

Compact Microwave Triple-Mode Bandpass Filter in Planar Technology

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Abstract: This paper introduces a novel microwave planar filter design using triple – mode resonator. In order to achieve the filter size reduction we use the multilayer technology. The structure consists of two dielectric layers separated by a common ground plane. The triple – mode resonator consists of two dual-mode resonators which are placed on different sides of dielectric layers. Electrical connection between the two resonators is realized by using a via-hole. We use the dual-mode resonator with the short circuited central stub. The filter is designed for the center frequency of 1 GHz. In order to reduce the simulation time for the filter design, we propose a new circuit model, because the circuit-level simulations are significantly faster than three-dimensional electromagnetic (3D EM) simulations. The 3D filter structure is decomposed into domains and each of them is modeled by a microwave network. The results of the 3D EM simulation and circuit-level simulation are in good agreement.

Keywords: Bandpass filter, Dual-mode resonator, Miniaturization, Multilayer technology, Triple – mode resonator.

1 Introduction

Due to the increased number of new services and development of new wireless technologies, it is necessary to strictly limit the assigned frequency band for each device. Also, the need for mobile communication and size reduction of the user devices imposes the need to significantly miniaturize the components of wireless systems [1 – 2]. An important part of each device intended to operate at RF and microwave frequencies are passive circuits such as resonators and filters. These components represent one of the obstacles for miniaturization and performance improvement of devices for wireless communications that support services such as mobile telephony (900 MHz, 1.8 GHz, 1.9 GHz, 2.1 GHz), GPS (1.6 GHz), WiMAX (3.5 GHz), WiFi (2.4 GHz, 5.8 GHz).

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Miniaturization is one of the main requirements imposed during the design of microwave filters [3 – 5]. One of the methods, used to reduce the filter size occupation, is the realization in multilayer technique [6 – 7]. In multilayer technology, component layout is no longer confined to one plane, thereby a greater degree of freedom in allocating individual components is obtained and the flexibility in the design and miniaturization of the device is achieved [8 – 9].

The filter can be miniaturized by using a resonator with two resonant frequencies (2RF), dual-mode resonator [10 – 11]. Microstrip dual-mode resonators and filters have been the subject of intensive research efforts in recent years. A main feature and advantage of this type of resonators lies in the fact that each of the dual-mode resonators can be used as a doubly tuned resonant circuit, and therefore the number of resonators required for an n-degree filter is reduced by one-half, resulting in a compact filter configuration. The first two resonant modes, which occur in the resonator, are actually the even mode and the odd mode. Depending on the dimensions of the resonator, these two modes can have the same or different modal frequencies and also the modal resonant frequency of one mode can be either higher or lower than that of the other one. Another distinct characteristic of the dual-mode open-loop resonator is that the two modes are not coupled to each other even after the modes are split [1].

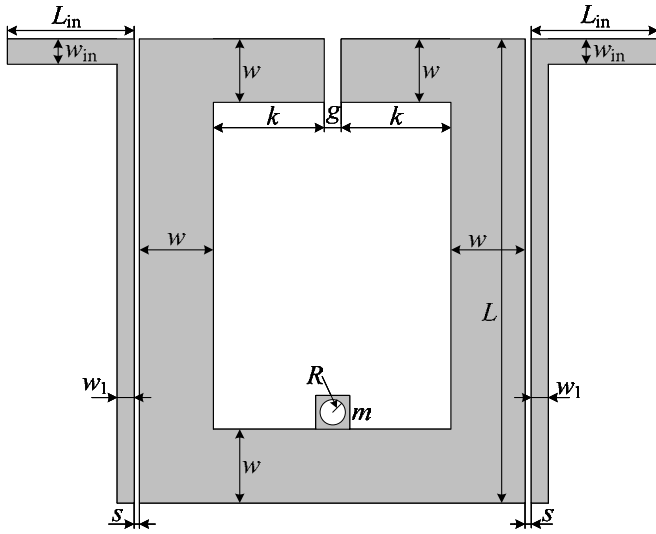


Fig. 1 – *Microstrip filter with 2RF resonator.*

Triple — mode bandpass filters for RF/microwave applications have been intensively studied recently. A triple – mode microstrip square-loop resonator was reported in [12]. It was realized by adding an additional path to a microstrip

