On the Design of Compact Dual Band Rejection Filters using Circular Open Loop Resonators

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Abstract:
In this article, we describe the design of band pass and band rejection filter of a circular shape for UWB communication applications. The dual band rejection rejection and multiband have been achieved by using circular shape multi-armed open-loop resonators. Each resonator pair of arms creates a reject band in the transmission response. Broad band stop is obtained using one circular open-loop resonator By properly adjusting the multireject bands, appropriate multi-transmission bands are created. This filter is fabricated with optimized dimension and tested. The measurement results are compared with simulated results. Both are in closed agreement. The diameter of the circular open loop resonators, its width and spacing are the crucial parameters decide the bandwidth of the signal.

Keywords*:* open-loop-resonator, band pass filter, band rejection filter, multi band pass filter.

1. Introduction

The filters are the demanding components of wireless communication system. It is widely used in the front end of RF modules. In recent researches, the requirement of filter should be of compact size and effective spurious suppression. Microwave planar band stop filters play a key role in modern communication systems. Open-loop resonators have been implemented for band pass and band stop filters in planar configuration. This planar filter meets the requirement of satellites, mobile phones, and other wireless communication systems [1, 2]. Along with this, dual-band and multiband filters are in demand for multistandard wireless communication systems. Dual-band planar filters have been used in dual-band wireless communication systems.

Dual band first achieved by combining two filters of different frequencies. But, this increases the overall size [2–4] because were realized in cascade with wideband band pass and band stop filter [2]. In other method, two pass bands were achieved using open stubs which create a transmission zero in pass bands [3, 4]. Stepped impedance resonators (SIRs) were also utilized to achieve dual-band filters by properly adjusting the impedance ratio and electric length of SIRs [5]. On the other hand, few researchers have proposed the design of triple-band filters. Quendo et al. [6] proposed the dual behaviour resonators (DBRs) as good candidate for the design of tri-band filters. Mokhtari et al. [7, 8] proposed a design methodology to these kinds of filters using cross-coupled networks represented by coupling matrix. However, both designs lack compactness. In [6], the coupling of two tri-band DBRs was needed to achieve a second order triple-band filter response with six poles (two poles in each band) and five transmission zeros (single zero between each transmission band and two transmission zeros to the left and to the right of all pass bands). This cascade topology significantly increased the size of the filter. In [7] and [8], six hairpin resonators were used to achieve a triple-band filter response with six poles (two in each band) and four transmission zeros (two transmission zeros between each two bands). The usage of this number of resonators also increased the size of the overall structure [7, 8].

In this article, we present a new type of microstrip band stop filter using an triangular open-loop resonator. Based on triangular open-loop resonators, a compact multiband microstrip band pass filter is proposed using a multireject band resonator.

2. Geometry of Filter Circuit

The proposed multiband filter using three microstrip circular pair of arms open-loop resonators is shown in Figure 1. The circular shape open resonators are directly connected with 50 Ω feed line. The circular open – loop resonator with the constant width has impedance of around 128.15 Ω. The filter has been designed on a substrate with a relative dielectric constant $_r$ = 4.3 and a thickness of 1.53 mm. The filter is simulated using software HFSS. The dimensions of the proposed filter achieved during optimization as follows: R_1 = 3.8 mm, R_2 = 4.5 mm, R_3 = 5.4 mm, S_1 = 0.4 mm, S_2 = 0.6 mm, $W_{s1} = W_{s2} = W_{s3}$ = 0.3 mm, C_1 = 0.9 mm and C_2 = 1.0 mm. These all dimensions are tabulated in Table 1. The other dimensions of filter are like W (50 Ω) = 3 mm, Li = 0.25 mm and Lx = 8.6 mm as shown in Figure 1. The microstrip feed line has a characteristic impedance of 50 Ω. The overall size of the proposed band stop filter is 17 mm x 17 mm as shown in Figure 1. This multi band rejection filter was designed using 3D-electromagnetic software HFSS. The optimized dimensions of filter are tabulated in Table 1.

