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Pseudo-elliptic narrow bandpass filter using shorted coupled-line of higher order design

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Article Info	ABSTRACT
	This paper presents an implementation of quarter wavelength single-shorted coupled-lines for narrow bandpass filter application. It is shown as a new way of creating a single resonance bandpass filter by inter-connected of two single-shorted quarter wavelength coupled-line sections. By adding more single-shorted coupled-line into the configuration, the form of halfwavelength resonator can increase the degree of order of the filter. For the design of 4th order resonator, the coupled-lines are arranged inter-connected to each other forming five-fingers lines layout. Due to the inter-connection of the coupled-lines, transmission zeros appear at the two stopbands which improves the selectivity of the filter response. Investigation on the parametric of the 4th order resonator is conducted to observe the controlling parameters and it's realiability responses of the resonator. For compactness, five-fingers meandered lines is proposed. It is found that the size of the meandered lines resonator was successfully reduced by 33% compared to the five-fingers straight lines resonator of the same order. For validation of concept, the 4th order meandered lines resonator was designed at 1 GHz and fabricated on RO3210 microstrip substrate with characteristics given as h = 1.27 mm, ε_r = 10.2 and tan δ = 3x10-3. The measurement results show good agreement with the simulation results.

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1. INTRODUCTION

Increasing consumer demand on the modern wireless devices required the sensitivity and capabilities of the communication system. As one of the important role in the modern communication, the filtering element was design based on the specific requirement in line with the desired technology communication field [1]. Researches and developments on the filter designs had focused on improving the filter performances in areas such as insertion loss, bandwidth, selectivity and etc [2]. Numerous topology designs of bandpass filter including the parallel coupled line were introduced depended on the characteristics requirement of the application used.

The classical parallel coupled-line was proposed by Cohn in 1958 [3]. Further researches for improvement on this topology still going on until today [4-5]. The classical parallel coupled-line topology structure consist of coupled-line with series connection. As the degree of order depends on the number of halfwavelength resonator, this will increase the total length of the filter. This is due to the fact that more coupled-lines are connected in series to the base topology [6-8]. Furthermore, in terms of the selectivity of the filter, there are no transmission zero offer in the classical parallel coupled-line response [9].

Further research and development on the coupled-line topology were explored by researcher to improve the performance and cababilities of the filter to fulfill the modern communication system that require compact size, accurate and very high selectivity of the filter. In order to achieved compactness and reduce size of the filter, several techniques were used such as patch capacitor [10], folded design [11], meandered pattern [12-13], additional of active elements [14] and defected ground structure (DGS) [15].

In this paper, a new topology bandpass filter using two single-shorted coupled-lines is proposed, where a section of the single-shorted coupled-line are inter-connected to form half wavelength resonator. By introducing new coupled-lines inter-connected to the base cell will form new half wavelength resonator that leads to the number of degree of the filter. Therefore, the 4th order bandpass filter can be formed by inter-connecting three new single-shorted coupled-line into the basic configuration. When compared to the conventional parallel copled-line, the advantage of this topology is that, it exhibits transmission zeros at the stopbands of the filter response. Furthermore, by employing five-finger straight-lines arrangement of the single-shorted coupled-lines, will optimize the axis surface area of the filter. To reduce the size, meander technique is applied to the design. The five-fingers meander-lines offers approximately response when compare to the five-finger straight-lines filter design.

