Design of an Ultra-Wideband Bandpass Filter for Millimeter Wave Applications

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***Abstract*—The advancement in filter designs for ultra-wide frequency spectrum are accelerated highly in this technological era. The main goal is to avoid interference of spurious signals with the authenticated signals resulting into counterfeiting of outcomes. This paper depicts the designs of Ultra-Wideband Bandpass filter (UWB BPF) with three different structures; using dual shunt ring resonator, split ring resonator and square patch resonator embedded at the centre of two parallel coupled microstrip lines. These designs are proposed with enhanced filter characteristics than conventional designs for millimeter wave range in automotive applications with improvement factors like traffic alerts and lane change assist. The frequency spectrum of 22-29GHz is used to meet FCC specifications along with 25.5GHz as the centre frequency. The complete simulations of the proposed designs are carried out using HFSS V13 software utilising RT/Duroid 6002 as a substrate with dielectric constant of 2.94. All designs are fabricated on the same substrate with equal substrate area of 5.8mm*2.8mm and thickness of 0.127mm. The return losses are 14dB, 16dB and 36dB and insertion losses are 0.4dB, 0.39dB and 0.30dB respectively of the proposed designs. The large fractional bandwidth of nearly 40%, high selectivity up to 82dB, especially in case of dual square patch resonator design, are extracted.**

***Index Terms*—Automotive Radar Application; Bandpass Filter (BPF); Coupled Microstrip Lines; Millimeter Wave; Ultra-Wideband Bandpass (UWB).**

I. INTRODUCTION

The modern millimeter wave (MMW) ranges are applied in automotive applications, such as HD video, Wireless Gigabit (WiGig) applications and sensors, demanding for compact designs with high reliability, lifetime and low cost of UWB BPF's. Due to enhanced requirements in automotive, satellites and sensors fields, a large demand for simple and efficient devices fabricated using well-tested techniques came into existence. Several techniques are utilised in the design of bandpass filter. Those techniques include small size, low cost and high reliability. Enhanced filter features such as high selectivity, return losses, reflection coefficients, a large number of transmission zeroes, idle gain characteristics and low insertion losses are also introduced [1]. Since 2002, after the FCC regulations [2] for ultra-wide frequency spectrums, the 22GHz to 29GHz frequency ranges are reserved for automotive radar and sensor applications [3]. Initially, the automotive sensor designs are carried out at 60-77GHz frequency ranges [4-7] and it generally designed in 0.18µm CMOS technology [5-9]. It produces acceptable filter parameters but lacking additional features of automotive like blind spot detection, parking aid and lane change assist sensing [10]. To overcome these problems and to extend the filter features, the designs of filters are carried out at a much lower frequency of 24GHz (initiated by China in November 2012 [11]) which is then followed by the entire world. The designs focusing on the long-range radar (LRR) are designed at 77GHz while for short-range radar (SRR) applications 24GHz frequency is used [12]. The frequency range of 22-29GHz is extensively used in the direction of new designs with efficient key features to fulfil consumer requirements and avoid interference of signals with high-performance LAN and other frequency bands. Several conventional designs at this range are proposed with different techniques and components.

A design with dual-mode ring resonator and multiple modes coupled parallel lines is proposed [13] with a return loss of 15dB and return loss of nearly 2dB. Another design utilising a Shunt step resonator and open circuit stub embedded between two parallel coupled lines [14] provides return loss of 12dB with insertion loss nearly 3.7dB. A design with dual split ring resonator along with shunt step impedance open circuit stubs embedded at the middle of two coupled microstrip lines also provides an insertion loss of 0.6dB with return loss nearly 13dB [15]. Similarly, the bulk of fabrications are carried out to enhance the filter parameters since it is the most developing sector with advancement in applications of trending technologies in the wireless communication system. Any proposed design can be effective if it has low insertion losses, higher return losses with enhanced stability, fractional bandwidth and reduction in size and complexity.

In this paper, three filter design models are proposed using different identical components like split ring resonator (SRR), shunt ring resonator and square patch resonator. These components reduce design complexity due to compact size with enhanced filter characteristics. These designs provides lower insertion losses of 0.4dB, 0.39dB and 0.3dB with higher return losses of about 14dB, 16dB and 35dB respectively. These results are far superior to conventional designs and featured with improved filter characteristics.