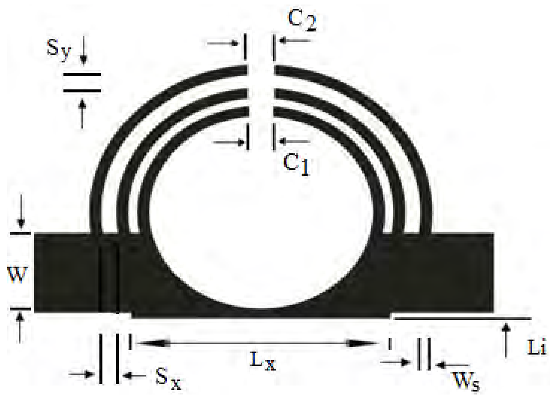

Fig. 1. Proposed geometry of dual band stop filter

Table 1 Dimensions of Proposed Filters

Design Parameter	I (mm)	II mm)	III (mm)	mm
W_{s1} , W_{s2} W_{s3}	0.3	0.3	0.3	
R_1,R_2,R_3	3.8	4.5	5.4	
S_1, S_2		0.4	0.6	
C_1	0.9			
C_2		1.0	1.0	
Lx				8.6
Li				0.25
W (50Ω)				3.0

3. The Proposed Compact Band Pass Filter (BPF)

The multiband filter is designed using circular shape multi pair arms open-loop resonators with the input/output ports directly coupled to the resonators as shown in Figure 1. The dual band rejection band is achieved using the open loop resonators. The number of these transmission bands depends on the used number of resonator pair arms. The three open loop resonators pair arms exhibit the three pass band two band rejection including low pass transmission bands which facilitates the design of combined low pass band pass filters. The bandwidth of the filters and their center frequency can be adjusted with various design parameters like gap width of open loop resonators, width of the strip loop and their interspacing and radius of each loop.

4. Parametric Analysis

The proposed filter with triple pair arms open loop resonators is analyzed with respect to design parameters. A parametric study has been carried out for triple-armed open loop resonators using commercial software HFSS, which is based on finite element method. The structure was designed on FR4 substrate of a thickness of 1.53

mm and a relative dielectric constant of 4.3. All pair of arms width is kept constant and equal to 0.3 mm which corresponds to 128.15mm. This filter structure is expected to have a three band pass transmission band and dual reject bands.

4.1 Effect of Open Loop Resonators Length and their Spacing

First, the lengths of arms (L) from the feed line as shown in Figure 1 were varied keeping all other dimensions constant. The simulated results of triple open loop resonators with respect to the length variation of inner arm from 8.2 mm to 8.6 mm are shown in Figure 2. It is observed that the center frequency of the band pass response is critically dependent on this dimension. As the length of open loop resonator arm varies, center frequency of the bandpass also changes as shown Figure 2. As the vertical length of loop resonator changes the spacing S_1 is also change. So, it can be said that the bandwidth of the band pass transmission band can also be controlled be changing L and S simultaneously in opposite trends as shown in Figure 3.

