A Reconfigurable Bandpass to Bandstop Filter Using PIN Diodes Based on the Square Ring Resonator

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Abstract— This paper presents a reconfigurable, bandpass to bandstop switchable filter, based on the square ring resonator topology with two tuning stubs, which control the filter's response. In the proposed design, switching between the bandpass and bandstop response is achieved by strategically placing two PIN diodes, at locations where the diodes do not affect the resonating response of the overall design. Skyworks SMP1345-079LF RF PIN diodes are used in order to allow switching between bandpass to bandstop responses. The operating frequency of the filter is at 2.4 GHz. The -3 dB bandwidth for the bandpass filter ranges from 1.9 GHz to 3.2 GHz, with an average insertion loss of 0.8 dB. For the bandstop filter the loss is 0.3 dB and the -10 dB rejection bandwidth is from 2.2 GHz to 2.7 GHz. DC bias lines of $\lambda/4$ overall length are integrated with radial matching stubs, to ensure compact overall size of the circuit. The key advantage of this type of filter is the efficient switching ability between the two different operational states, the bandpass and bandstop. The proposed filter is simulated on a commercially available, low cost Roger 4003C substrate having $\epsilon_r = 3.55$ and $\tan\delta = 0.0027$ and substrate thickness 0.813 mm. The proposed filter can be a good candidate for transceivers operating in strong interference environments, for reconfigurable radios, or for alternating transmission and reception schemes, in the highly congested, 2.4 GHz frequency band.

1. INTRODUCTION

Microwave filters are of paramount importance when dealing with RF communication systems. Modern day developments in this area have led to the necessity for compact, multipurpose and efficient designs. Under this prism, electronically switchable filters are gaining wide interest from both researchers and developers. Microwave filters are designed keeping in mind both structure compactness and easiness in their switching ability among alternative operational modes. Using commercially available PIN diodes, filters can be designed to switch between different geometric shapes with different resonating frequencies which result in eventually reconfigurable structures.

The microstrip square ring resonator, has been widely used for the development of microwave filters due to its compact size, low radiation loss and high Q factor [1]. Nowadays, emerging wireless communication systems require multiband, multifunctional and switchable capabilities. Under these circumstances a single filter cannot meet the requirements for all operating bands while the use of multiple filters occupies larger surface area with higher design cost [2]. To solve this problem, reconfigurable filters [3] are required. Bandpass and bandstop filters are two of the most commonly encountered components for any communication system. Bandpass filters are used to pass a specific band of frequencies while bandstop filters are required to suppress specific band of frequencies [4]. A compact and low insertion loss, square ring resonator, bandpass filter, has been presented in [5]. Several bandpass filters with switchable bandwidth based on the square ring resonator using PIN diodes have been presented in the past [6–8]. Recently reconfigurable filters from bandpass to bandstop filters were reported [9] based on varactor diodes by using odd and even degenerate modes. In [10, 11] reconfigurable bandpass to bandstop filters with controllable poles were presented. Although these reported reconfigurable bandpass to bandstop filters show additional features, they are more complex in terms of design and they have considerably larger size, when compared with the suggested filter topology.

In this paper, a simple, compact and low cost design is presented, based on a square ring resonator with two tuning open stubs capable of switching between bandpass and bandstop response around the center frequency of 2.4 GHz. The transition from bandpass to bandstop response is achieved using electronic switching, i.e., by using a DC voltage source to forward or reversely bias two PIN diodes.

2. PROPOSED RECONFIGURABLE BANDPASS-BANDSTOP FILTER DESIGN

It is well known that several modes can be supported by the ring resonator and can be excited if desired, depending on the perturbation and coupling methods. In addition resonance occurs when standing waves are set up along the ring something that happens when the circumference of the ring is an integer multiple of the guided wavelength. To understand the basic phenomena underlying the operation of the ring, it is useful to first understand its field configuration for the different modes which are described in detail in [1]. In the absence of any discontinuity a maximum field point occurs at the point where the feed line excites the resonator. It is also worth noting that this point is independent of the position of the feed line that extracts microwave power. This is very important from the standpoint of mode suppression. As it can be seen in Figure 1 the output feed line is placed to an angle of 270 degrees where there is a field minimum for first and third modes. As a result, since there is odd-mode excitation and the output feed line is coupled to a position where there is a minimum electric field the ring circuit provides a stopband and exhibits bandstop characteristic.

