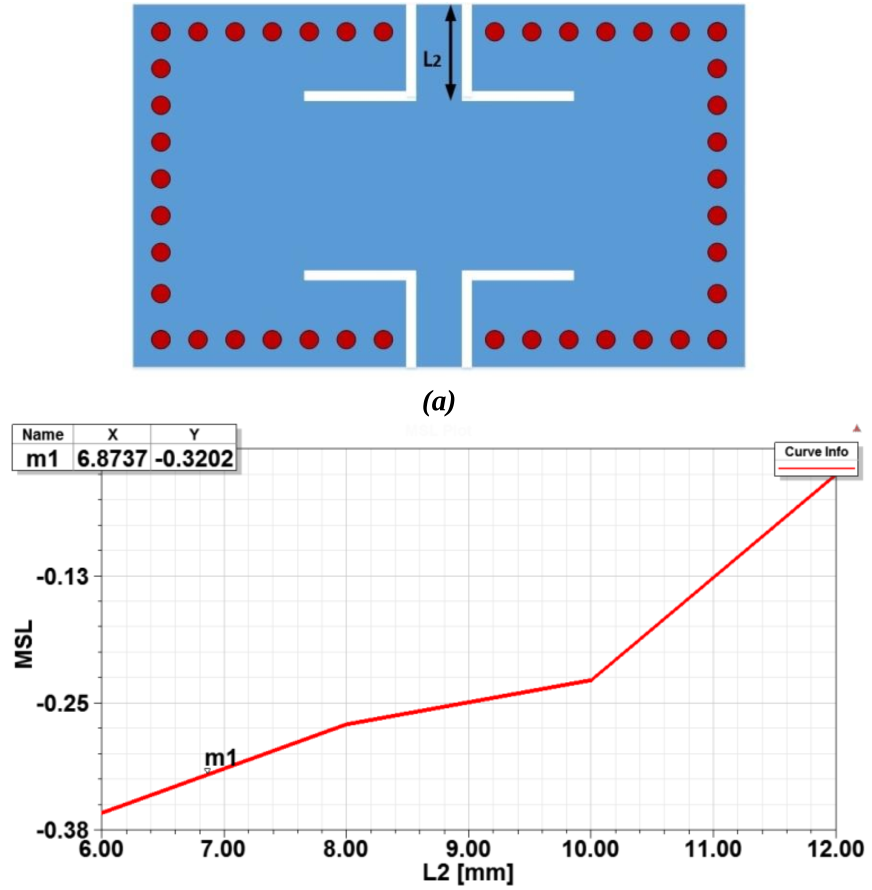
- **Calculate L_5**

When L_5 increases, the coupling between DGS resonators decreases and vice versa and when L_5 decreases, the coupling between them increases. So, we can specify L_5 by drawing the M_{23} as a function of L_5.

The M_{23} coupling is plotted as a function of L_5 in Fig. 4. According to the diagram for M_{23}=0.07, L_5=8.7mm should be considered.

- **Calculate L_2**

When L_2 increases, the coupling between source and load resonators increases, and vice versa. So, we can specify L_2 by drawing the M_{SL} as a function of L_2. The M_{SL} coupling is plotted as a function of L_5 in Fig. 5.



(a)

(b)

Fig. 5. (a) M_{SL} coupling schematic and (b) M_{SL} Coupling coefficient as a function of L_2

According to the diagram shown in Fig. 5(b), for M_{SL}=-0.32, L_2 =6.8 mm should be considered.

- **Calculate L_4:**

The M_{12} coupling is plotted as a function of L_4 in Fig. 6. Accordingly, for M_{12} = -0.28, the value L_4 = 23.75 mm should be considered.

- **Calculate L_3**

The L_3 resonator acts like a monopole antenna, so its electric length is calculated as follows:

$$L_3 = \lambda_g / 4 = 66.34/4 = 16.58\ mm \qquad (2)$$

where λ_g is the wavelength at 2.4 GHz (center frequency).

- **Calculate L_1**

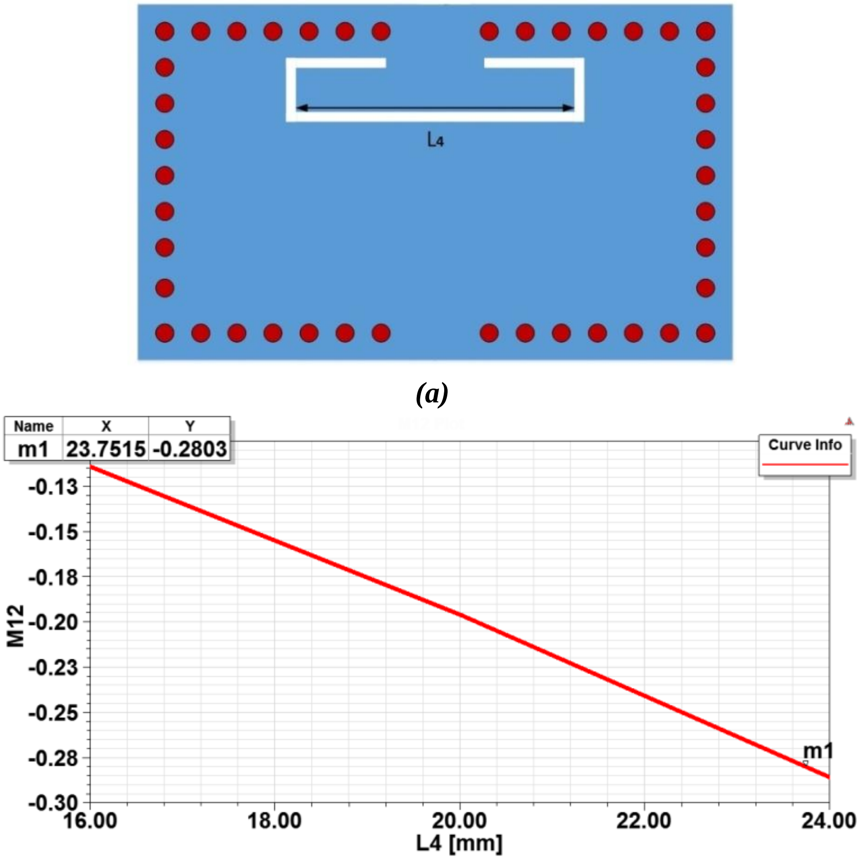
The initial length of each resonator is about half the wavelength at the central frequency [7]. So, the L_1 value is calculated as:

