A 3rd Order Narrowband Bandpass Filter Based on Shorted Coupled-Lines Resonator

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***Abstract*—This paper presents a class of side-coupled shorted coupled-lines resonator topology for narrowband bandpass filter applications. The base topology is constructed by inter-connecting two shorted quarter-wavelength coupled-line sections to exhibit a single resonance bandpass filter response. The degree of order of the resonator can be increased by inter-connecting additional shorted quarter-wavelength coupled-line sections to the base cell. Based on this concept, a 3rd order bandpass filter is constructed by inter-connecting two new shorted quarter-wavelength coupled-line sections into the base cell. The advantage of this new 3rd order filter arrangement is that, the affect of inter-connecting the shorted coupled-line sections had caused cross-coupling between the adjacent coupled-lines to produce a transmission zero at the lower passband. For compactness, all the coupled-lines of the 3rd order filter are meandered, resulting to 40% of size reduction. To prove the concept, the 3rd order bandpass filter was simulated using fullwave electromagnetic simulation tool. The filter was designed at 1 GHz on microstrip substrate type Roger RO3210. A prototype of the 3rd order bandpass filter was fabricated and the results are compared and are found agreable.**

***Index Terms*—Bandpass filter, coupled-line, cross coupling, inter connected, meander, side-coupled, transmission zero.**

I. INTRODUCTION

THE technology in the field of telecommunication growing rapidly inline with high demands on wireless and mobile communication devices. Bandpass filter, as one of the major component in modern communication, requires high accuracy and performance of the filtering function to select the desired frequency while optimizing the size and topology.

Since 1937, there were various type of filter topologies such as ring, hairpin to name a few, including coupled-line [1]. As for the coupled-line filter topology proposed by Cohn [2] in 1958, the quarter-wavelength coupled line was used by connecting them in series forming parallel coupled-lines topology. The degree of order of the coupled-lines topology was based on series arrangement, and as more coupled-lines are connected in series resulted to increasing the length of the filter [3]–[6]. Further improvement on the topology were explored by researches to improve the performance and size of the coupled-lines filter in meeting the modern communication systems that require high spectral efficiency and size miniaturisation.

In terms of miniaturization, bandpass filter as a device that requires low insertion loss, sharp rejection needs to go for compact size in meeting the modern requirement. In order to reduce the size of filter design, there are several popular techniques can be used such as meander pattern [6][7], patch capacitors [9], defected ground structure (DGS) [10] and additional of active elements [11].

In this paper, a bandpass filter design using side-coupled shorted coupled-lines is proposed. Two quarter-wavelength shorted coupled-line sections are interconnected to form straight-line of half-wavelength resonator forming single resonance bandpass filter. Based on this topology, a 3rd order bandpass filter is proposed. The advantage of this 3rd order bandpass filter when compared with the conventional parallel coupled lines is that it exhibits a transmission zero at the lower side of the passband, hence improve the selectivity of the filter. Meander-line technique is applied on the topology to reduce the overall size of the filter area while offers the same performance of the straight-line filter design.

II. FILTER TOPOLOGY

The proposed structure depicted in Fig.1 can be considered as a symmetrical design of a side-coupled shorted coupled-lines single mode resonator. This basic topology consists of half wavelength resonator resulting from combination of two side-coupled shorted quarter wavelength coupled-line sections. The even- and odd- mode impedances of the coupled-line sections are denoted as Z_{oe} and Z_{oo} respectively. The ideal response of the single mode resonator is shown in Fig. 2, with the value of the impedances are given as Z_{oe1}=70Ω, Z_{oo1}=38Ω, Z_{oe2}=79Ω and Z_{oo2}=42Ω, to resonate at 1 GHz.

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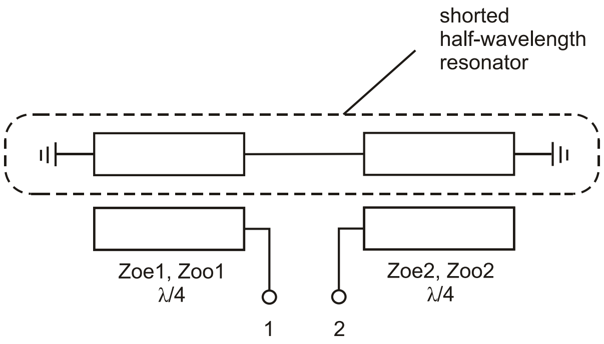

Fig. 1. Schematic diagram of the side-coupled shorted half wavelength single mode resonator.