square-loop dual-mode resonator [12]. In [13], microstrip triple – mode resonators loaded with two T-shaped open stubs were introduced. Reference [14] presents a triple – mode hexagonal bandpass filter with capacitive loading stubs. Also, a triple – mode microstrip bandpass filter using a single patch-loaded cross resonator was realized in [15]. A compact size and high isolation microstrip quadruplexer based on the tri-mode net-type resonators was presented in [16].

This paper presents a procedure for miniaturization of a bandpass filter with a triple – mode resonator using multilayer technology which is the extension of the research presented in [17].

2 Filter Design with 2RF Resonator

One approach for a compact filter design is to use 2RF resonators. In this research, we used the resonator with the short circuited central stub. It is easy to adjust the specified filter selectivity by using these resonators.

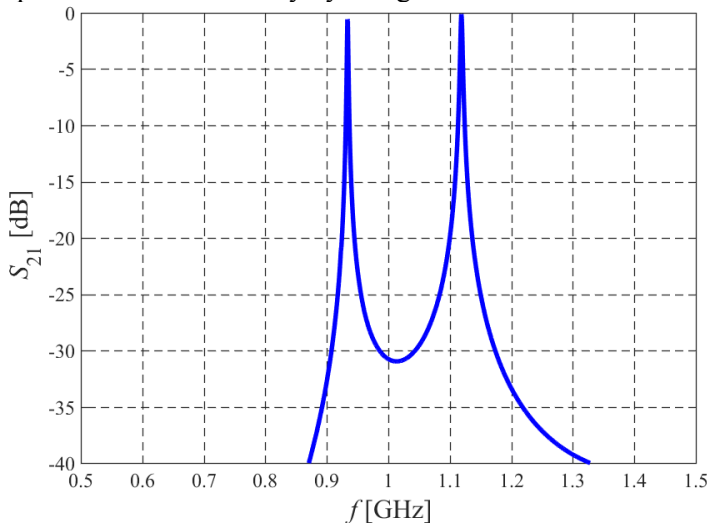


Fig. 2 – Resonant frequencies of the unloaded resonator shown in Fig. 1.

Table 1

Parameters of the filter shown in Fig. 1. All dimensions are in mm.

Resonator					Feed line			Via	
w	L	k	g	s	w_{in}	L_{in}	w_1	R	m
3	15	3.35	0.3	0.05	1.1	5	0.5	0.12	0.5

Microstrip bandpass filter is designed using the proposed 2RF resonator (Fig. 1). The filter is designed for the center frequency of 1 GHz (f_0) and a fractional bandwidth (FBW) of about 22%.

In this study, we use a substrate with the following parameters: $\epsilon_r = 10.8$, $\tan\delta = 0.001$, substrate thickness $h = 1.27$ mm, metallization thickness $t = 18$ μm . The conductor conductivity is set to $\sigma = 20$ MS/m to take into account the losses due to the surface roughness and the skin effect.

The filter is designed using the algorithm presented in [1] and the dimensions are given in **Table 1**. The resonator is capacitively coupled to the feed lines implemented as a 50 Ω microstrip line ($w_{\text{in}} = 1.1$ mm). The resonant frequencies of the unloaded (2RF) resonator, i.e. frequencies of the even and odd mode, are shown in Fig. 2. In order to adjust resonant frequencies, the feed lines are located at a distance of about $2h$ away from the resonator, where h is the thickness of the microstrip substrate.

