An Investigation of Switchable Matched Bandstop to Bandpass Filter Based on Lossy Resonator

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***Abstract*—Filters are the basic component of transceivers and receivers in the RF front-end communication system, either as band reject or band select units. This research is about an investigation of the new switchable filter which is can switch from matched bandstop to bandpass filter based on lossy resonator, where the lossy resonator topology can be used to partially compensate for the loss. The aim of this research work is to investigate the switchable matched bandstop to the bandpass filter response using lossy resonator based on EM modeling. This filter will be realized in parallel-coupled L-shape resonator. A PIN and varactor diodes will be used to make the filter switchable. This switchable filter provides two modes of operation; matched bandstop and bandpass response. The operating frequency is 2.4 GHz. The theoretical analysis together with EM modeling of the new switchable matched bandstop to bandpass response are presented in this paper.**

***Index Terms*—Switchable Filter; Lossy Resonator; Matched Bandstop; Bandpass.**

I. INTRODUCTION

Filters are the basic component of transceivers and receivers in the RF front-end communication system, either as band reject or band select units. A single device or filter could not do the needs of all groups operating in modern wireless communication systems. As modern microwave systems, advancing towards cognitive operations, more switchable filter will be needed to empower the maximum capacity of these system performances [1]. Thus, there have been broadly developed tunable and switchable filters for wireless communication and cognitive radio system.

For example, in a cognitive radio, this filter is used in the radio system to select signals of interest or attenuate interfering signals. It depends on the environment or mode of operation of the radio. In [2], switchable and cognitive radios require frequency agile radio front-end modules to cover an extensive variety of wireless communication spectrum. One of the most challenging aspects of agile system design is adjustable filtering, due to difficult specifications concerning physical size, tuning range, and insertion loss, among other performance parameters. Therefore, switchable filters are very important components and have been focusing on recent research and development [3-12].

A new switchable filter with the ability to switch between matched bandstop to bandpass filter is proposed. A new filter topology using lossy resonators has been reported [13], where the topology can be used to partially compensate for the loss. The aim of this research work is to investigate the matched bandstop switched to the bandpass filter response using lossy resonator based on parametric study and realize in momentum simulation. The switchable filter will be designed in parallel-coupled L-shape resonator matched bandstop filter (which is a lossy resonator) and PIN and varactor diodes will be used to achieve this.

II. METHODOLOGY

A. Matched Bandstop Filter Topology

In [13], the authors were successfully shown perfectly infinite stopband attenuation of the matched bandstop where high notch depth and selectivity can be produced by just using two lossy low-Q resonators in microstrip technology. This idea was from [14], that builds upon the perfectly-notch concept where it consisted of two identical lossy resonators connected to the 90° hybrid coupler or directional coupler as shown Figure 1. This technique enables the use of two low-Q lossy resonators for high attenuation of bandstop filter applications. Therefore, its advantages are not only to produce higher stopband attenuation as well as being perfectly matched in both the passband and stopband.

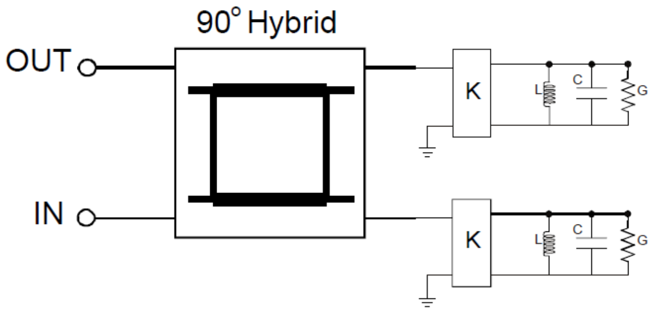


Figure 1: Conceptual diagram of an enhanced Q notch filter employing a 3-dB, 90° hybrid coupler [13]

As stated in [13], if $Y_o = 1/Y_e$ for all frequencies, then $|S_{11}| = 0$ for all frequencies, and the network possesses the allpass property. If $Y_o = Y_e$ at a certain frequency, then $|S_{12}| = 0$, and the network produces infinite attenuation at that frequency. Based on Figure 2, the network has a symmetrical of two-port network, which is consisted of two identical resonators with an unloaded Q of $\omega C/G$, and four admittance inverters.