2. FILTER TOPOLOGY

The proposed new coupling structure depicted in Figure 1(a) consists of end-shorted half wavelength resonator. The half wavelength resonator is created from the inter-connection of two single-shorted quarter wavelength coupled-line sections with two sets of odd- and even-mode characteristics impedances. This topology creates a single resonance bandpass filter response as depicted in Figure 1(b). The resonator is designed at 1 GHz with the value of impedances; Z_{oe1}=69Ω, Z_{oo1}=43Ω and, Z_{oe2}=76Ω, Z_{oo2}=47Ω.
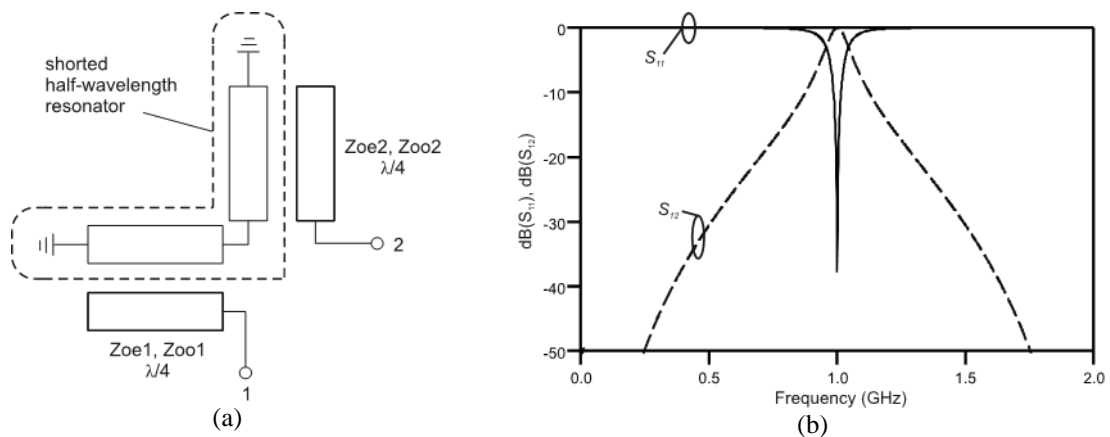

Figure 1. (a) Schematic and (b) Ideal frequency response for end-shorted half wavelength resonator

To further explore the concept, the base topology can be inter-connected with additional couple-lines for higher order filter design. With additional of n numbers of single-shorted coupled-lines, $n + 1$ order bandpass filter can be created.

To proof the concept, additional of 3rd and 5th coupled-lines are added to the base cell to create 2nd and 4th order bandpass filters as shown in Figure 2(a) and 2(b) respectively. With these arrangements, it can be seen that the half wavelength resonators are created in such a way that the shorted-end and open-end resonators are arranged in alternate manner. Furthermore, with fingers layout arrangement of the coupled-lines, side-by-side surrounding the axis up to 4th order, it maintaines the size of the resonators at ¼ λ x ½ λ. This leads to optimizing the surface area of the filter.

