Switchable Absorptive Bandstop to Bandpass Filter using Stepped-Impedance Dual Mode Resonator

M.K Zahari[1], B.H Ahmad[1], Wong Peng Wen[2], N.A. Shairi[1]
[1]Centre for Telecommunication Research and Innovation (CeTRI), Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer, Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[2]Electrical and Electronics Engineering Department,
Universiti Teknologi Petronas, Tronoh, Malaysia
khairyzahari@hotmail.com

***Abstract*— In this paper, a new switchable absorptive bandstop to bandpass filter using stepped-impedance dual mode resonator is proposed. This switchable filter provides two modes of operation which is absorptive bandstop and bandpass response. The first part of this paper presents a theoretical analysis of the absorptive bandstop filter using stepped-impedance dual mode resonator. The absorptive bandstop response can be achieved by connecting λ/4 length with the stepped-impedance dual mode resonator with correct diameter and position of via hole as an inductive element. The second part of this paper presents an investigation and design of the switchable absorptive bandstop to bandpass filter. PIN diodes are used as the switching element. The selectivity of the bandpass response can be improved by using extended via hole. The parametric studies together with the EM simulation of the new switchable absorptive bandstop to the dual mode bandpass filter is presented in this paper.**

***Index Terms*— Absorptive Bandstop; Bandpass; Stepped-Impedance; Matched Bandstop; Switchable Filter.**

I. INTRODUCTION

Microwave bandpass and bandstop filters are part of the RF front-end communication system and have been grown in recent years. It requires a large space to design bandpass and bandstop in one circuit. The need of bandpass and bandstop filter at a time in the communication system is very important because of the presence of low and high interfering signals near to the desired signal. Bandpass filter can be used for low interfering signals, while for bandstop filter suitable for high interfering signal. Therefore, there are many research have been focused recently [1]-[6]. The common problem that occurred in this system is the interference and also the physical size of the filter. Therefore, the development of the switchable bandstop to bandpass filters based on stepped-impedance resonator is essential to overcome this drawback and also to meet the ever increasing demands on miniaturization and switching capabilities. In the conventional bandstop filter technique, it requires a shunt stub element, which make the circuit's size become larger [7][8]. An absorptive bandstop design has been introduced [9], which is based on two low-Q lossy resonator's topology to partially compensate for the loss. However, this type of filter is large in size to produce a single notch with an infinite attenuation because of the second order resonator. Therefore, in this paper, a new switchable absorptive bandstop to bandpass filter will be proposed based on stepped-impedance dual mode resonator. The dual mode response can be achieved by comprising a transmission line of 1/2 wavelength with the shunt stub and via hole as the inductive element in the mid-plane. This design also used to miniaturize the filter's size [10].

II. THEORETICAL OF MINIATURIZED ABSORPTIVE BANDSTOP FILTER

The miniaturized dual mode resonator has been introduced to reduce the significant size of the filter based on stepped-impedance resonator and the filter's practical implementation as shown in Figure 1 [11]. The resonance condition for even and odd mode are given in (1) and (2).

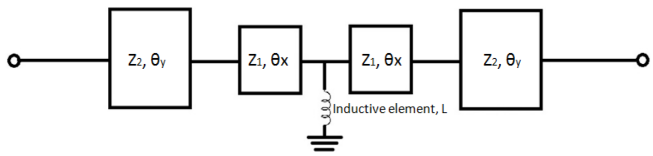


Figure 1: Miniaturized stepped-impedance dual mode resonator[11]

The structure is resonant for both even and odd modes when its input admittance is zero

$$Y_{even} = Y_{odd} = 0 \quad (1)$$

For odd mode, the input admittance at the resonance condition as follows

$$Y_{odd}\Big|_0 = tan(\theta_x)tan(\theta_y) = R \quad (2)$$

Where θ_x and θ_y are the electrical length of the transmission line sections respectively. Let θ_x and θ_y in (2) is simplified and given by

$$tan^2(\theta_y) = R \quad (3)$$

Therefore, it has been shown that at the resonant frequency, the total electrical length of the resonator $\theta_T = 4\theta_y$ is less than half-wavelength with the control of impedance ratio R. The even mode of the input admittance of the resonance condition stated as follows