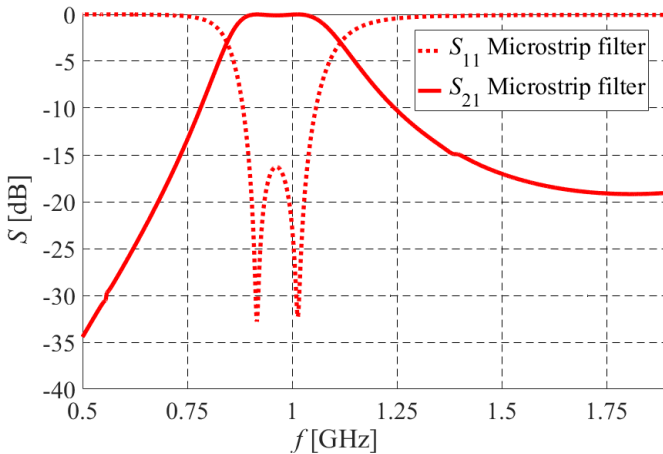


Fig. 3 – *S*-parameters of the planar microstrip filter with 2RF resonator.

S-parameters of the microstrip filter, obtained by simulation, are shown in Fig. 3. We use 3D EM simulator WIPL-D Pro [18] for the design and analysis of the considered structures.

3 Multilayer third – order filter using triple-mode resonator

Novel third – order bandpass filter is designed in multilayer technology. The filter has been designed using one triple – mode resonator. The triple – mode resonator is realized with two connected 2RF resonators with slightly different dimensions.

The third – order filter is designed for the center frequency of 1 GHz and a fractional bandwidth (FBW) of 20%.

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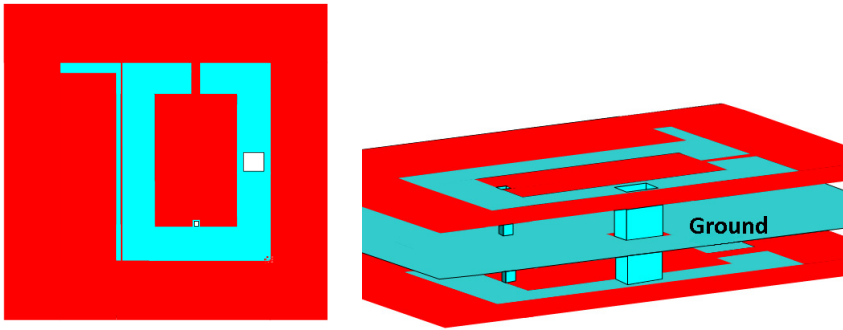


Fig. 4 – 3D EM model of MultiBPF in WIPL-D Pro.
(Colors can be seen in electronic version)

