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Original scientific paper

A COMPACT LOWPASS/DUAL-BAND BANDPASS FILTER FOR MICROWAVE APPLICATION

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Abstract. *A combination of lowpass and dual band bandpass filter with improved selectivity is presented in this manuscript. Two circular split ring resonators which are connected at the upper side, provide a lowpass filter characteristics. In order to achieve combined lowpass with dual passband response two L-shape stubs are incorporated into the lowpass filter structure. The parametric analysis of the proposed filter has been carried out using CST microwave studio. The numerical result shows a 3-dB cutoff frequency for lowpass at 1.22 GHz, first and second passband resonant frequencies are 2.44 GHz and 3.7 GHz respectively. The proposed filter is compact and overall size of the proposed filter is 32.9 mm×15mm.*

Key words: *Microstrip, Lowpass Filter (LPF), Bandpass Filter (BPF) and Multiband Bandpass filter*

1. INTRODUCTION

In modern microwave and millimeter wave communication systems, microstrip based filters are playing an important role due to their ability to pass certain frequency and reject others and having the characteristics like compactness, cost effectiveness, light weight, sharp rejection, low insertion loss, high selectivity, etc. In modern communication system, the filters with multiband with low insertion loss as well as compact and light weight are required [1-2]. There are many techniques for the design and development in multiband filters [3]. In 1971 [4], concept of ring resonator are introduced by Wolff and Knoppik. The ring resonator is still used for multiband filter, due to its high quality factor as well as compactness, the subsequent studied has been presented by many authors [5-6]. The grounded slotted structures are also used to design multiband filters, which allow back to back and front to front configuration for dual band bandpass filter characteristics with compact size [7]. The dual-band bandpass filter can also be realized using stepped impedance resonator (SIR) and shunted stub resonator [8-9]. The multilayer dielectric techniques are also used to realize dual passband filters, but the method and fabrication

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process are complex. In [10], coupled resonator pairs have been used to design passband filter with the help of low temperature co-fired ceramic (LTCC) technology.

In the aforementioned literature, the researchers are concentrated on the design and development of multiband filters only. In many applications, lowpass with bandpass filters are required like: mixers and hybrid fiber coaxial supporting systems [11-12]. In mixers, lowpass and bandpass filters are used to separate intermediate frequency (IF) and local oscillator (LO) frequency. In 2016 [13], combination of lowpass and single bandpass filter is presented using stub-loaded transmission lines and stepped-impedance stubs. The impedances and lengths of the transmission lines are used to control the resonance frequencies, while shunting stubs are used stop band attenuation improvement. The lowpass and bandpass filter can be realized using defected ground structure (DGS) and complementary split ring resonator (CSRR). The CSRR are used for LPF with sharp cutoff and wide stop band, while a gap is added in series with the transmission line for passband [14]. The lumped element resonator structure is also used to design lowpass and dual-band bandpass filter [15]. The dual-band bandpass filters with LPF characteristics are designed using different techniques like, dual mode resonator [16], multi armed open loop resonators with direct feed [17], hairpin-slots [18] etc. In 2019 [19], a compact lowpass and dual-band bandpass filter using $\lambda/5$ length of folded coupled line and open circuited L-shape strip has been presented. The filter presents controllable transmission zero with controllable center frequencies and passband bandwidth.

In this paper, a compact lowpass and dual band bandpass filter are designed using a combination of two circular shape split ring resonator which and connected at the upper side and a L-shape stub. The numerical analysis has been carried out using CST microwave studio. The proposed filter has its advantages of independent control of resonance frequency as well as transmission zeros location. The organization of the manuscript is as follows. In the first section, the lowpass filter geometry and analysis is presented. In the second section design of lowpass and dual pass band discussion are presented. The third section is based on final filter design, result and discussion. In the last section conclusion has been presented.

2. LOWPASS FILTER GEOMETRY

Geometry of the microstrip lowpass filter is shown in Fig. 1. The resonator is printed on Rogers RT/Duroid 6010 substrate having loss tangent 0.0023, dielectric constant 10.2 and thickness of the dielectric substrate 1.27mm. The figure shows that there are two sections: (i) 50 Ω microstrip transmission line, and (ii) double split ring resonator, which are connected through strip. The corresponding frequency response of filter drawn in Fig. 1 is shown in Fig. 2, which reveals lowpass frequency response.