$$S_{11} = S_{22} = \frac{1 - Y_e Y_o}{(Y_o + 1)(Y_e + 1)} \quad (1)$$

$$S_{12} = S_{21} = \frac{Y_o - Y_e}{(Y_o + 1)(Y_e + 1)} \quad (2)$$

The circuit shown that both allpass and the perfect notch property are met when $K_1 = \pm\sqrt{2G}$ and $K_2 = G$. The power at stopband frequencies is absorbed by the losses of the present resonators and is not reflected as in conventional filters [13].

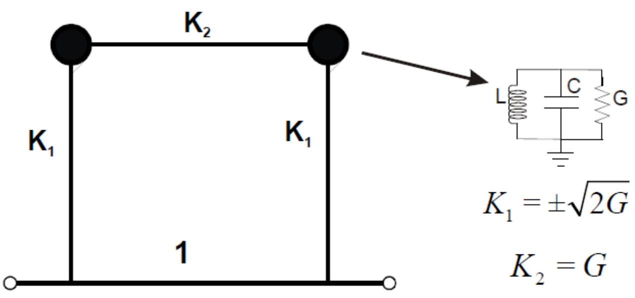


Figure 2: A coupled-resonator model of a matched bandstop filter [13]

B. *Realization of Parallel-couple L-Shape Matched Bandstop Filter*

The matched bandstop filter has a characteristic of allpass network where an ideal lossless allpass network has the property of passing all frequencies with zero attenuation, and thus must present a perfect match at all frequencies [13]. The perfectly notched concept [13] was applied to improve the Q factor of bandstop limiter in the filter design. Based on a reflection mode filter, this concept makes use of two identical lossy resonators coupled to a 3-dB 90° hybrid coupler with correct coupling factors. At the center frequencies, the incident signals are critically coupled to the resonators and absorbed in the resistive part of the resonator leaving no reflected signals at the output, thus achieving a theoretically infinite attenuation. Figure 3 shows the realization of L-shape matched bandstop filter and Figure 4 shows the matched bandstop response.

The overview of the matched bandstop filter using lossy resonators was reported in [15], where the two low-Q lossy resonator was applied in a perfectly-matched bandstop filter, tunable filter, switchable filter from matched bandstop to Allpass and RF switches such as SDPT.

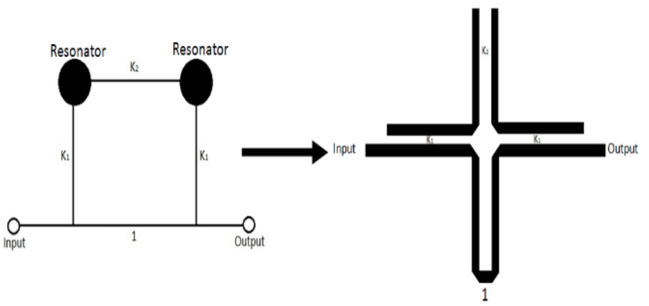


Figure 3: Realization of matched bandstop filter using two low-Q lossy resonators [13]

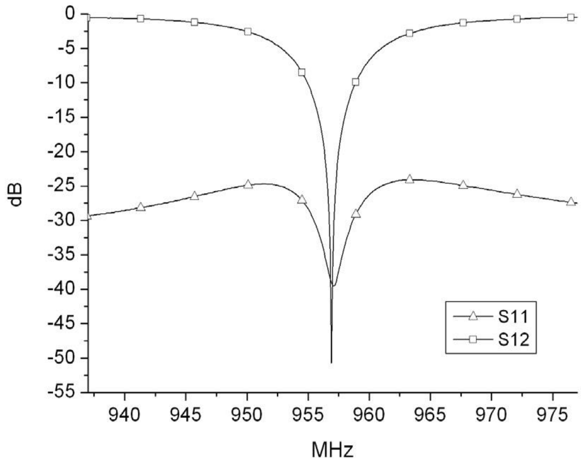


Figure 4: Perfectly-matched bandstop response [13]

III. Results And Discussion

A. *An Investigation of Switchable Matched Bandstop to Bandpass Filter*

From the literature review, there are many inventions [15] have been investigated and developed based on this topology. One of the new ideas is to propose a new design of switchable matched bandstop to bandpass filter, where matched bandstop to bandpass filter is still unexplored by other researcher. Figure 5 shows the circuit of parallel-coupled L-shape resonator where it consists of two identical lossy resonators connected to the 90° length with correct coupling factor, which is simulated using simulation tools. The theoretical of the band-reject mode of operation for transmission and reflection responses is performed using ADS simulation.