$$Y_{even}\Big|_{=0} = \tan(\theta_y + a\theta_y)\,tan(\theta_y) = R \quad (4)$$

The inductive element can be modeled as a shorted shunt stub with characteristic impedance Z_L. The equivalent electrical length of the stub is θ_L. The dual mode bandpass filter was designed based on the stepped-impedance dual mode resonator [11][15]. The filter is designed using Rogers RT Duroid 5880 with a substrate thickness of 787 µm and dielectric constant of 2.2. The operating frequency is 2.4 GHz with 200MHz bandwidth. The inductive element is represented by a via hole at the center point of the resonator to achieve the dual mode bandpass response as shown in Figure 2. The response of the dual mode bandpass filter in the EM simulation as depicted in Figure 3.

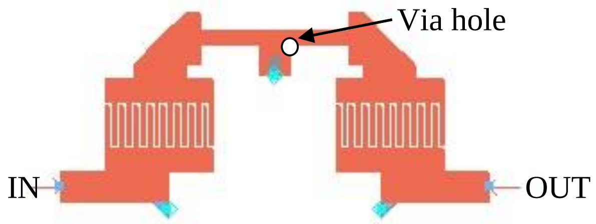


Figure 2: Stepped-impedance dual mode bandpass filter

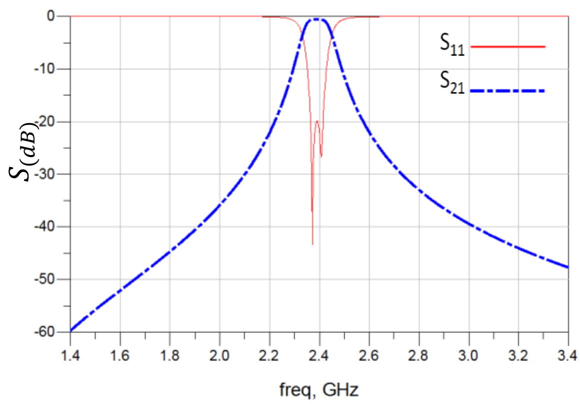


Figure 3: Dual mode bandpass filter response

A. Absorptive Bandstop Filter Using Low-Q Lossy Resonator

In [9], the authors were successfully demonstrated an ideal infinite stopband attenuation of the absorptive bandstop where high notch depth and selectivity can be produced with only two low-Q lossy resonators in microstrip technology. This idea was from [12] that builds upon the perfectly-notch concept where it consists of two identical lossy resonators connected to the 90° hybrid coupler or directional coupler as shown in Figure 4. This technique enables the use of two low-Q lossy resonators for high attenuation of bandstop filter applications. Thus, its advantages are not only to produce higher stopband attenuation but also being perfectly matched in both the passband and stopband as well as compact in size.

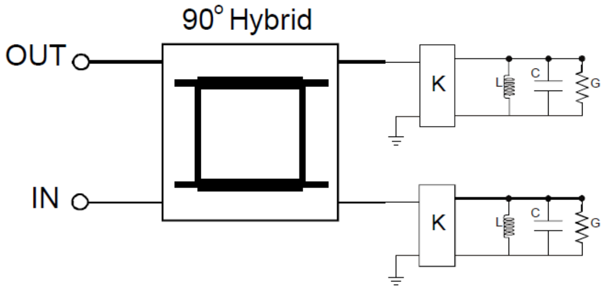


Figure 4: Diagram of an enhanced Q notch filter employing a 3-dB, 90° hybrid coupler [9]

This topology has a symmetrical structure of two-port network defined by utilizing the conventional method for odd and even mode analysis. Consider an even and odd mode analysis of an absorptive resonator in Figure 5, the transfer matrix of the symmetrical network is given by:

$$[T_R] = \begin{bmatrix} \left(\frac{Y_e + Y_o}{Y_o - Y_e}\right) & \left(\frac{2}{Y_o - Y_e}\right) \\ \left(\frac{2Y_e Y_o}{Y_o - Y_e}\right) & \left(\frac{Y_e + Y_o}{Y_o - Y_e}\right) \end{bmatrix} \quad (5)$$