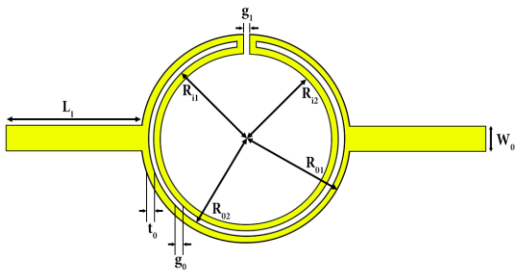

Fig. 1 Schematic diagram of lowpass filter prototype with dimensions L_1=6.54, t_o = g_o = g_1 = 0.3, R_{01}= 5, R_{02} = 4.7, R_{i1} = 4.4, R_{i2} = 4.1, W_0 =1.2 (All dimensions are in mm).

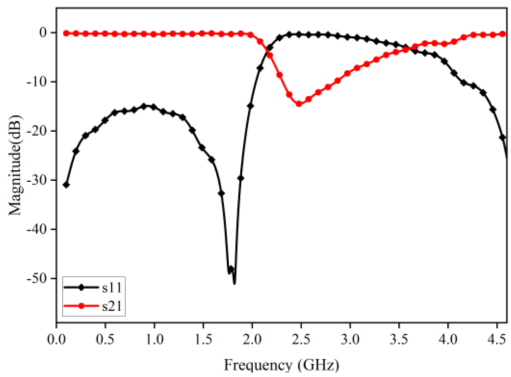

Fig. 2 Simulated S-parameters of the lowpass filter

In order to get particular cutoff frequency, the parametric analysis has been carried out. Initially a parametric analysis is carried out for R_{i2} with fixed other parameters, and its numerical analysis is shown in Fig. 3. The figure reveals that the radius R_{i2} is varied from 2.9 to 4.1 mm. For radius of 4.1 mm the 3-dB cutoff frequency is 2.15 GHz with its improved return loss. The figure also shows a passband frequency response at upper frequency.

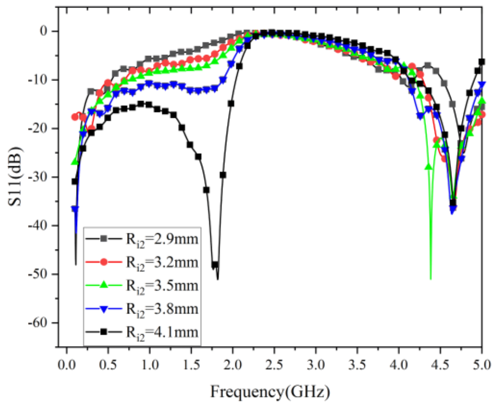

Fig. 3 Simulation results for the variation in S11 with respect to radius R_{i2}

Fig. 4. shows the variation of R_{o1} from 5 to 6.2 mm. The figure shows that the acceptable performance is achieved for the outer ring radius of 5 mm. The selectivity of the lowpass filter is also improved at these dimensional values.

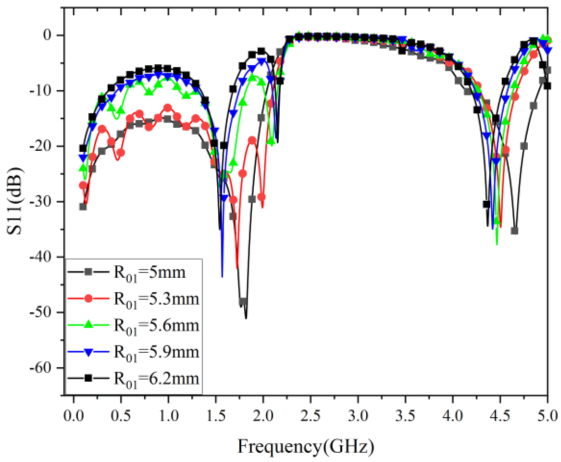

Fig. 4 Simulation results for variation in S11 with respect to radius R_{01}

3. LOWPASS AND BANDPASS FILTER DESIGN AND ANALYSIS

It has been observed from Fig. 4., that during the design of LPF a bandpass is also achieved at higher frequency, but the performance of the bandpass is very poor. In order to improve the passband a quarter wavelengths L-shape stub has been incorporated at both side of the jointed split ring resonator. The length of the stubs is chosen in such a way to get the acceptable band-pass response. The stub increases the overall circuit size of the device. It is therefore more preferable to combine both the lowpass and bandpass filter structures on the same length to overcome the large circuit size. The L- shape stub introduction in Fig. 1 is shown in Fig. 5.