The resonators are designed at 1 GHz, and the impedance values for both resonators are tabulated in Table 1. The designs are simulated using fullwave electromagnetic simulation tool and the ideal responses of the resonators are as shown in Figure 3(a) and 3(b).
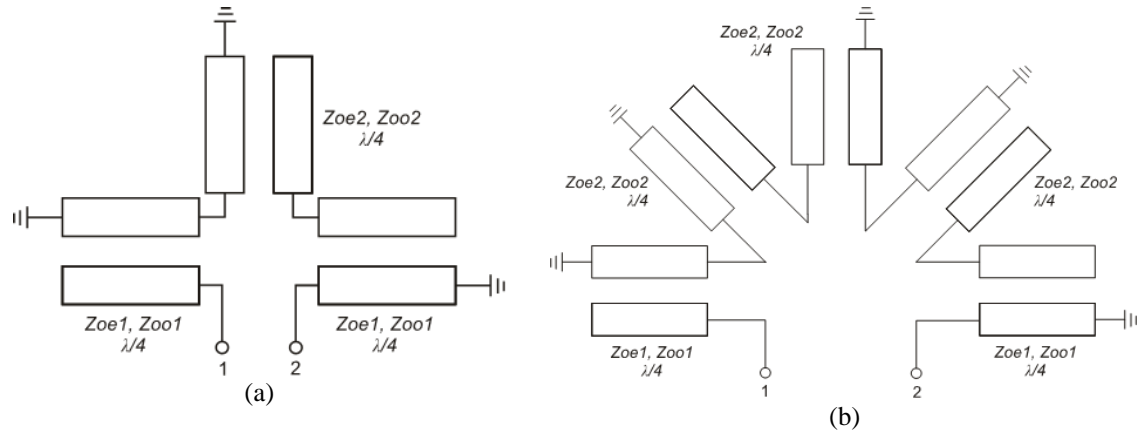
Figure 2. Fingers bandpass filter layout based on inter-connected single-shorted coupled-lines resonators, for (a) 2nd-order filter with two half wavelength resonator and (b) 4th-order filter with four half wavelength resonator
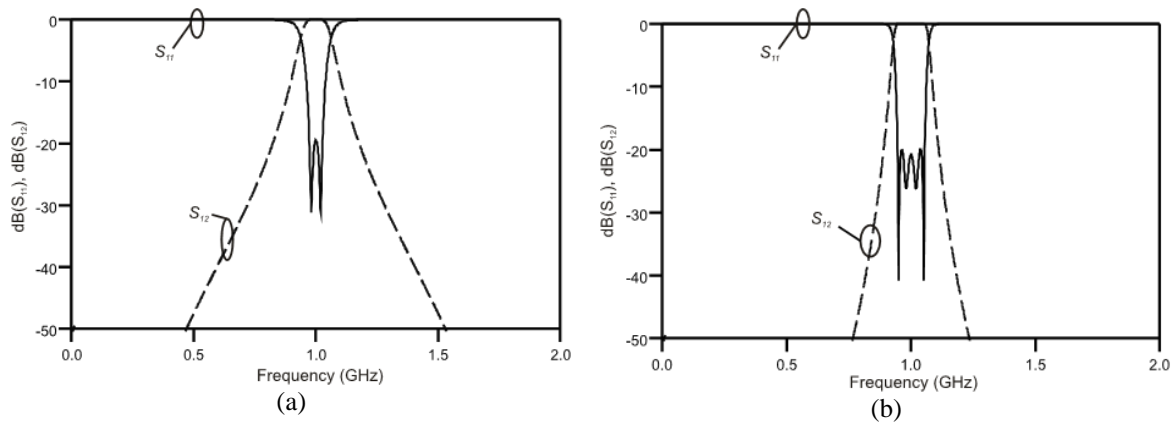

Figure 3. Ideal frequency response of the (a) 2nd and (b) 4th order bandpass filter

Table 1. Even- and Odd-Mode Characteristic Impedances of the 2nd and 4th Order Resonators

	Z_{oe1}	Z_{oo1}	Z_{oe2}	Z_{oo2}	Z_{oe3}	Z_{oo3}
2nd-order filter	95 Ω	46 Ω	38 Ω	29 Ω	-	-
4th-order filter	74 Ω	31 Ω	50 Ω	37 Ω	60 Ω	47 Ω

As shown in Table 1, the above impedances' values of the 2nd and 4th order resonators are chosen through their parametric study. From the parametric study, one can observe the variations of the filter response and investigate the behavior and controlling parameters of the resonator.

3.   4TH ORDER FILTER VARIATION OF ELECTRICAL RESPONSES

This section presents the parametric study of the 4th order resonator design. For realization of resonator on microstrip substrate, one has to choose a suitable characteristic impedance value that can be realized on the substrate [1]. Based on this information, the odd- and even-mode impedance values of the single-shorted coupled-lines of the 4th order resonators are established. Since the layout is symmetrical, hence only three instead of five sets of coupled-lines have to be optimized for symmetrical bandpass response.

For the variation parametric study, each value of the parameters is set in the range of 20Ω. All the three sets of the parameters; Z_{oe1}, Z_{oo1}, Z_{oe2}, Z_{oo2}, Z_{oe3} and Z_{oo3} are tabulated in Table 2.