$$L_1 = \lambda_g / 2 = 66.34/2 = 33.17\ mm \qquad (3)$$

The obtained dimensions are used as initial values and should be optimized by a simulation software such as HFSS.

- **Calculate W_1 and W_3**

In this structure, CPW (co-planar-waveguide) is used to feed SIW resonator and



(a)

(b)

Fig. 6. (a) M12 coupling schematic and (b) M12 Coupling coefficient as a function of L4.

DGS resonators. Therefore, for 50 ohms matching, the width of CPW and its gaps should be properly chosen, hence the values of W_1 and W_3 were calculated as 0.3 and 1.5 mm, respectively.

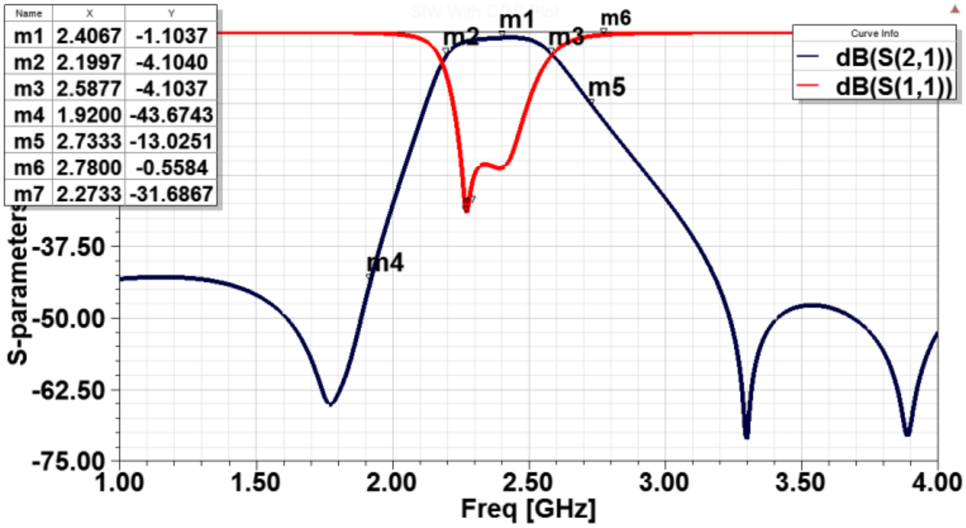
2.2. Simulation and Dimension Optimization

In the last step, based on the initial vales that obtained from the previous steps, a complete simulation of the proposed structure has been performed by HFSS and the dimension values are optimized. Ultimate amounts are written in the Table 2. Also, the simulation result is shown in Fig. 7.

The proposed filter output specifications such as bandwidth, size and insertion loss (I.L) are compared to other SIW-based filters in Table 3. As seen, the relative bandwidth of our filter is much better than other samples. Also, our filter dimensions are smaller than most of the mentioned samples.

Table 2. ***Geometrical sizes of the filter sample.***

Variable	Size (mm)
L1	23
L2	8.4
L3	12.7
L4	27.5
L5	9
W1	0.3
W2	6
W3	1.5
W4	0.3



Name	X	Y
m1	2.4067	-1.1037
m2	2.1997	-4.1040
m3	2.5877	-4.1037
m4	1.9200	-43.6743
m5	2.7333	-13.0251
m6	2.7800	-0.5584
m7	2.2733	-31.6867

Fig. 7. Final filter response.

Table 3. ***Comparison with SIW filters presented in references.***

Reference	Size (cm)	Fractional Bandwidth and Center Frequency	I.L (dB)
[5]	0.39*0.39	9.2%@4.9	1.1
[8]	0.42*1.27	3.66% @ 5.75	2.05
[9]	0.2*0.2	5.8%@2.4	3.6
	0.43*0.43	6.45%@5.2	3.1
[10]	0.65*0.62	3%@5.0	1.6
[11]	0.76*0.76	5%@5.0	1.3
This work	0.4 * 0.2	16.2%@2.4	1.1

3. CONCLUSION

In this paper, SIW filter with DGS resonators is presented, with better frequency selectivity and high fractional bandwidth. The proposed structure is an elliptical 3rd order filter with three transmissions zero. The central frequency, insertion loss and bandwidth of this filter are 2.4GHz, 1.1 dB and 388 MHz respectively. The final fractional bandwidth of this filter is 16.2%, which is noticeable from article [5] and other examples.

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