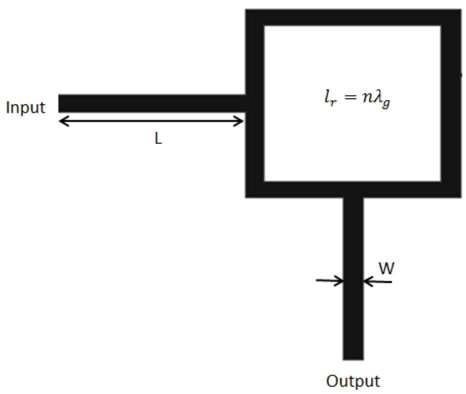

Figure 1: Bandstop filter based on ring resonator.

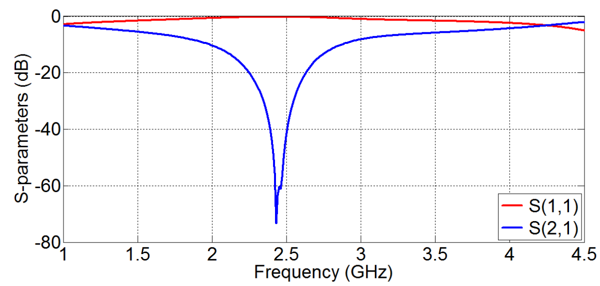

Figure 2: Simulated S-parameters for the bandstop filter (From Figure 1).

L is the common length of both feed lines and W is their width. The lengths and widths of the two feed lines are kept the same to avoid multiple mode generation. The circumference of the ring resonator is given by $l_r = n\lambda_g$, where n is the mode number and λ_g is the guided wavelength. The guided wave length is given in Equation (1).

$$\lambda_g = \frac{c}{f\sqrt{\epsilon_r}} \tag{1}$$

where c is the speed of light, f is the operating frequency and ϵ_r is the relative dielectric constant. With $L = 18$ mm and $W = 1.8$ mm, the full wave simulated S-parameters are displayed in Figure 2. As it can be seen the filter provides a -20 dB band rejection from 2.3 to 2.6 GHz, while the resonance frequency is set at 2.4 GHz.

A reconfigurable bandpass to bandstop filter using a microstrip square loop resonator is proposed in Figure 3, in which the square ring is used as the resonator and two microstrip tuning stubs are used as the perturbation elements. The bandpass filter is developed from the bandstop filter that was introduced earlier in Figure 1. The proposed reconfigurable bandpass-bandstop ring resonator filter, as shown in Figure 3, is very similar to the traditional dual-mode ring resonator filters with stub-loaded perturbation elements.

Two tuning open stubs having length $\lambda/4$ at 2.4 GHz, placed at the centre of either side of the ring resonator and in orthogonal to each other orientation are used to achieve a wide passband response with a steep roll-off frequency characteristic. By changing the lengths of these two tuning stubs, the frequency response of the ring circuit is varied. Two attenuation poles are thus created and form a wide passband filter response. This approach can be interpreted as using two stopbands induced by two tuning stubs in conjunction with the wide passband. The effect of the addition of the two tuning stubs is a steeper roll-off frequency response, and wider passband zone.

In this work the filter was simulated using cost effective Roger 4003C substrate having $\epsilon_r = 3.55$, $\tan\delta = 0.0027$ with a substrate thickness of 0.813 mm. The Skyworks SMP1345-079LF PIN diode switches are incorporated in order to realize the switchable design from bandpass to bandstop filter. As can be observed from the schematic in Figure 3, the PIN diodes are located directly on the square ring and they electrically connect and disconnect the open stubs with lengths S1 and S2 respectively. The overall inner ring size is 17.2 mm × 17.2 mm. For the circuit simulations the PIN

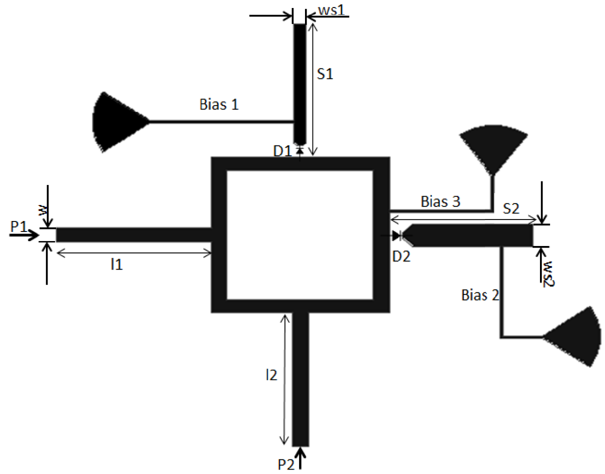

Figure 3: Proposed design for reconfigurable bandpass-bandstop filter.