The filter was designed center frequency 2.4 GHz. From the result as depicted in Fig. 6, the return loss S_{11}, is below than -25 dB in the frequency band of interest. It is also shown that the filter is having very low insertion in the pass band and present an infinite insertion loss S21, about -75 dB at the resonance.

Based on the lossy resonator topology in Figure 2, the parameters that need to be considered to investigate, such as the resonators, K-inverter (K1 and K2) and also the 90° length that coupled to the resonators.

From the schematic design, the parameter of the design can determine which of the parameter can be switched to bandpass response. This can be done by disable the parameter. After several analyses of the parameter, the location of the parameter that able to switch to bandpass response is illustrated in Figure 7.

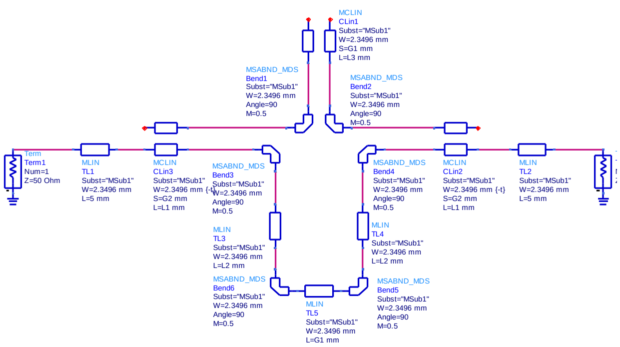


Figure 5: Schematic design of parallel-coupled L-shape resonator

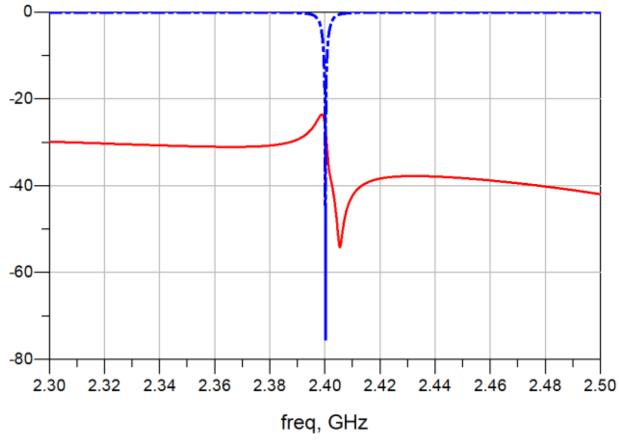


Figure 6: Perfectly matched bandstop response from schematic simulation

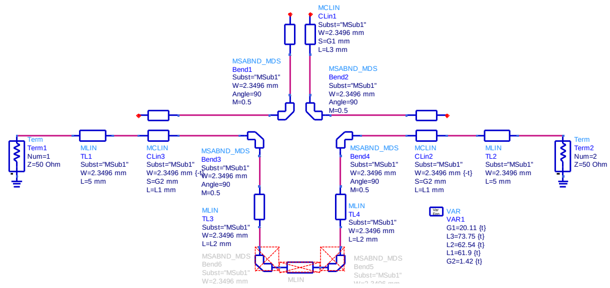


Figure 7: The location of parameter that can switch the matched bandstop to bandpass response