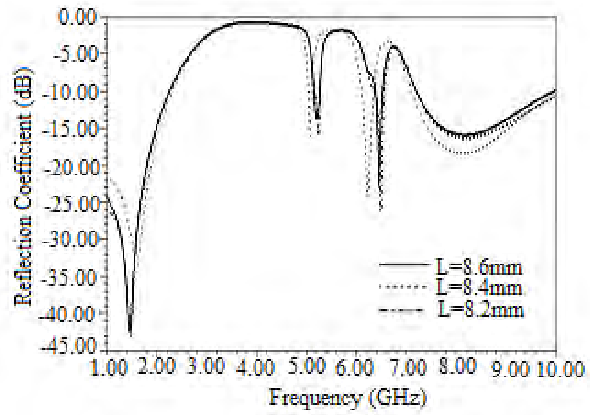

Fig. 2. Effect of circular open loop length

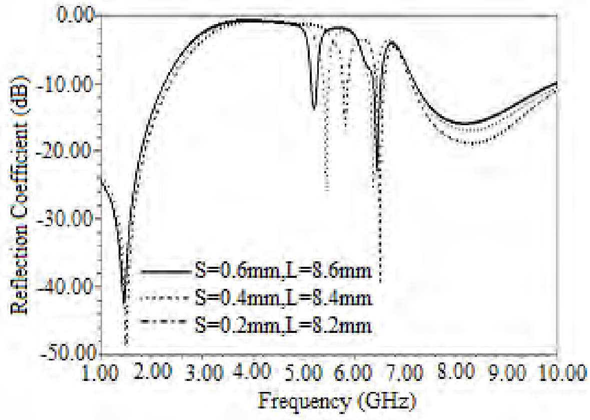

Fig. 3. Effect on the bandwidth by changing arm length L and spacing between open loop arms

4.2 Effect of Open Loop Resonators

The effect of number of circular shape open – loop resonators are shown in Figure 4. First, single open – loop resonator is simulated. It is observed that pass band is obtained from DC to 2.28 GHz with broader stop band from 2.28 GHz to 7.5 GHz. In the next step, two circular open loop resonators are simulated. From the simulated results, it is observed pass bands are from DC to 2.22 GHz, 6.23 GHz to 6.41 GHz and stop band exists from 2.22 GHz to 6.23 GHz. In third step, the circuit is simulated for three circular open loop resonators. Simulated results with three open loop pair arms offer pass band from DC to 2.01 GHz, 5.12 GHz to 5.2 GHz and 6.12 GHz to 6.24 GHz. The stop bands are observed at 2.01 GHz to 5.12 GHz, and 5.2 GHz to 6.12 GHz. It is clear as the number of open loop resonator increases the number of pass band increase with stop bands of smaller bandwidth. The all simulated results with first, second and third arms are combined as shown in Figure 4.

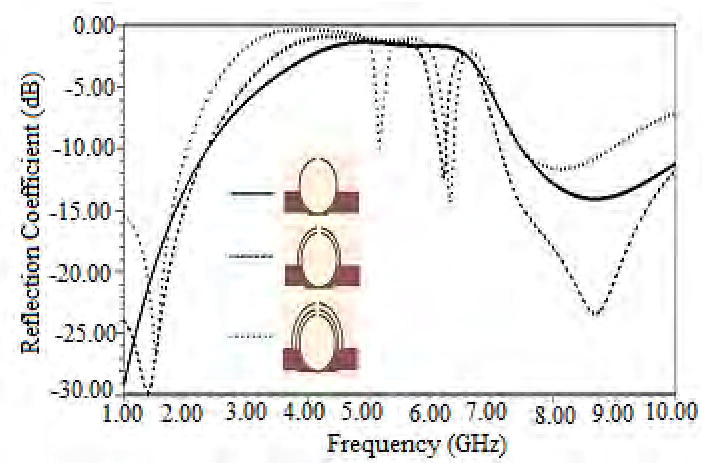

Fig. 4. Effect of number of circular open – loop resonators

4.3 Effect of Slit Gap of Open Loop Resonators

The gap widths (C_1, C_2) of each open loop resonator pair arm was separately simulated to know the effect of gap width on each reject band almost separately. The gap width between the small open loop resonator arms C_1 was varied by 0.8 mm, 0.9 mm, 1.0 mm showing that it basically affects the higher frequency reject band as shown in Figure 5. Finally, the gap width between the large open loop resonator arms C_2 was varied. This gap width basically affects the lower frequency reject band as shown in Figure 6. That means that effect on the rejection band can be obtained by varying the two gaps C_1 and C_2. It can be said effect of changing the open loop gap widths (C_1, C_2) between each arm shows the capability of controlling each reject band.