II. DESIGN AND ANALYSIS OF THE UWB BPF FOR MILLIMETER RANGE

In this section, proposed designs with different techniques and specifications are depicted. The proposed designs comprise of three different filter components like split ring resonator, shunt ring resonator and square patch resonator. These are dual in number with identical parameters and embedded at the centre of two coupled microstrip lines. All three designs provide different results. A study of all filter parameters is carried out, and comparative analysis is done. These designs provide better results than conventional designs [13-15]. All the designs are carried out on RT/ Duroid

6002 substrate with dielectric constant of 2.94 and loss tangent (tanδ) of 0.0012. The simulations are carried out with HFSS V13 software with a centre frequency of 25.5GHz. The filter design is compact with a small size of 5.8mm*2.8mm due to small and simple filter components. The SRR provides small occupancy area due to a compact size and increases the coupling effect of microstrip lines due to its property of high magnetic susceptibility in the presence of electric field [16]. Utilization of shunt ring resonator provides high selectivity at the centre frequency. Square patches are simple to design, and small in size provides high return loss and fractional bandwidth. The coupled microstrip lines used at both sides have length 2.1mm and width 0.06mm. The input and output patches are utilised as feedlines for the proposed design.

A. *Design with Dual Identical Shunt Ring Resonator*

The design comprises of dual identical shunt ring resonator and two coupled microstrip lines affixed with input-output feedlines at both ends as inscribed in Figure 1.

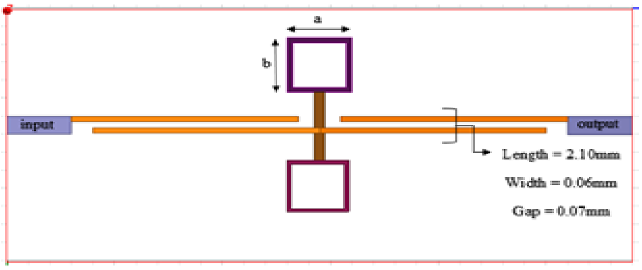

Figure 1: Circuit model of the proposed design with dual identical shunt ring resonator

The dimensions of microstrip lines are demonstrated in the Figure itself. The dual shunt ring resonators are compact provides better selectivity with low losses and appropriate fractional bandwidth. The dual identical shunt ring resonator design is easy to fabricate with lower occupancy area on the substrate resulting enhancements in the outcomes of filter parameters. The specifications and dimensions of the proposed model utilising dual identical split ring resonator are depicted in Table 1.

Table 1.
Description of Parameters and Specifications of the Proposed Design with Dual Identical Shunt Ring Resonator

Parameters	Specifications
Width of shunt ring resonator (a)	0.60mm
Length of shunt ring resonator (b)	0.60mm

The dual identical shunt ring resonator is designed with square patches having equal length and width dimensions. This proposed model is comparatively easier as compared to conventional fabricated filters.

B. *Design with Dual Identical Split Ring Resonator (SRR)*

The design proposed with dual split ring resonator and the dimensions of two coupled microstrip lines are depicted in Figure 2. Introduction of SRR in filter design at the centre of microstrip lines increases the selectivity of the filter at the centre frequency of 25.5GHz.

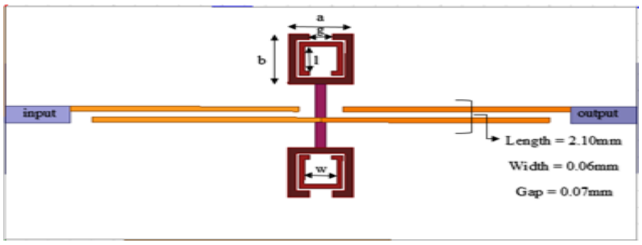

Figure 2: Circuit model of the proposed design with a dual identical split ring resonator

Addition of SRR increases the coupling effect of the filter due to its property of high magnetic susceptibility in the presence of an electromagnetic field. Other benefits of SRR are low radiation loss, high Q factor and small size due to sub-wavelength measurement at quasi-static resonance. Dual SRR reduces the substrate occupancy area due to small size with increased filter parameters.

The specifications of the proposed model with identical dual SRR are depicted in Table 2.

Table 2
Description of Parameters and Specifications of the Proposed Design with a Dual Identical Split Ring Resonator

Parameters	Specifications
Width of outer core of SRR (a)	0.60mm
Length of outer core of SRR (b)	0.60mm
Width of inner core of SRR (w)	0.40mm
Length of inner core of SRR (l)	0.40mm
Gap between cores of SRR (g)	0.20mm

The specifications of both the SRR's are solely identical and symmetrical with the width and length of outer cores of 0.6mm, and that of inner cores are 0.4mm. The size of SRR is very compact resulting into a smaller substrate occupied area with enhancement in coupling effect. The two identical coupled microstrip lines with the width of 0.06mm and length of 2.1mm are affixed at both ends with the feed lines at the gap of 0.07mm. These are aligned especially for the coupling phenomenon which is further accelerated by dual identical SRR configuration. The complexity of SRR based design is quite enriched as compared with dual shunt ring resonator design but the coupling effect of SRR based design is comparatively higher due to its inherent properties.