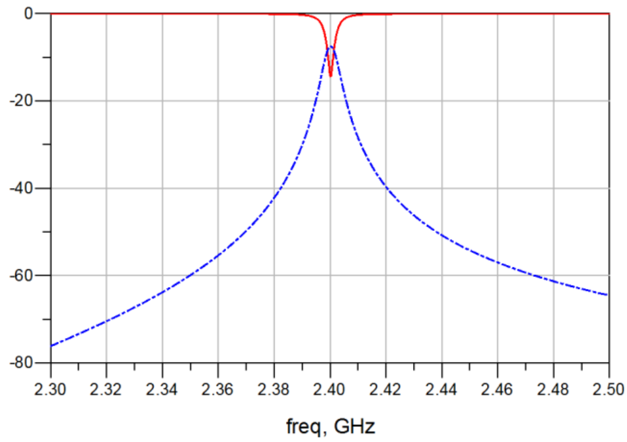


Figure 8: Lossy bandpass response

When the 90° length is disable, the filter produced bandpass response as depicted in Fig. 8. The circuit having a very low insertion loss in the pass band and present an infinite insertion loss at the resonance. The return loss is around -18 dB and insertion loss is -7.5 dB, which is a lossy bandpass response.

B. *Realization of Switchable Matched Bandstop to Bandpass Filter*

Parametric analysis has been done to investigate which of the parameter can be switched to the bandpass response. The location of PIN diodes to operate as a switch as shown in Figure 9. Two PIN diodes were used because respective to the symmetrical structure.

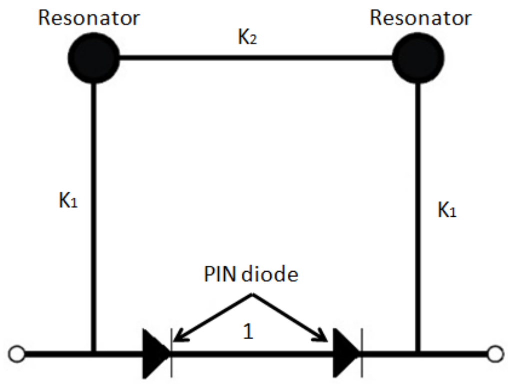


Figure 9: Generalized coupled resonator model of operation and the location of the PIN diodes

Based on the parametric analysis, EM modeling was designed and has been simulated to prove the theory. The filter was designed using simulation tools such as ADS software, where Rogers RT Duroid 5880 is chosen as the substrate with dielectric constant εr = 2.2, thickness of the substrate is 787 µm and the metal thickness is 24 µm. Figure 10(a) is the realization of the parallel-coupled L-shape resonator. The 90° length of the filter circuit was integrated with PIN diodes. The PIN diodes operate 'ON' and 'OFF' to produce matched bandstop or bandpass filter response.

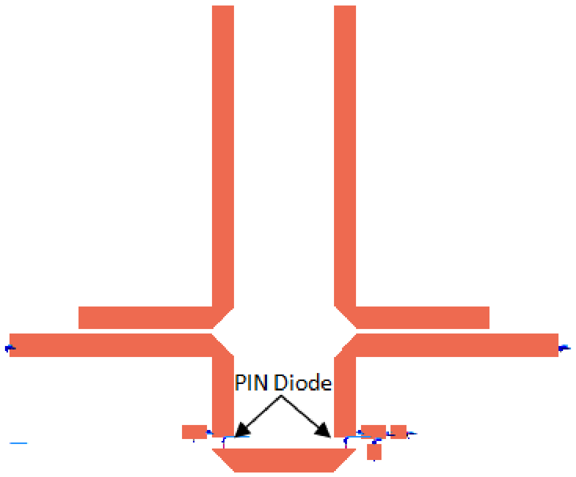
When the PIN diodes were supplied with +5V, then the PIN diodes were turned 'ON' and matched bandstop response was produced. When the PIN diodes were supplied with 0V, then the PIN diodes were turned 'OFF' and the bandpass response was produced. The biasing for PIN diodes consisted of DC power supply, RF chokes, DC block, and 100 Ω resistor. The resulting EM simulation of the parallel-coupled L-shape filter is centered at 2.4 GHz. Figure 10(b) shows the bandpass response, where the return loss is -18 dB and an insertion loss is - 6.7 dB with the transmission zero was exist at 2.36 GHz and 2.43 GHz.