diodes are replaced with either $3\,\Omega$ resistors, or 0.15 pF capacitors [12] for the ON and OFF state of the PIN diodes respectively. Once DC bias voltage is applied directly on the radial stubs of the bias lines named Bias1 and Bias3 with a forward current of 10 mA the two PIN diodes are turned ON. Hence, open stubs $S1$ and $S2$ become connected with the ring, resulting in the wideband passband filter response of Figure 4. When the PIN diodes are simultaneously reverse biased, the tuning stubs are disconnected which in return produces a bandstop response as shown in Figure 5.

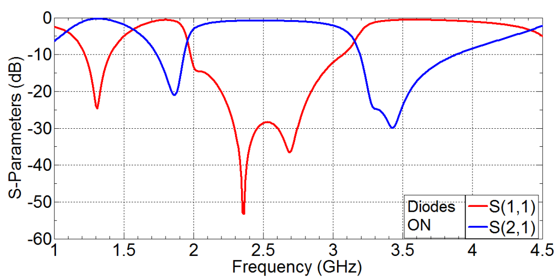

Figure 4: S-parameters of bandpass filter (ON State).

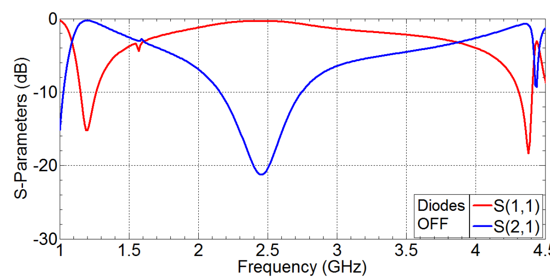

Figure 5: S-parameters of bandstop filter (OFF State)

High impedance DC bias lines of 110 Ohms characteristic impedance are integrated with radial stubs for biasing the diodes. The angle, positions and dimensions of the radial stubs directly affect the S parameter responses therefore they are optimized using parametric simulations. The angle of the radial stubs is chosen to be 70 degrees after optimization. The complete list of filter parameters is given in Table 1.

Table 1: Filter parameters

Symbol	Value (mm)
$l1$ (Input line)	18
$l2$ (Output line)	18
w (Width of input/output line)	1.8
$S1$ (Length of stub 1)	17.8
$S2$ (Length of stub 2)	16.8
$ws1$ (Length of stub 1)	1.4
$ws2$ (Length of stub 2)	3

3. SIMULATION RESULTS AND DISCUSSION

The reconfigurable filter simulations have been carried out using a full wave simulator. When both diodes are simultaneously forward biased, a bandpass filter response is achieved having -3 dB passband zone from 1.9 GHz to 3.2 GHz with an average insertion loss of around 0.8 dB in the pass band zone while having a return loss below −30 dB for the larger part of the passband zone. The presence of the two tuning stubs cause two attenuation poles at 1.85 GHz with −22 dB rejection, at 3.4 GHz with −30 dB rejection. The simulated S-parameters for bandpass response, are presented in Figure 4.

When the diodes are reversed biased, a bandstop filter response is achieved with a −10 dB bandwidth that ranges from 2.2 GHz to 2.7 GHz with a rejection level greater than 20 dB and with an average loss of 0.3 dB. The simulated S-parameters are shown in Figure 5.

4. CONCLUSION

A simple to fabricate, low cost, reconfigurable, bandpass to bandstop filter is proposed based on the square ring resonator. The design consists of two tuning stubs and two PIN diodes as switching elements. By switching the PIN diodes ON and OFF a reconfigurable bandpass-bandstop filter is achieved. The reconfigurable filter was designed with a center frequency at 2.4 GHz having a passband zone ranging from 1.9 GHz to 3.2 GHz and −10 dB rejection band ranging from 2.2 GHz to 2.7 GHz. In bandpass mode the filter had less than 1 dB of insertion loss with a fractional bandwidth of 54%. The overall filter design can be fabricated on a 57 mm × 57 mm size board. The proposed reconfigurable filter can be a good candidate for high interference systems and for alternating transmission and reception schemes, in the highly congested 2.4 GHz frequency band.

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