C. *Design with Dual Square Patch Resonator*

The circuit model of proposed filter design using dual square patch resonators embedded at the centre of two coupled microstrip lines are depicted in Figure 3. The designing and fabrication of square patch resonators are extremely simpler as compared with the formerly proposed filter designs.

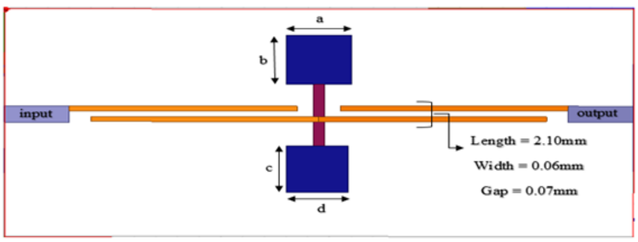

Figure 3: Circuit model of the proposed design with a dual square ring resonator

The size of square patch resonators is extremely compact thereof reducing the substrate occupancy region to a greater extent. The introduction of dual square patch resonators reduces the design and operation complexities with an enhancement of the filter parameters to an appreciative range. The outcomes of this proposed designs are comparatively far superior to classical designs as well as formerly proposed designs. The dimensions of coupled microstrip lines are already inscribed in Figure 3 while the dimensions of square patch resonators are depicted in Table 3.

Table 3
Description of Parameters and Specifications of the Proposed Design with Dual Square Patches

Parameters	Specifications
Width of the upper square patch(a)	0.60mm
length of the upper square patch(b)	0.60mm
Width of the lower square patch (c)	0.57mm
Length of the lower square patch(d)	0.57mm

The dual square patches with Upper Square patch dimensions of 0.60mm and that of the lower square patch is 0.57mm. The acute reduction of 0.03mm in dimensions of lower square patch results into zenith level of increment in filter parameters. The proposed design embedded with dual square patches are comparatively easier with better outcomes of filter parameters.

III. Characterization Results and Discussion

The results of the proposed models of filter designs utilising identical dual resonators like shunt ring resonator, split ring resonator and square patch resonator are depicted and discussed in this section. The performance, efficiency and lifetime of any filter design can be easily outlined by the study of its outcomes. The filter parameters affecting its performance are return losses, insertion losses, fractional bandwidth and selectivity. In this result section, S-parameters of filters is depicted with the discussions of other parameters. The S-parameters includes S (1, 1), S (1, 2), S (2, 1) and S (2, 2) depicting return loss, isolation coefficient, insertion loss and reflection coefficient respectively. These parameters describe the characteristics and behaviour of the filter design.

A. Results of Proposed Design with Dual Shunt Ring Resonators

The results of the proposed model using dual identical shunt ring resonators are demonstrated through the graph in Figure 4.

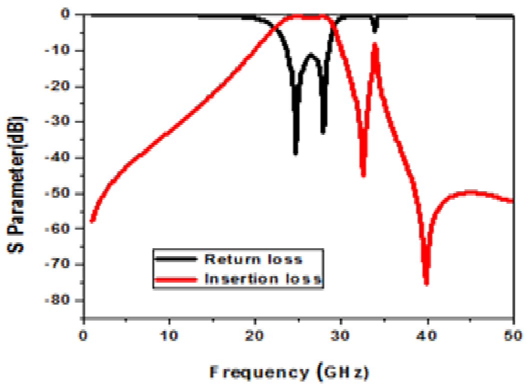

Figure 4: Graph depicting the S-parameters of the proposed filter with dual shunt ring resonator

The design with dual identical shunt ring resonator provides return loss of about 14dB at a middle frequency of 25.5GHz which extends to 37dB at 24.7GHz. The insertion losses so obtained are nearer to 0.4dB which is almost in equal order to that of isolation coefficient while the reflection coefficient relates directly with return loss. The fractional bandwidth is about 28% with peak selectivity of 45dB at centre frequency 25.5GHz.

B. Results of Proposed Design with Dual Split Ring Resonators (SRR)

The results of the proposed model using dual identical split ring resonators (SRR) are demonstrated through the graph in Figure 5.