As described above, the coupling structure of the filter for K-inverter can be tuned to enhance the bandpass response. There are two conditions of this filter to operate, the first condition is when PIN diodes (SW1 and SW2) switch 'ON' as shown in Figure 11. During this state, the PIN diodes will be short circuit and producing matched bandstop filter. While for the varactor diodes (VD1, VD2, and VD3) is used to tune the K-inverter which is to control the gap of the coupling resonator. 0V is applied to the varactor diodes to produce matched bandstop filter. The second condition is, when PIN diodes (SW1 and SW2) switch 'OFF'. During this state, the PIN diodes will be open circuit and producing bandpass filter. While for the varactor diodes (VD1, VD2 and VD3) is used to tune the K-inverter, which is to control the gap of the coupling resonator. Voltage is applied to the varactor diodes (VD1, VD2 and VD3) to produce bandpass filter. Therefore, the generalized coupling resonator model of the switchable matched bandstop filter to bandpass filter as depicted in Figure 11, where have the same structure as the generalized coupled resonator model of a matched notch filter in Figure 3. The expression of coupling K_1 and K_2 is defined as:

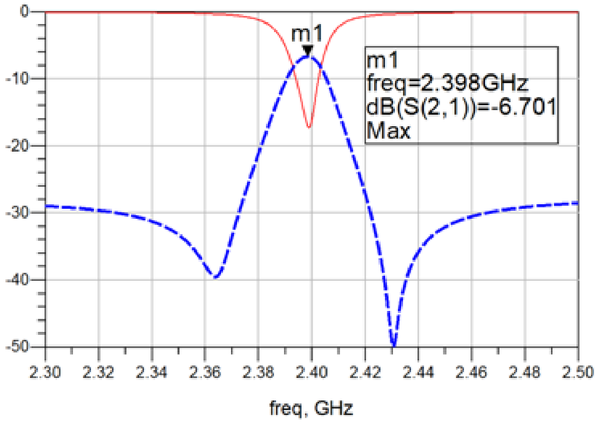
$$K_2 = \pm G \quad (3)$$

and

$$K_1 = \pm\sqrt{2G} \quad (4)$$



(a)



(b)

Figure 10: (a) Realization of parallel-coupled L-shape resonator in momentum simulation with PIN diodes (b) Bandpass response after the PIN diodes is turned 'OFF'

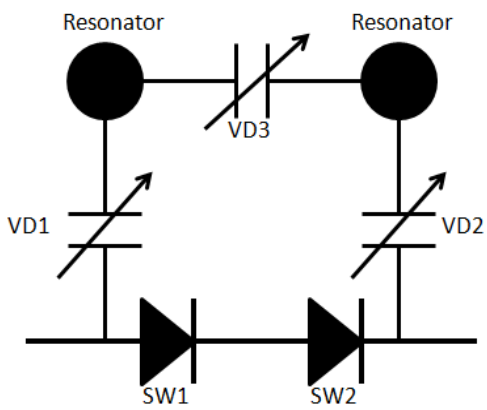


Figure 11: Generalized coupled resonator model of switchable matched bandstop to bandpass filter

The realization of the filter as depicted in Figure 12 consisted of parallel-coupled L-shape half-wavelength microstrip resonators coupled to a thru-line with switchable elements. PIN diodes were attached at the 90° length to switch the response from matched bandstop to bandpass filter. The biasing for PIN diodes was using a line biasing type that having a quarter wavelength with the characteristic impedance of 100 Ω.