Where Y_e is even mode and Y_o is the odd mode of admittance of the resonator and by converting the transfer matrix in (5) to S-parameter, can get as follows

$$S_{11} = S_{22} = \frac{1 - Y_e Y_o}{(Y_o + 1)(Y_e + 1)} \quad (6)$$

and

$$S_{12} = S_{21} = \frac{Y_o - Y_e}{(Y_o + 1)(Y_e + 1)} \quad (7)$$

The network have the allpass property if $|S_{11}| = 0$, when $Y_o = 1/Y_e$ for all frequencies. While, the network produces infinite attenuation, if $|S_{12}| = 0$ when, $Y_o = Y_e$ at a certain frequency. Based on Fig, the network consists of two low-Q lossy resonators with an unloaded Q of $\omega C/G$, and four admittance inverters. The circuit shown that both allpass and the perfect notch property are met when $K_1 = \pm\sqrt{2G}$ and $K_2 = G$. Compared with the conventional bandstop filter, the losses of the present resonator absorbed the power at stopband frequencies and is not reflected. Figure 6 shows the absorptive bandstop response.

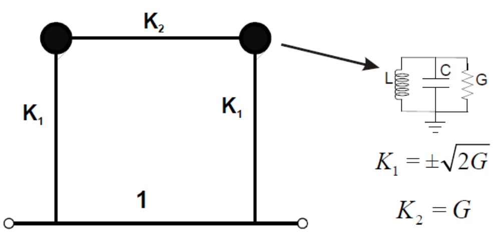


Figure 5: A model of coupled-resonator for an absorptive bandstop filter [9]

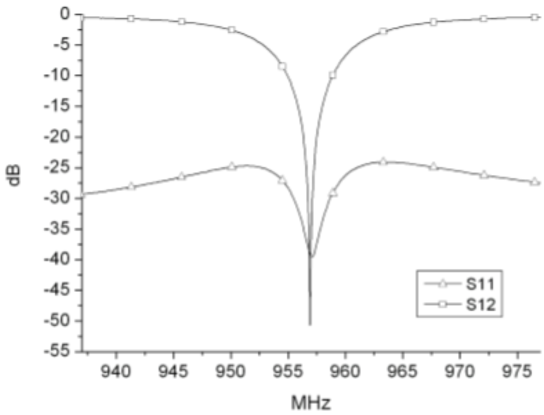


Figure 6: Perfectly-matched bandstop response [9]

B. Miniaturized Absorptive Bandstop Filter

An absorptive bandstop filter has been proposed in [14]. The filter was designed using stepped-impedance dual mode resonator. The equivalent circuit as depicted in Figure 7. The absorptive bandstop filter based on stepped-impedance dual-mode resonator is achieved by adding $K_3 = \lambda/4$ wavelength between the input and output of the resonator. The coupling K_1 is represented as inter-digital capacitor, while for K_2 is represented by via hole shunted at the middle point of the resonator. The structure of absorptive filter as shown in Figure 8.

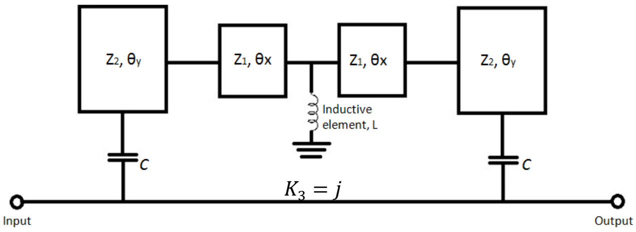


Figure 7: Circuit implementation of the miniaturized absorptive bandstop filter[10].