Table 2. Variation Parameter for Ideal 4th Order Bandpass Filter Response

Graph	Parameter	Min Value (Ω)	Max Value (Ω)
Figure 4	Z_{oe1}	65	85
Figure 5	Z_{oo1}	20	40
Figure 6	Z_{oe2}	45	65
Figure 7	Z_{oo2}	25	45
Figure 8	Z_{oe3}	60	80
Figure 9	Z_{oo3}	30	50

Figure 4 shows the variation of Z_{oe1} from 65Ω to 85Ω while fixing the other impedances at ideal value (Z_{oe1}=74Ω, Z_{oo1}=31Ω, Z_{oe2}=50Ω, Z_{oo2}=37Ω Z_{oe3}=60Ω and Z_{oo3}=47Ω). It can be seen that Z_{oe1} influences on bandwidth, insertion loss and return loss of the filter. As shown in Figure 5, the variation values of Z_{oo1} from 20Ω to 40Ω seen the changes of bandwidth compare to the Z_{oe1}. For the variation values of Z_{oe2}, Z_{oo2} Z_{oe3} and Z_{oo3} are shown in Figure 6, 7, 8 and 9 respectively.
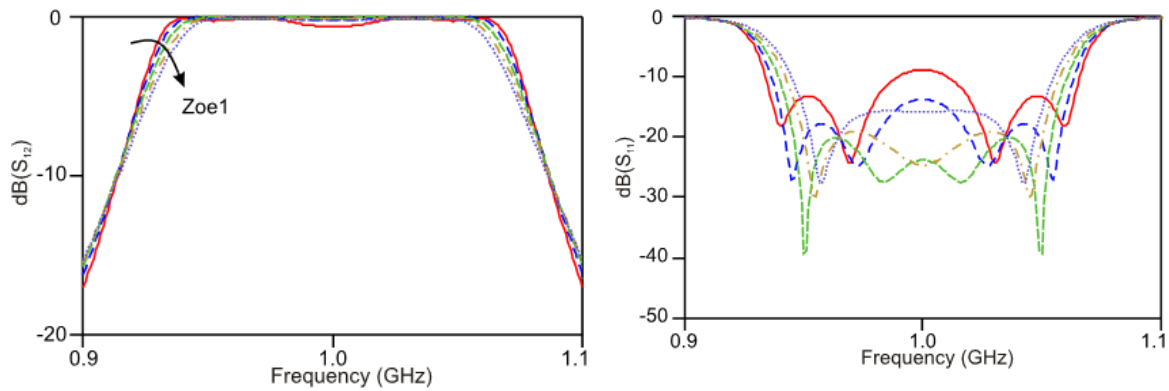

Figure 4. Ideal variation values of Z_{oe1} from 65Ω to 85Ω and the electrical responses
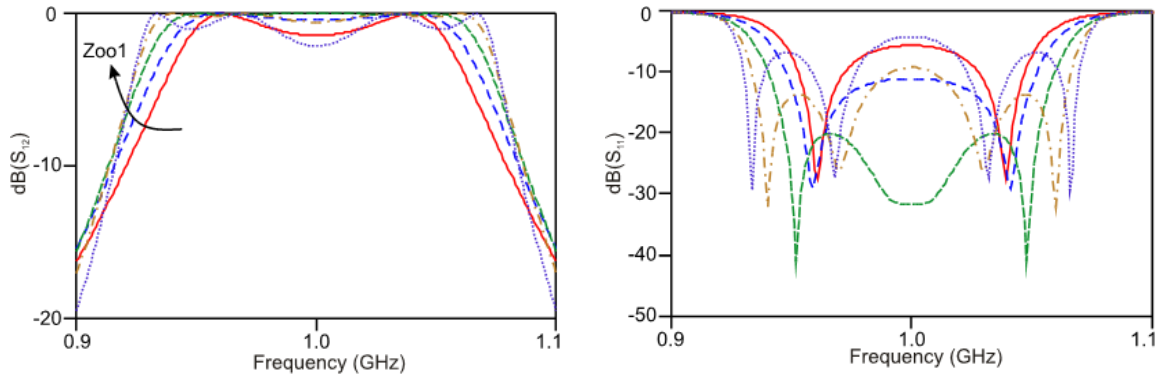