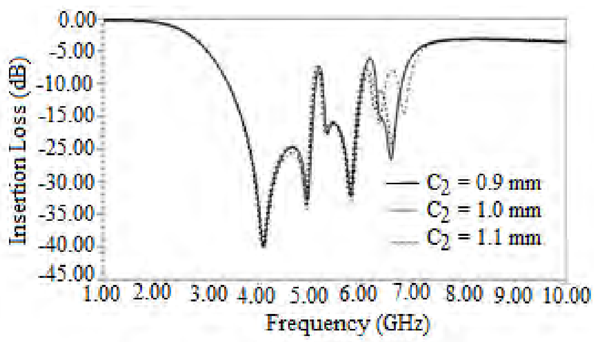

Fig. 5. Simulated results by varying the slit gap (C_1) of circular shape open loop resonator

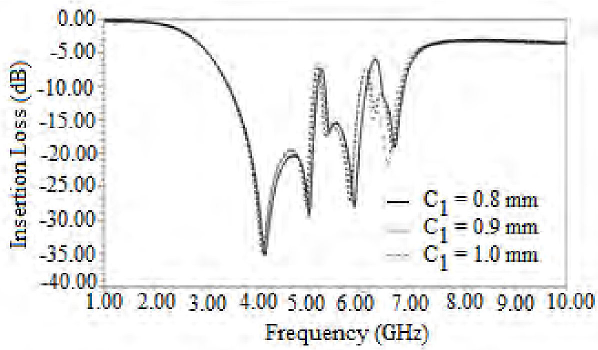

Fig. 6. Simulated results by varying the slit gap (C_2) of circular shape open loop resonator

5. Effect of Circular Cut

The proposed multi pair arms open loop resonators directly coupled with input and output feed line as Figure 1. First, the proposed filter has been analysed and optimized with triple circular open loop resonators arms directly connected with 50 Ω input and output line. It is observed that return loss is hardly 10 dB in all the three pass bands without circular cut. There is a need to improve the return loss. To improve the return loss, a inner circle is made cut in feed line and optimized. The simulated result with and without circular cut is shown in Figure 7. The simulated result of final proposed filter in shown in Figure 7 with dotted line. It is observed with this the bandwidth of all the three bands reduces but return loss is improved in all the three pass bands.

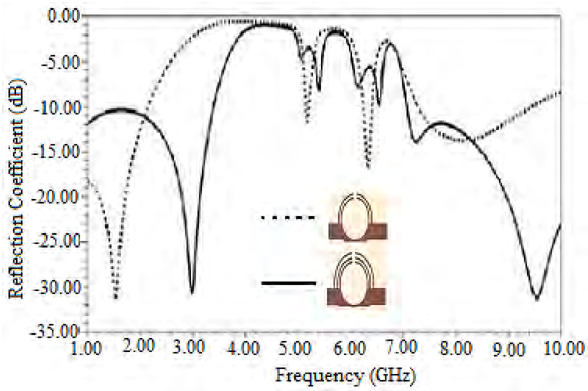

Fig. 7. Reflection Coefficient (dB) with and without circular cut in feed

6. Experimental and Simulated Results and Discussion

The multi pair arms open loop resonators filter circuit is shown in Figure 1 with optimized dimensions. The multi-rejection filter is fabricated with optimized dimensions. The filter is tested using vector network analyzer. The acquired measured return and insertion loss is shown in Figure 8. The measured results with three open loop resonators exhibits pass band from DC to 2.01 GHz, 5.12 GHz to 5.2 GHz and 6.12 GHz to 6.24 GHz. The stop bands are observed from frequency 2.01 GHz to 5.12 GHz and 5.2 GHz to 6.12 GHz as shown in Figure 8. This filter is simulated using 3D-Electromagnetic software HFSS. The measured and simulated results are in close agreement as shown in Figure 8. As seen from the measured and simulated result, the return loss is better than 15dB in the passband. The stop band rejection levels are better than 22 dB with sharp fall means high selectivity. It is also clear as the open loop resonators pair arms increases the number of pass band also increase. Same time the insertion loss in each band is expected to increase except first.