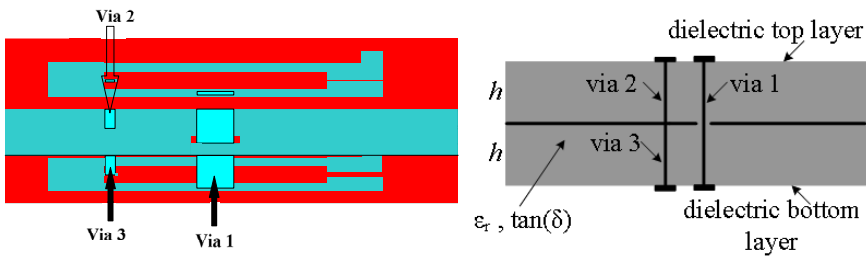


Fig. 5 – Vias in cross section of the filter: via 1 connects two resonators, vias 2 and 3 connect resonators with the common ground plane.
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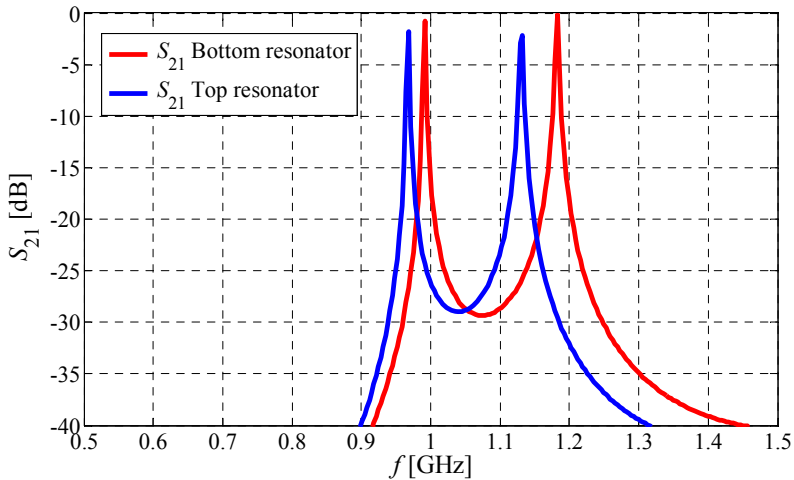


Fig. 6 – The resonant frequencies of the unloaded top and bottom 2RF resonators of MultiBPF.
(Colors can be seen in electronic version)

The proposed miniaturized multilayer bandpass filter (MultiBPF) is shown in Fig. 4. The structure consists of two dielectric layers, which are separated by a conducting plane – the common ground. The triple – mode resonator consists of two dual-mode resonators which are conductively connected by via [19 – 21]. Resonators are positioned one below the other, on different sides of the dielectric layers. The proposed filter design achieves the desired compactness and meets the miniaturization requirements.

Electrical connection between two resonators, placed on opposite sides of the structure, is realized by using a via-hole, as shown in Fig. 5. Two resonators are connected with via, which is a vertical metal connection between resonators in different layers. Via 1 has no electrical contact with the common ground plane. This is achieved by removing the metal around via 1 in the central plane of the filter structure. Via 2 and via 3 are used for grounding the miniaturized resonator as shown in Fig. 5. These vias connect the common ground with the top and bottom parts of the resonator.

The resonant frequencies for the individual unloaded top and bottom 2RF resonators of MultiBPF are presented in Fig. 6.

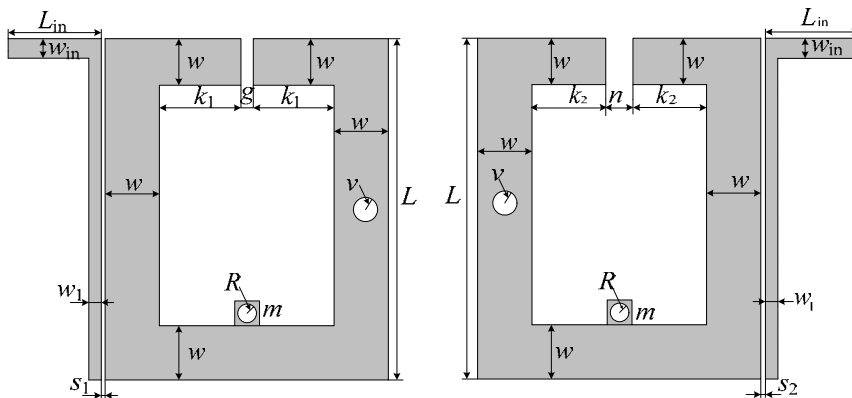


Fig. 7 – 2RF resonators on the top and the bottom dielectric layer of MultiBPF.

Table 2

Parameters of MultiBPF shown in Fig 7. All dimensions are in mm.

		Top resonator			Bottom resonator		
w	L	k_1	g	s_1	k_2	n	s_2
3	15	3.35	0.3	0.05	2.9	1.7	0.05
Feed line			Via				
L_{in}	w_{in}	w_1	v	R	m		
5	1.1	0.5	0.225	0.12	0.5		

2RF resonators on the top and the bottom dielectric layer of MultiBPF are shown in Fig. 7 and their dimensions are presented in **Table 2**. Feed line on the top layer is coupled with the top resonator, while the feed line on the bottom layer is coupled with the bottom resonator.