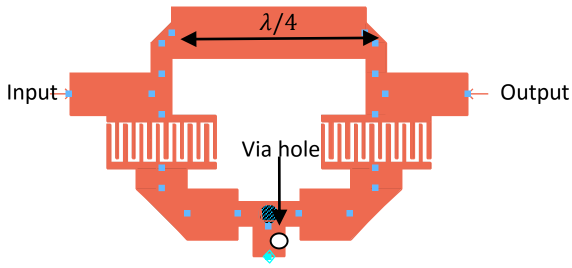
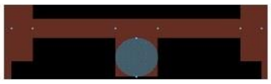
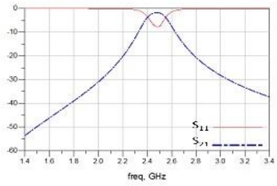
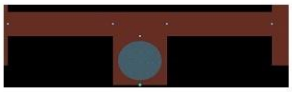
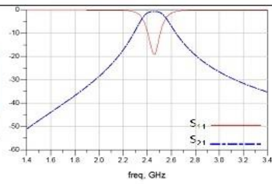
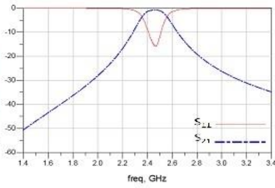
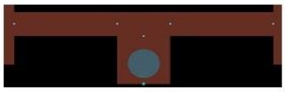
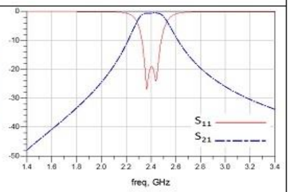


Figure 2: Layout design of miniaturized absorptive bandstop filter.

C. The Effect of Via Hole

The response of the dual mode bandpass filter can be achieved by determining the correct diameter and the location of the via hole as shown in Table 1 below. Via hole represents as an inductive element which is can be realized by shunted stub.

Table 1
Bandpass response based on the diameter and the location of the via hole

Diameter (cm)	Location	Response
1		
0.8		
0.6		
0.6		

III. Switchable Absorptive Bandstop to Bandpass Filter

A. Realization of Switchable Filter

This filter provides two modes of operation, which was absorptive bandstop and bandpass response. Previously, the parametric studies of the miniaturized dual mode bandpass filter and an absorptive bandstop filter have been done. Theoretically, the filter can be switched to perform either bandpass or bandstop response. PIN diodes (SW1 and SW2) are used as switching elements that integrate with the filter's structure between the stepped-impedance resonator and 90° length. The first condition was when PIN diodes were switched 'ON'. During 'ON' state, the PIN diodes were short circuited and produced the absorptive bandstop response. The second condition was when PIN diodes were switched 'OFF'. During 'OFF' state, the PIN diodes were open circuited and the filter produced a bandpass response. Figure 9 shows the equivalent circuit of switchable absorptive bandstop to bandpass response.

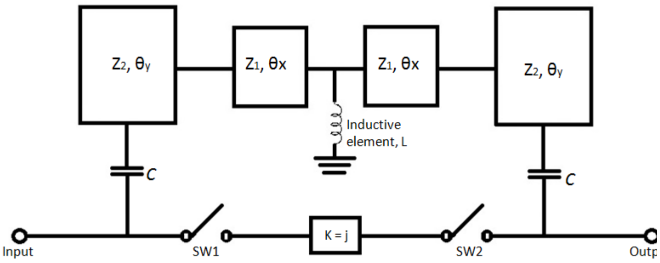


Figure 9: Equivalent circuit of switchable absorptive bandstop to bandpass filter.

This structure is a symmetrical for absorptive bandstop filter circuit, the resonance condition can be derived by using odd and even mode analysis from (6) and (7). The realization of switchable absorptive bandstop to bandpass filter as shown in Figure 10. PIN diodes were used to connect or disconnect the resonator with λ/4 wavelength to produce an absorptive bandstop response. Additional via hole was designed to enhance the dual mode bandpass response.

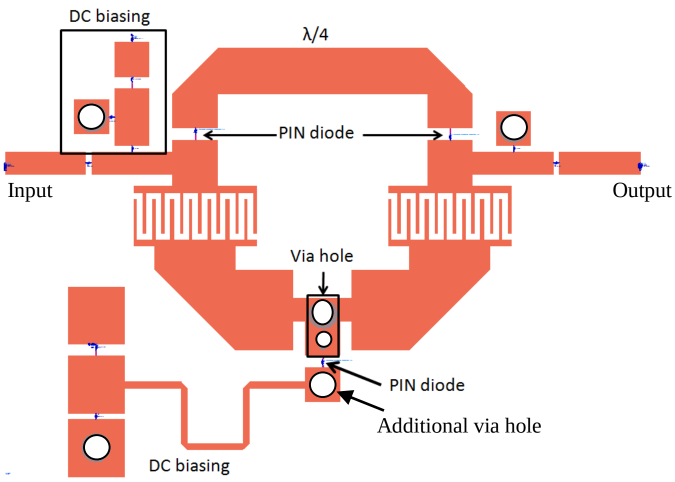


Figure 3: Realization of switchable absorptive bandstop to bandpass filter.