Figure 5. Ideal variation values of Z_{oo1} from 20Ω to 40Ω and the electrical responses

The observation of variation responses when the value of 2nd coupled-line varied as tabulated in Table 2. As depicted Figure 6 & 7, both of the parameters influence on the bandwith. However, the controlling of Z_{oo2} on bandwidth is more dominant compare to Z_{oe2}. The coupling coefficient, k for 1st coupled-line is 0.41 while 2nd coupled-line is 0.15. Noted that, lower coupling coefficient resulting to weaker coupling effect that influenced on bandwidth.
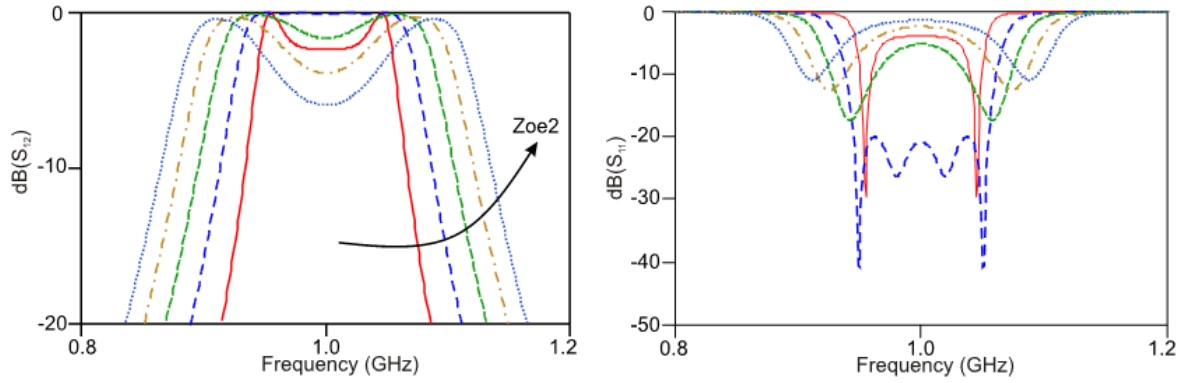
Figure 6. Ideal variation values of Z_{oe2} from 45Ω to 65Ω and the electrical responses

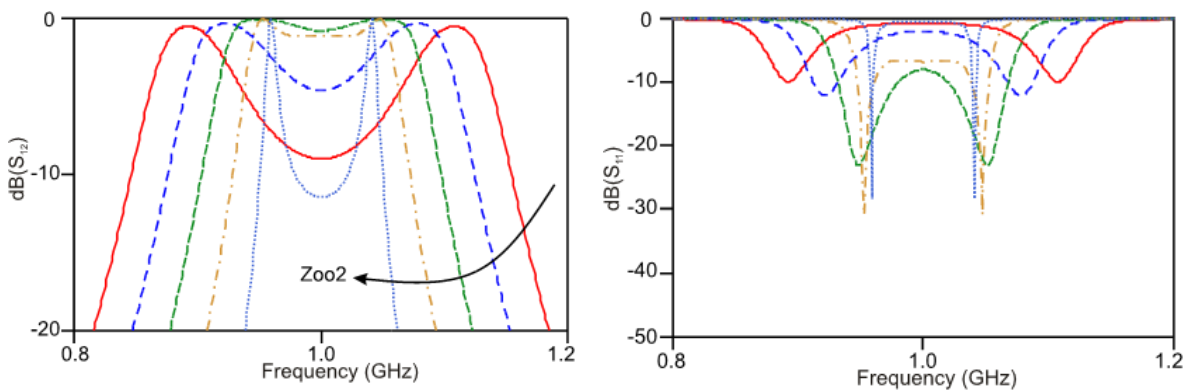Figure 7. Ideal variation values of Z_{oo2} from 25Ω to 45Ω and the electrical responses