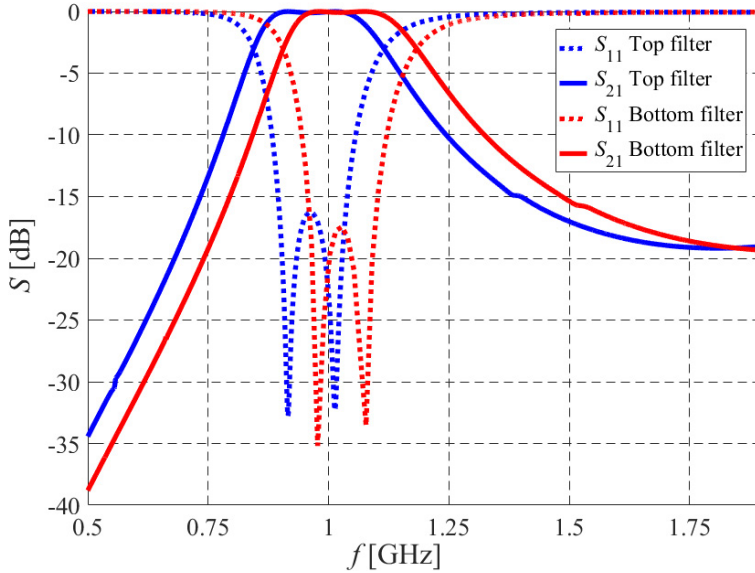


Fig. 8 – S -parameters of individual 2RF resonator filters in the top and the bottom layers.
(Colors can be seen in electronic version)

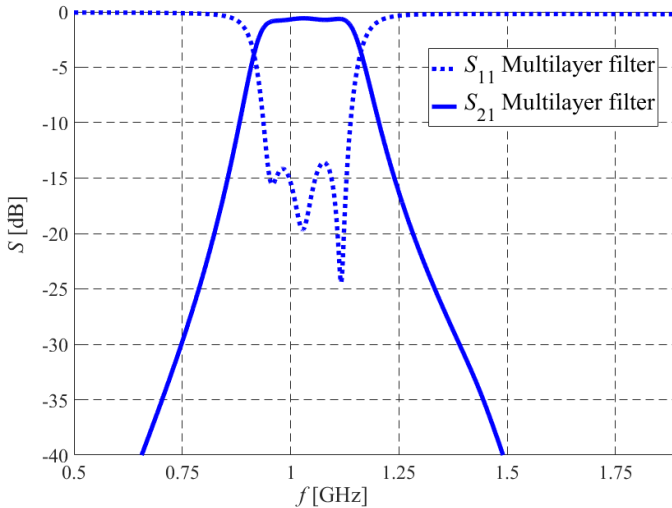


Fig. 9 – S -parameters of MultiBPF.
(Colors can be seen in electronic version)

Fig. 8 represents responses of individual filters, in the top and bottom layers, obtained by the 3D EM simulation.

The response of MultiBPF, obtained by the 3D EM simulation, is shown in Fig. 9. It can be observed that the filter has the desired selectivity. The filter insertion loss in passband is less than 0.6 dB, while the return loss is greater than 14 dB.

Multilayer filter occupies a rectangle of $0.12 \lambda_g \times 0.13 \lambda_g$ ($13 \text{ mm} \times 15 \text{ mm}$) excluding the feed lines and guard zone. λ_g is the guided wavelength of a 50Ω microstrip line on the desired substrate for the center frequency. The proposed MultiBPF implementation enables the footprint reduction around 50% compared to the planar microstrip topology.