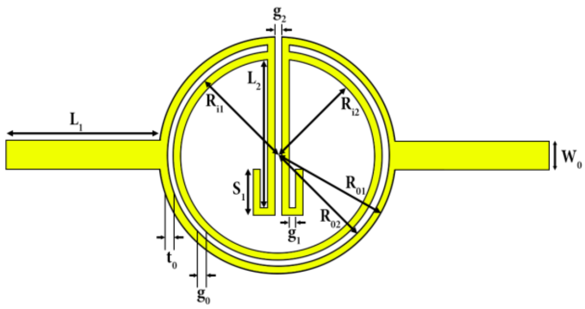

Fig. 5 Schematic diagram of lowpass and bandpass filter prototype.

The stub dimensions are: L_2 = 6.58 mm, S_1 = 1.95mm and g_1 = 0.3mm. The Fig. 6 shows the frequency response of the proposed filter. The figure reveals that a lowpass with dual band bandpass filter characteristics. The 3-dB cut-off frequency for the lowpass filter is at 1.34 GHz, first passband lies between 2.05 to 2.8 GHz with bandwidth of 0.75 GHz and the second passband lies between 2.92 to 4.62 GHz with bandwidth of 1.7 GHz. The 2.39 and 3.67 GHz are the resonant frequencies of the first and second passband respectively.

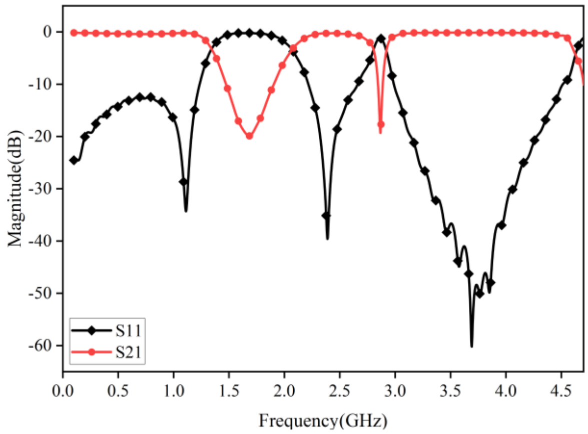

Fig. 6 Simulated S-parameters of the proposed lowpass filter

4. PROPOSED FILTER DESIGN, RESULT AND DISCUSSION

The performance of the filter which is shown in Fig. 6, is not good and not applicable in any microwave applications. In order to improve the filter performance, two identical resonator structure has been connected through transmission line at an optimized distance of L_3 = 1.71 mm. In order to achieve L_3 = 1.71 mm, a parametric analysis has been carried out and shown in Fig. 8. The figure reveals that, at 1.71 mm, the performance of the proposed filter is acceptable. The proposed Lowpass dual-band bandpass filter has also been modeled on the same substrate RT/Duroid 6010 (dielectric constant (ε_r) = 10.2 and having loss tangent (tanδ) =0.0023). The final LP-DBF is shown in Fig. 7.