Next, observation is performed on a 3rd coupled-line. The variation of electrical responses for Z_{oe3} and Z_{oo3} are shown in Figure 8 and 9 respectively. The increment of Z_{oe3} or decrement of Z_{oo3} would increase the bandwidth but at the same time degrade the return and insertion losses due to mismatch of impedances.
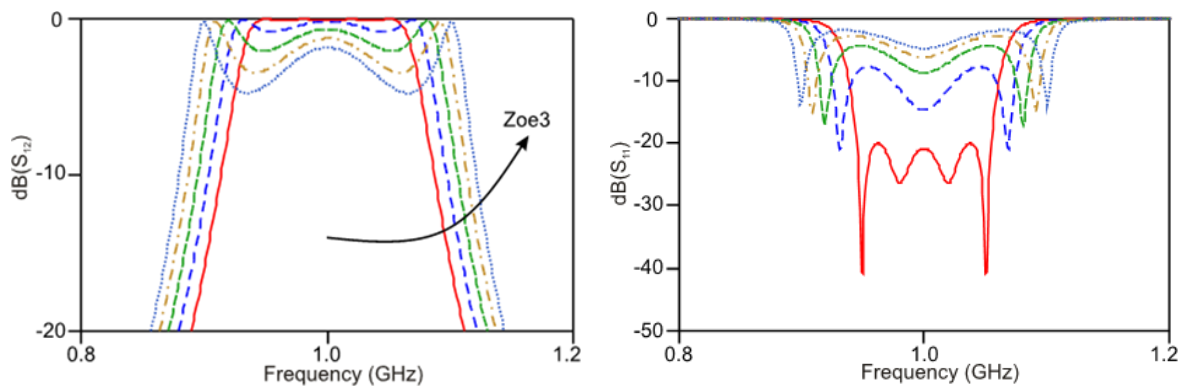

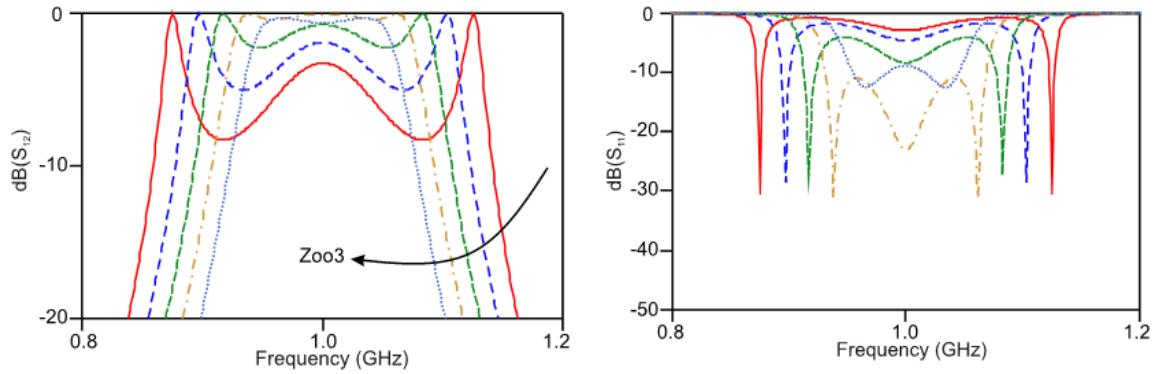Figure 8. Ideal variation of Z_{oe3} from 60Ω to 80Ω and the electrical responses

Figure 9. Ideal variation values of Z_{oo3} from 30Ω to 50Ω and the electrical responses

Based on the illustrate ideal responses of parametric variation study for the 4th order bandpass resonator, it can be said that the odd- and even-mode impedances of the 2nd and 3rd single shorted coupled-lines dominantly controlled the bandwidth of the resonator with variation in the range of 5%. Hence, this resonator design is suitable for narrowband bandpass fiter applications. In terms of impedance matching, all the parameters need to be optimized accordingly for best results to obtain bandpass response.