4 Circuit Model of the Multilayer Third-order Filter

Compared to 3D EM simulators, circuit-level simulators analyze the filter almost instantaneously. We are using the concept of the circuit model as a primary tool to analyze and design a filter. Using the diakoptic approach, the 3D filter structure is decomposed into domains and each of them is modeled by a microwave network.

Therefore, repeated circuit simulations can be efficiently used to identify the key filter parameters which predominantly affect the filter characteristics. These key parameters can be effectively used to fine-tune the filter performance and meet the specifications. Using the circuit model, the desired bandpass filter is designed. After fine tuning, the filter is analyzed by the 3D EM solver.

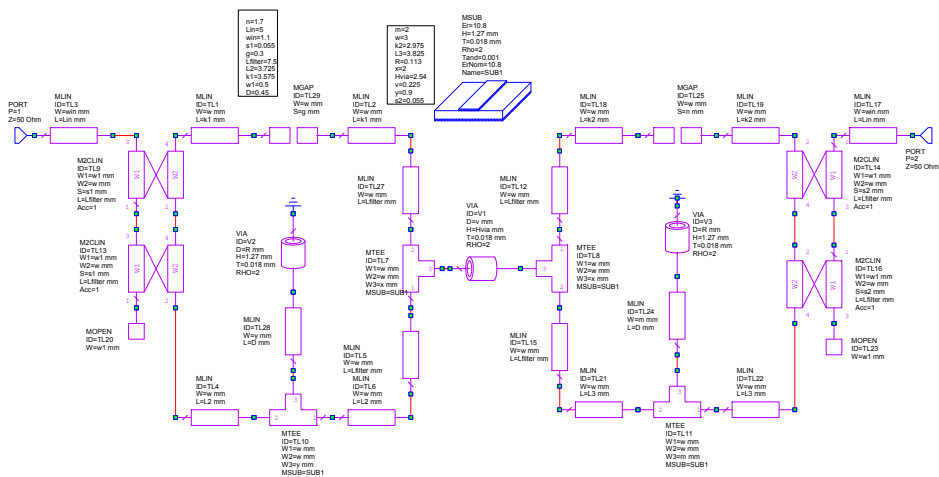


Fig. 10 – Circuit model of MultiBPF.

Table 3

Circuit model parameters of MultiBPF shown in Fig. 10. All dimensions are in mm.

		Top resonator				Bottom resonator			
w	L_{filter}	k_1	g	s_1	L_2	k_2	n	s_2	L_3
3	7.5	3.575	0.3	0.055	3.725	2.975	1.7	0.055	3.825
Feed line			Via						
L_{in}	w_{in}	w_1	x	y	H_{via}	v	R	D	m
5	1.1	0.5	2	0.9	2.54	0.225	0.113	0.45	2

The proposed circuit model of MultiBPF is presented in Fig. 10. The dimensions of the circuit model are shown in **Table 3**. The circuit-level simulations are performed by NI AWR Microwave Office [22].