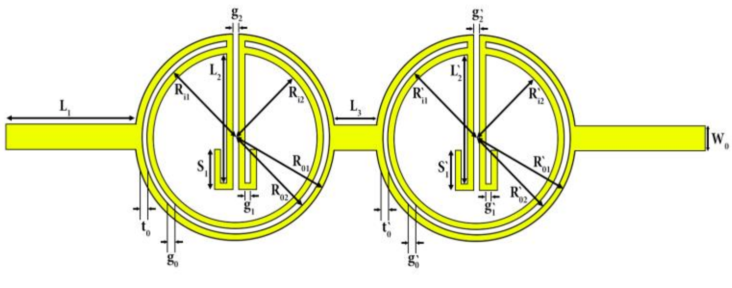

Fig. 7 Schematic diagram of lowpass and bandpass filter prototype

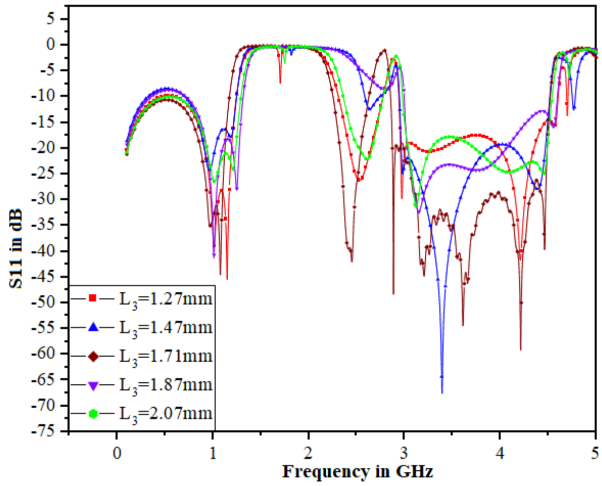

Fig. 8 Variation of S11 parameters with length L_3

In order to achive a perfect filter characteristics, parametric analyis of stub length L_2 has been carriedout. The corresponding S11 and S21 charatceristics are plotted in Fig. 9 and 10. The paramteric analysis of Fig. 9 shows that, the lowpass and first passband are remains unchanged while second passband is varied. It also overseved that the resonant frequency has been shifted at the lower side when the L_2 is increased. The reutn loss is also improved whrn the length is increases. The figure also reveals that the return loss is 20 dB.

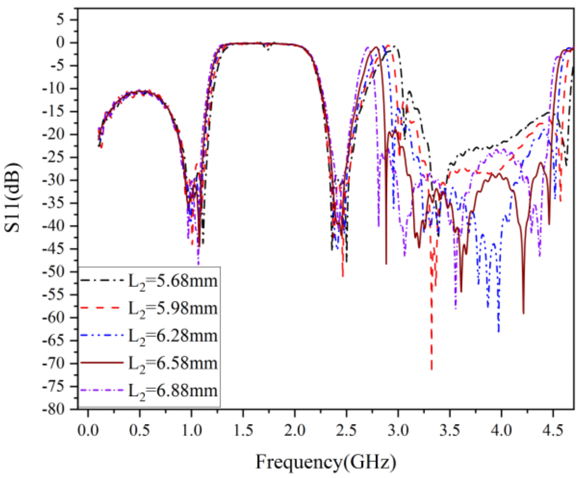

Fig. 9 Variation of S11 parameters with length L_2

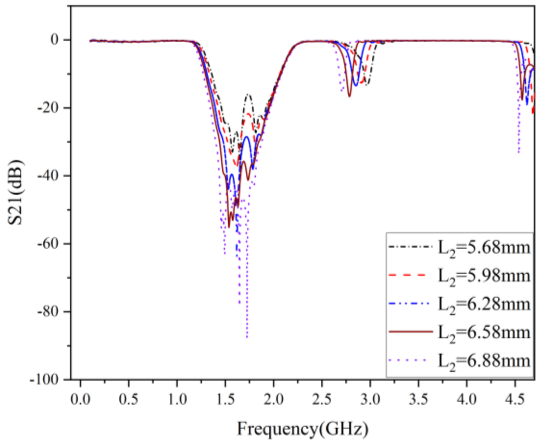

Fig. 10 Variation of S21 parameters with length L_2

The return loss variations gives us the optimum results for the operating frequencies in the second passband which can be utilized for the intended applications. The stub length S_1 = 1.95 mm is kept constant, which is used in the L- shape bent stub. There is a pole which can be seen in the fisrt passband, which improves the filter performance. The selectivity of the first passband also increases with increase in stub length L_2.The S21 parameter variations has been shown in the Fig. 10. The increase in length L_2 of the stubs shows a sharp transition at the 3-dB cutt of point for the lowpass band which improves the out of band performance. The 3-dB cut-off point is marginally reduced with the increase in length L_2 from 5.68 mm to 6.88 mm. The first stopband response is also improved with the parametric variations increments.

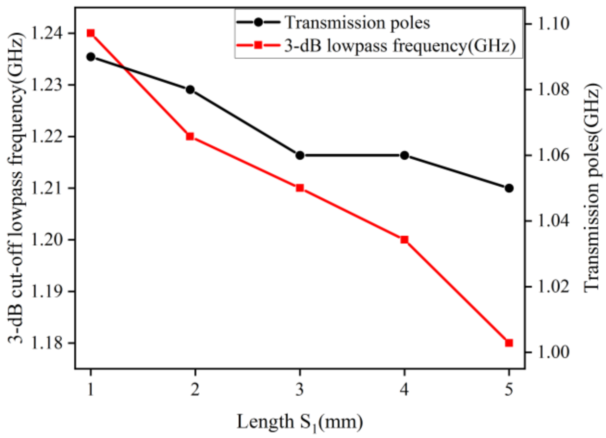

Fig. 11 Simulation results for the S_1 length optimization

The length S_1 of the proposed filter has been optimized from 1 to 5 mm and its corresponding 3-dB bandwidth and transmission poles are shows in Fig. 11. The figure reveals that, position of the transmission pole appearing in this band has been shifting slightly towards origin but not by much factor. The transmission pole has also shifted from 1.09 GHz and 1.05 GHz with the increase in length S_1. The 3dB cut-off frequency of the lowpass frequency response has also been optimized for the stub length S_1. Minor shifts in the cut-off frequency towards origin can be seen with the increasing length.The cut-off frequency goes from 1.24 GHz to 1.18 GHz. The analysis for the lowpass band has been done and there is no significant change in the the position of transmission ploes or the cut-off frequency.