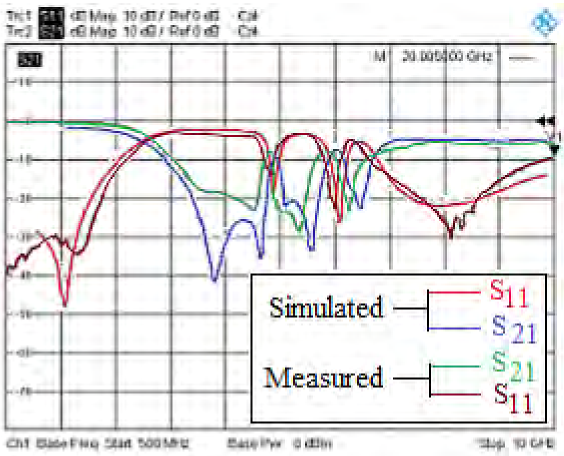

Fig. 8. Measured and Simulated Results (S_{11} and S_{21}) of proposed multi circular shape open-loop resonators filter

7. Group Delay and Phase Variation

Group delay and phase linearity are the two parameters used to ascertain the quality of the pulse to be pass through the filters. The proposed filter circuit is simulated for group delay and phase variation versus frequency. The simulated results are shown in Figure 9 and Figure 10 respectively. It is observed from simulated results that group delay is less and almost constant in the pass bands. It indicates the phase linearity in the pass band. It also indicates pulse will pass through the filter in pass band without distortion. It is also observed that group delay is very high in the stop bands. That is why phase variation is large in the stop bands.

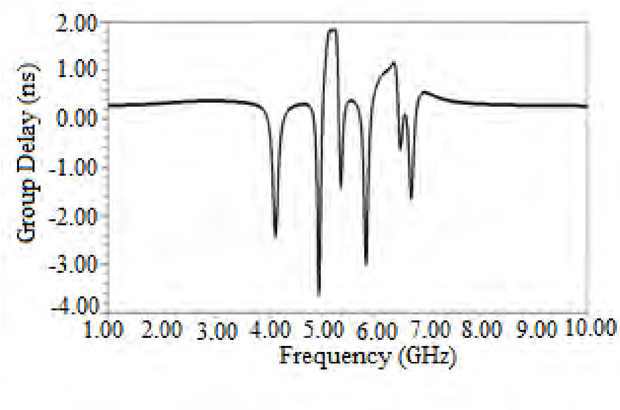

Fig. 9. Group Delay versus frequency for circular shape multi arms open loop resonator shape filter

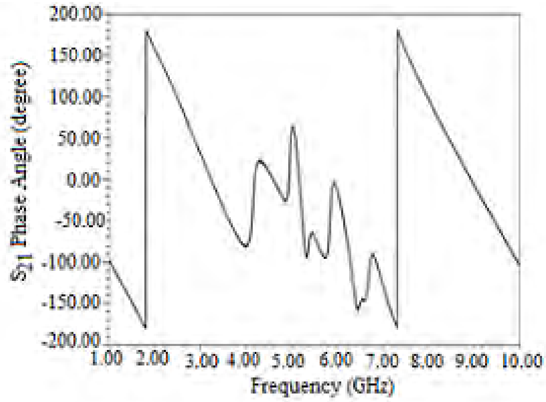

Fig. 10. Phase versus frequency of multi-arms open loop resonators

8. Conclusions

In this article, the design of a small-size dual-mode band stop filter has been presented and experimentally demonstrated. A unique type of multiband pass microstrip filters has been proposed using open loop resonator. Triple arms open loop resonators have been investigated for the possibility of increasing the number of transmission bands by increasing the number of resonator arm pairs. The number of multiband pass and stop bands depends upon the number of open loop resonators pair of arms. The proposed filter is simple to design, easy to fabricate and compact in size and easy to integrate with devices. Such type of filter is useful for communication system.

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