4.   4TH ORDER FILTER REALIZATION

This section presents the layout and implementation of higher order bandpass filter design for 4th order resonator using microstrip technology. The first design is based on five-fingers straight-lines layout with area dimensions of 58.1 mm x 44.7 mm. For miniaturization, all the five fingers are meandered and the area dimensions achieved 44.9 mm x 38.6 mm, resulting to approximation of 32.6% size of reduction. Both layouts of the five-fingers straight-lines and five-fingers meandered-lines are shown in Figure 10 and Figure 11 respectively. The resonators are designed at 1GHz, simulated by using full wave electromagnetic simulator. For implementation, the five-fingers meandered-lines resonator was realized on Roger RO3210 microstrip substrate (h = 1.27 mm, ε_r = 10.2, tan δ = 3x10⁻³).
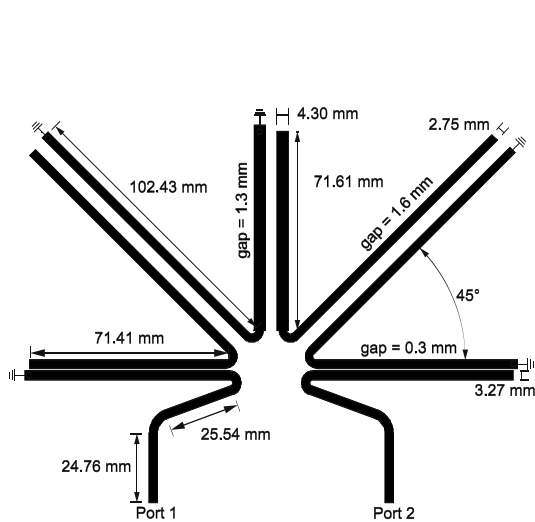

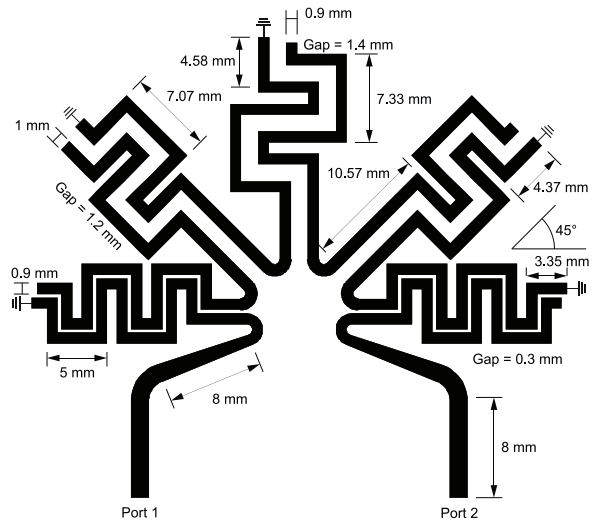Figure 10. Schematic layout 4th order five-fingers straight-lines bandpass filter

Figure 11. Schematic layout of 4th order five-fingers meandered-lines bandpass filter

Both resonators were successfully simulated. The comparison output of the simulations for five-finger straight-lines and meandered-lines is depicted in Figure 12. Both passband responses are centered at 1 GHz with insertion losses less than 3dB. The effect of the cross couplings occurs from adjacent of the