Based on the analysis of different parameters optimizations using CST Microwave Studio, the final dimensions for the proposed filter has been realized and tabulated in Table 1. The final results are highly promising and meet all the requirements of microstrip filter applications.

Table 1 Complete dimensions of the proposed filter

Parameter	Values in (mm)	Parameter	Values in (mm)
$L_1=L_1$`	6.54	$t_o=g_o=g_1=g_2$	0.3
t_o`$=g_o$`$=g_1$`$=g_2$`	0.3	$R_{01}=R_{01}$`	5
$R_{02}=R_{02}$`	4.7	$R_{i1}=R_{i1}$`	4.4
W_0	1.2	$L_2= L_2$`	6.58
$S_1= S_1$`	1.95	$L_3= L_3$`	1.71
$R_{i2}=R_{i2}$`	4.1	Size of the filter	32.9×15

The frequency response of the proposed filter has been simulated and is shown in the Fig. 12.

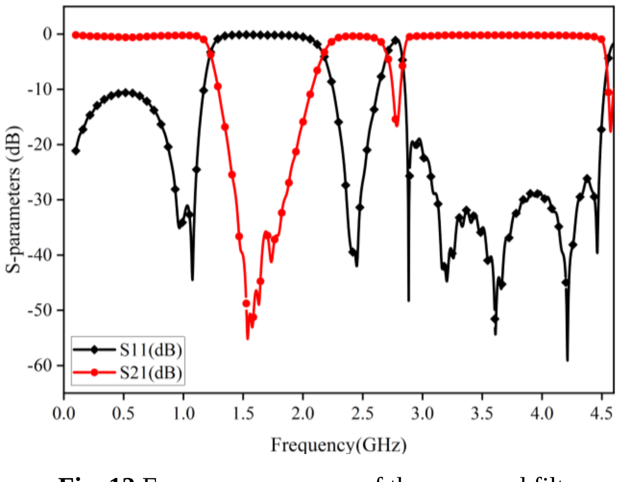

Fig. 12 Frequency response of the proposed filter

The figure shows that, a lowpass with two dual passband filter characteristics with improved selectivity and multiple transmission zeros has been observed in the results. The filter response shows lowpass 3-dB cutoff frequencies at 1.22 GHz, First and second resonant passband frequencies are 2.44 GHz and 3.7 GHz respectively with transmission zeroes at 1.53, 1.57 and 2.78GHz. The return loss of below 10 dB for lowpass and below 20dB for passband of the proposed filter has been achieved.

A comparison between the proposed filter and some of the reported filters is summarized in Table 2. The table reveals that the proposed filter has lower insertion loss and total circuit size of the proposed filter is 0.42 $\lambda g \times 0.19\ \lambda g$, which is compact.

Table 2 Comparison of the proposed filter with few other filters.

Reference No.	Lowpass 3-dB cutoff frequency in GHz	Bandpass cutoff frequency in GHz	Insertion loss in dB	Circuit Size in ($\lambda g \times \lambda g$)
11	1	2.4/ 5.8	0.8/ 2.1/ 2.5	0.31×0.18
13	1	5.2/-	0.8/0.5/-	0.175×0.15
16	4.5	9.1/-	0.3/0.4/-	-
19	1.05	1.9/ 3.0	0.3/0.9/0.8	0.13×0.06
This Work	1.22	2.44/ 3.7	0.15/ 0.5/ 0.45	0.42×0.19

5. Conclusion

A lowpass dual band-pass filter has been designed which is based on split ring resonators with inserted quarter-wavelength stubs. The filter provides great selectivity for the second passband as well as good lowpass frequency response. The lowpass 3-dB cutoff frequencies at 1.22 GHz, first and second resonant passband frequencies are 2.44 GHz and 3.7 GHz respectively with transmission zeroes at 1.53, 1.57 and 2.78GHz. The size of the filter is very compact and simple which is only 32.9 mm × 15 mm (0.42 $\lambda g \times 0.19\ \lambda g$).

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