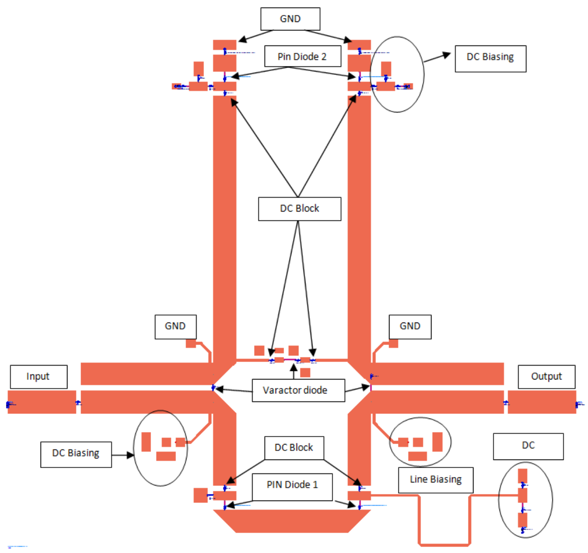


Figure 12: Realization of parallel-coupled L-shape resonator

The filter will produced matched bandstop response when the PIN diodes is turned ‘ON’ and bandpass response when PIN diodes is turned ‘OFF’. Figure 13 shows the matched bandstop response in the momentum simulation, where it is having S21 -30 dB and S11 is below than -20 dB which is perfectly-matched. The Q factor of the matched bandstop filter is 150. The insertion loss for bandpass response is about -6.7 dB, which is lossy. Therefore, the filter needs Varactor diode to enhance the bandpass response by controlling K1 and K2. By integrating the varactor diodes at the coupling resonator, the filter can produce a good bandpass response, but the center frequency was shifted about 100 MHz. Additional length was added at K2 coupling resonator so that the center frequency will shift back to 2.4 GHz.

Figure 14 shows the dual-mode bandpass response at center frequency 2.4 GHz with 200 MHz pass-band bandwidth. The bandpass response is having S_{21} close to 0 dB and S_{11} is below than -30 dB.

IV. CONCLUSION

In this study, a new switchable matched bandstop to bandpass filter was investigated. It was shown that from the matched bandstop response is able to switch to bandpass filter. The proposed filter was switched to produce either matched bandstop or bandpass response by turning ‘ON’ and ‘OFF’ the PIN diodes as the switching element incorporated into the filter structure. The result has shown that the filter exhibits high stopband attenuation in the bandstop mode. From the momentum simulation, it shows that the filter exhibits pass-band insertion loss around -6.7 dB in the bandpass mode. Further improvement of the insertion loss in the pass-band can be done by controlling the coupling resonator of K_1 and K_2. Varactor diodes were used to control the coupling gap of the resonator until the bandpass response occurred. The pass-band bandwidth is about 200 MHz and having a dual-mode response. The filter needs the additional length so that the center frequency of operation was shifted to 2.4 GHz. Future works of this filter will be fabricating and comparing the result between the momentum simulation and measurement.

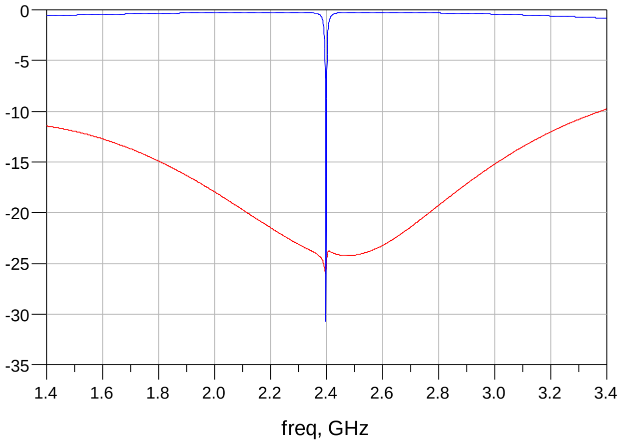


Figure 13: Matched bandstop response in momentum

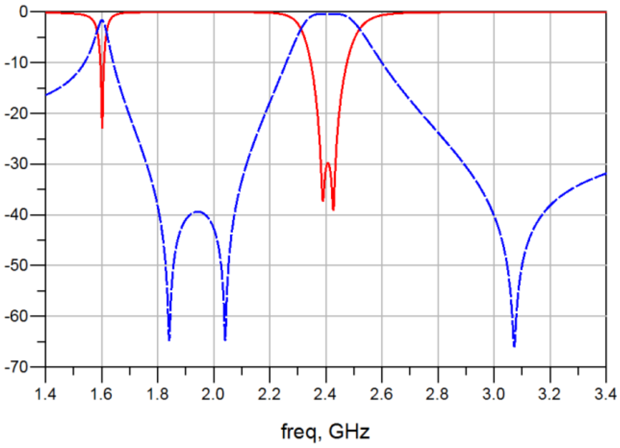


Figure 14: Bandpass response with center frequency at 2.4 GHz

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