coupled-lines in both designs lead to the creation of transmission zeros at both side of passband responses. The presences of transmission zeros contribute to high selectivity bandpass filter responses.
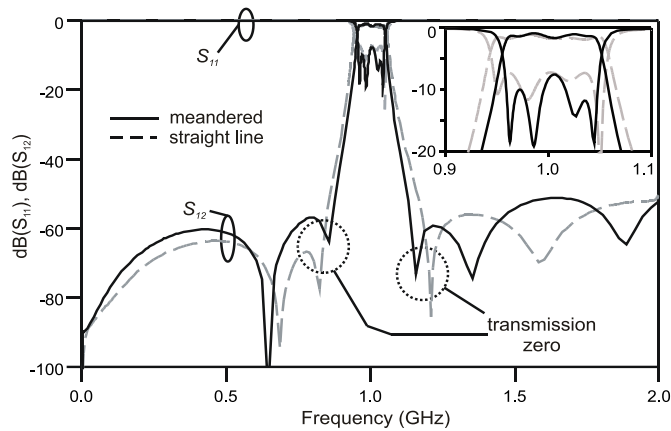

Figure 12. Comparison output of simulation for five-fingers straight-lines and
meandered-lines resonator designs

Finally, the 4th order five-fingers meandered-lines resonator was fabricated and measured. Figure 13(a) shows the photograph of the fabricated resonator on RO3210 substrate. The measurement result is compared with simulated and achieved good out-of-band rejection level beyond 50 dB as depicted in Figure 13(b). The resonance is centered at 1GHz with 5.2% relative bandwidth and insertion loss of 3.2 dB. Transmission zeros are found at the upper and lower side of the stopbands. The presence of transmission zeros due to the cross coupling effect among the coupled-lines is advantageous to the design, since it gives high selectivity and good rejection level of the filter response.
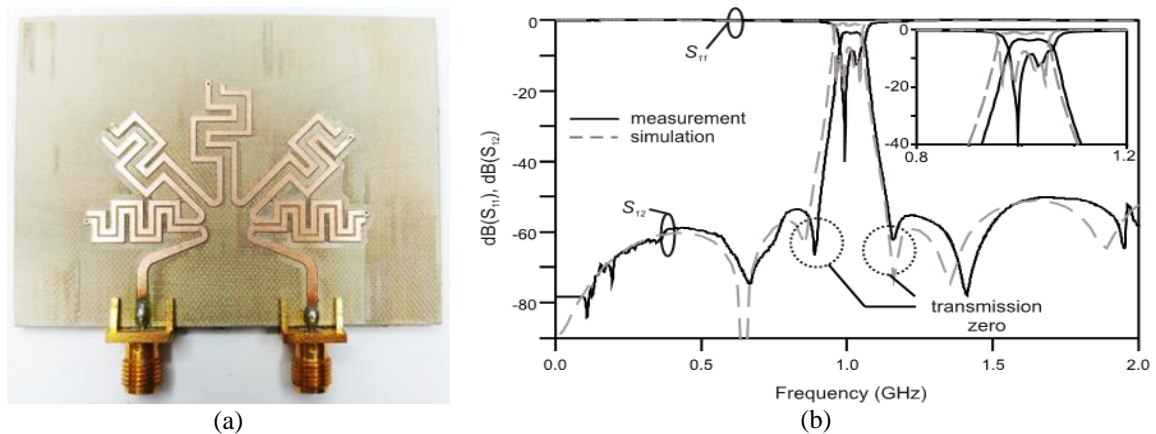

Figure 13. A 4th order meandered-lines bandpass filter of (a) photograph and (b) simulation and
measurement result

5. CONCLUSION

A bandpass resonator of single-shorted coupled-line topology was presented. By adding more coupled-line into the base cell, lead to the creation of higher order bandpass filters. Parameter study was conducted for 4th order resonator and was found that the characteristics of the resonator responses can be controlled by varying the impedance of the odd- and even-mode impedances of the coupled-lines. Meander technique was applied on the 4th order five-fingers lines and was successfully reduced the size of the resonator by more than 30%. Finally, the proposed filter of 4th order was realized on the microstrip substrate and the measurement results of the fabricated filters were found to be in good agreement with the simulation

results. The advantage of this topology is that, tranmission zeros were created on the 4th order bandpass filter response due to cross coupling effect. The occurrence of transmission zeros lead to higher selectivity of the filter and better rejection level.

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