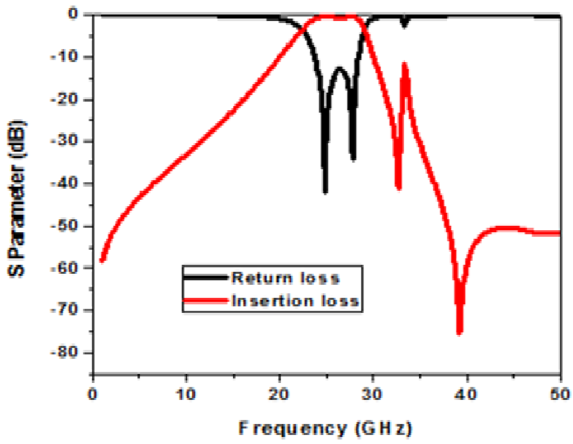

Figure 5: Graph depicting the S-parameters of the proposed filter with a dual split ring resonator

The design incorporates dual SRR patches provides the result outcomes as depicted in the graph of Figure 5. The S-parameters of the proposed filter are extracted in order to study several filter parameters. The return loss of this proposed design is approximately 16dB at the centre frequency, i.e. 25.5GHz extending to 46dB at 24.8GHz and insertion loss at the centre frequency is 0.39dB. The values return loss and reflection coefficient, as well as values of insertion loss and isolation, are identical for filter designs at the centre frequency. The fractional bandwidth of this design is approximately 28% with a high selectivity of 41dB near 32GHz. Selectivity defines the ability to avoid spurious signals. The several S-parameters defining the characteristics of the proposed filter shows better results for split ring resonator design as compared to the initially proposed design with dual identical shunt ring resonators.

C. Results of Proposed Design with Dual Square Patch Resonators

The results of the proposed model using dual square patch resonators are demonstrated through the graph in Figure 6.

The design with dual square patch resonators is very simple with apex increment in all the filter parameters. The return loss of dual square resonator filter design approaches to nearly 36dB which is extremely better than all the conventional designs of millimeter range to date as well as from both formerly proposed designs. The return loss and reflection coefficient are almost the same and extends to nearly 45dB at 25.9GHz. The insertion loss is also not compromised since S (2, 1) shows a low value of nearly 0.3dB. The designs with higher return loss result with

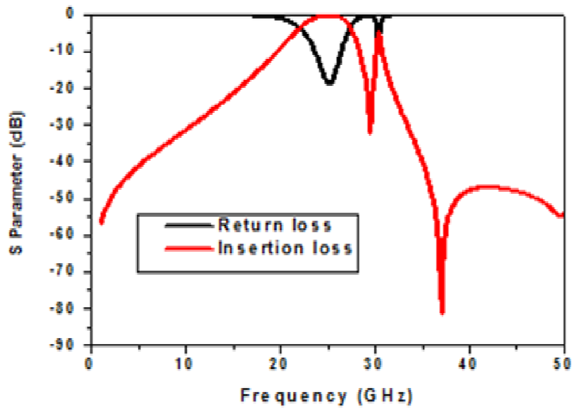

Figure 6: Graph depicting the S-parameters of the proposed filter with dual square patch resonator

increment in insertion loss, but this design provides desired results with small size and easy fabrication. The fractional bandwidth is about 28% with transmission zero of magnitude approximately approaching to 80dB at nearly 38GHz resulting into high selectivity.

Table 4
Comparison of Insertion Loss and Return Loss for all the Proposed Designs

Parameters	Insertion loss [S_{11}]	Return loss [S_{21}]
Design with dual shunt ring resonator	0.40dB	14dB
Design with dual split ring resonator	0.39dB	16dB
Design with dual square ring resonator	0.30dB	36dB

The comparison of insertion loss and return loss of all three proposed models with shunt ring resonator, split ring resonator and square patch resonator are described in Table 4.

It also reflects the hierarchical increment in return loss with a decrement in insertion loss in the proposed designs with shunt ring resonator, split ring resonator and square patch resonator respectively. The proposed work is further compared with conventional designs of this range in Table 5.

Table 5
Comparison of Parameters of the Proposed Design with Conventional Designs

Reference	Insertion loss	Return loss	Fractional BW	Size
[13]	2dB	15dB	20%	0.25×0.25mm^2
[14]	3.7dB	12dB	22%	5.80×2.80mm^2
[15]	0.6dB	12dB	28.7%	5.80×2.80mm^2
Proposed work with dual square patch resonator	0.3dB	36dB	28%	5.80×2.80mm^2

IV. CONCLUSION

In this paper, three UWB BPF designs for millimeter range of 22-29GHz are presented. The proposed models are equipped with shunt ring resonators, split ring resonators and square patch resonators providing enhancement in filter parameters like return loss exceed to 36dB and insertion loss to 0.3dB at the centre frequency of 25.5GHz. Higher fractional bandwidth provides a wide frequency spectrum with sharp selectivity to 80dB to avoid spurious signals. The low thickness of 0.127mm with the compact size of resonators provides small filter designs, the planar and simple design of resonators facilitates easy fabrication with higher efficiency of the filter. This paper provides better results than conventional designs and inherits the scope for future works.

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