The dual mode bandpass response was produced when the pin diodes that connect to the $\lambda/4$ length were switched 'OFF', with 200 MHz bandwidth, return loss was below than 10 dB and insertion loss 0.3 dB. The transmission zero was existed at 2.07 GHz and 2.64 GHz as shown in Figure 11.

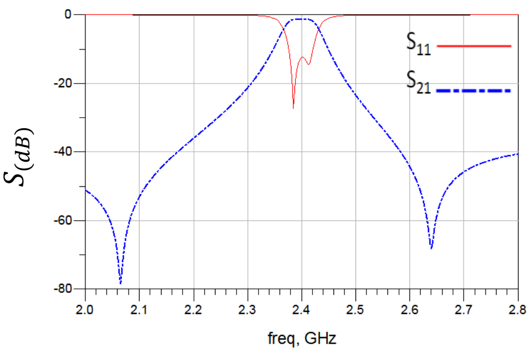


Figure 11: Dual mode bandpass response when PIN diodes are turn 'OFF'

The selectivity can be improved using additional via hole, which is connected to the center point of shunt stub using a pin diode and the response is shown in Figure 12. The new transmission zeroes were existed at 2.21 GHz and 2.5 GHz.

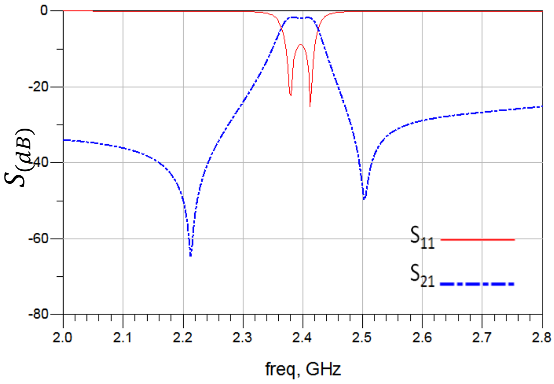


Figure 12: Dual mode bandpass response when additional via hole was switched 'ON'

An absorptive bandstop filter was produced when the PIN diodes were switched 'ON' and the resonator was connected to the λ/4 wavelength. The absorptive bandstop response as depicted in Figure 13, where insertion loss was 30 dB and return loss below than 15 dB and Q factor 150.

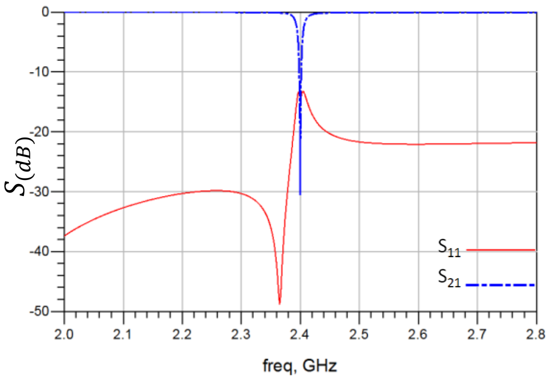


Figure 13: Absorptive bandstop response when PIN diodes are turned 'ON'

IV. Conclusion

A new switchable absorptive bandstop to bandpass filter based on a stepped-impedance dual mode resonator had been presented. It shows that the absorptive bandstop response able to switch a dual mode bandpass response. This can be done by disconnecting the stepped-impedance resonator with λ/4 wavelength. It also shows that the selectivity of the bandpass response can be enhanced by extending the via hole at the center of the resonator using PIN diode. The results from the simulation shows the filter displays high stopband attenuation in the bandstop mode. The center frequency of the filter operation is 2.4 GHz. From the EM simulation, the filter exhibits pass-band insertion loss around 0.3 dB and a return loss of about >10 dB in the bandpass mode. The pass-band bandwidth is about 200 MHz and has a dual-mode response with improved selectivity. For the future works, the filter will be fabricated and the result will be compared with the simulation and measurement results.

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