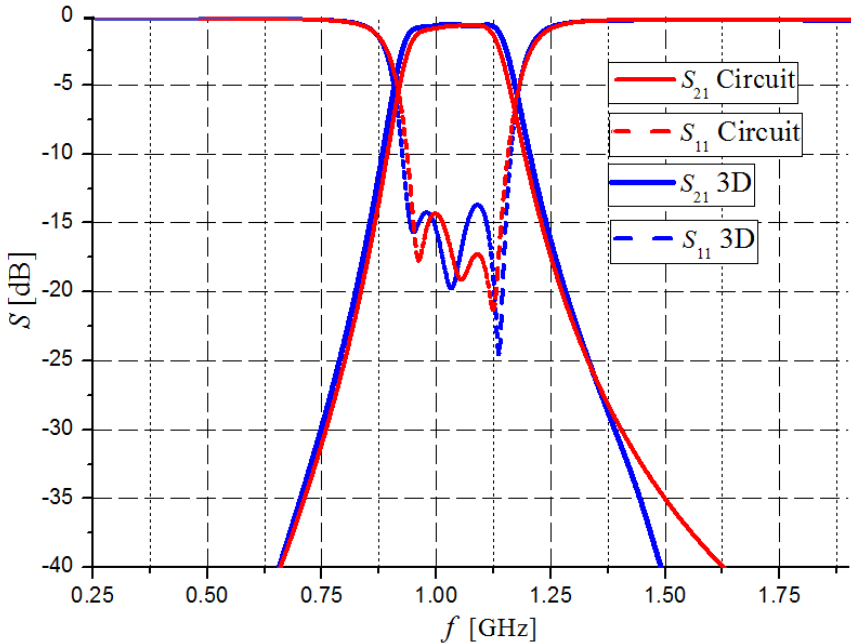


Fig. 11 – *Frequency responses of MultiBPF: 3D EM simulation and circuit-level simulation. (Colors can be seen in electronic version)*

The filter’s frequency response obtained by WIPL-D Pro is compared to the simulation results generated by NI AWR Microwave Office and there is a good agreement as shown in Fig. 11. However, dimensions of the circuit elements are slightly modified to match the desired filter response obtained by the 3D EM simulation.

Table 4
Comparison of the filter (MultiBPF) characteristics of the 3D EM model and the equivalent circuit model.

MultiBPF	f_0 [GHz]	S_{21} [dB]	B [MH]
3D model (WIPL-D)	1	-0.6	200
Circuit model (MWO)	1	-0.7	197

Table 4 shows the comparison of the filter (MultiBPF) characteristics for the 3D EM model with the equivalent circuit model. There is a relatively good agreement of the obtained results, thus the proposed circuit can be adopted as the relevant representation of the considered multilayer filter.

Table 5
Comparison of our filter with reported filter designs (f_0 – centre frequency, FBW – fractional bandwidth, IL – insertion loss).

Ref. No	f_0 [GHz]	FBW [%]	IL [dB]	Circuit size
[13]	1.8	22.3	0.31	$0.29 \lambda_g \times 0.46 \lambda_g$
[15]	2.15	11.1	2.15	$0.34 \lambda_g \times 0.34 \lambda_g$
[14]	2.4	4.79	1.4	$0.39 \lambda_g \times 0.34 \lambda_g$
[12]	5.06	4.347	2.2	$0.28 \lambda_g \times 0.28 \lambda_g$
This work	1	20	0.6	$0.12 \lambda_g \times 0.13 \lambda_g$

Table 5 summarizes the comparisons between performances of the proposed MultiBPF and several other triple-mode bandpass filters which are reported in literature. Our filter design exhibits a compact filter size in multilayer technology and very good results regarding the filter size reduction. Our filter is among the best achieved results (the smallest circuit size and the insertion loss in the passband) compared to other filters which use triple – mode resonators.

5 Conclusion

In this paper, a novel design of a third – order microwave filter has been presented. Third – order filter was designed using one triple – mode resonator. The filter has been realized in multilayer technology. The structure consisted of two dielectric layers separated by the ground plane. The triple – mode resonator consists of two dual-mode resonators connected with via. Two resonators were positioned on the outer sides of the two dielectric layers. The proposed filter design achieves desired compactness and meets the miniaturization requirements. The proposed filter realization was intended for the compact implementations of microwave devices.

The 3D EM modeling of the proposed filters was performed by WIPL-D Pro EM Solver. In order to reduce the time needed for demanding 3D EM analyses, we proposed the equivalent circuit models for faster filter analysis and design. The 3D filter structure was decomposed into domains and each of them was modeled by a microwave network.

The design methodology was presented. Results obtained by the circuit-level simulation and the 3D EM simulation were in a good agreement. Our miniaturized filter achieved a small footprint due to the multilayer implementation ($0.12 \lambda_g \times 0.13 \lambda_g$). The proposed design provides a possibility to easily increase the filter order by adding resonators.

6 Acknowledgment

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