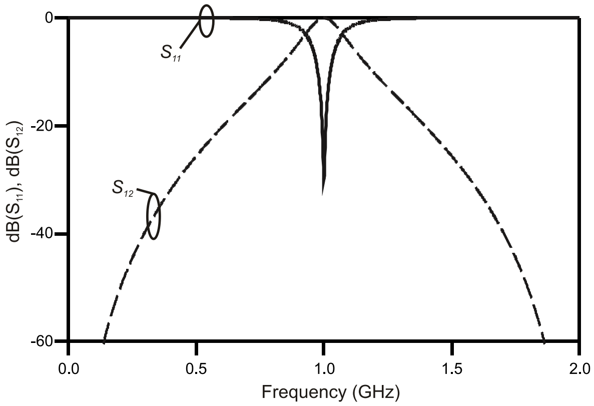

Fig. 2. Ideal frequency response of the side-coupled shorted half-wavelength single mode resonator.

To further explore the concept, an additional of two quarter-wavelength shorted coupled lines are added into the base cell to give a symmetrical design of a 3rd order bandpass filter, as depicted in Fig. 3. The new topology illustrated a four-finger coupled-lines arrangement with two sets of impedance values. The first and fourth coupled-lines impedances are denoted as Z_{oe1} and Z_{oo1}, while the 2nd and 3rd coupled-lines impedances are denoted as Z_{oe2} and Z_{oo2}. Hence, controlling parameters of the filter can be minimized.

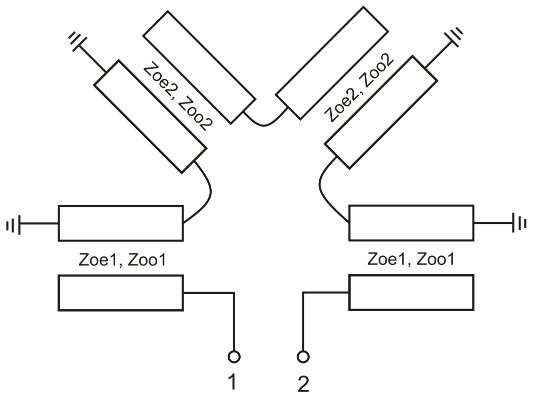

Fig. 3. Ideal circuit diagram of the 3rd order four-fingers bandpass filter.

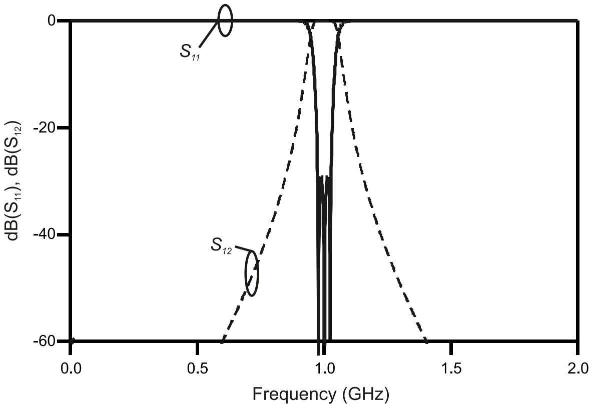

Fig. 4. Ideal frequency response of the 3rd order bandpass filter

Next, based on the four-finger arrangement, the 3rd order bandpass filter is designed at 1 GHz with the two sets of impedances are valued at Z_{oe1}=61Ω, Z_{oo1}=26Ω, Z_{oe2}=49Ω and Z_{oo2}=39Ω. The filter is simulated using electromagnetic fullwave simulator and the response of 3rd order modes is depicted in Fig.4.

III. 3RD ORDER FILTER VARIATION OF ELECTRICAL RESPONSES

This section discussed the findings based on the investigation on the influence of the parameters of the 3rd order filter on electrical responses in terms of bandwidth, insertion loss and return loss. The investigation is performed by varying one of the parameter values of the shorted coupled lines, while fixing the rest of the parameters based on the set of values given by Z_{oe1}=61Ω, Z_{oo1}=26Ω, Z_{oe2}=49Ω and Z_{oo2}=39Ω, designed at 1 GHz. The range of variation of the impedances for each parameter are tabulated in Table 1.

TABLE I
Variation Parameter for Ideal 3rd Order Bandpass Filter Response

Graph	Parameter	Min Value (Ω)	Max Value (Ω)
Fig. 5	Z_{oe1}	45	65
Fig. 6	Z_{oo1}	20	40
Fig. 7	Z_{oe2}	45	85
Fig. 8	Z_{oo2}	20	40

Fig. 5 depicts the variation of electrical responses when Z_{oe1} is varies from 45Ω to 65Ω, while fixing the rest of parameter values at Z_{oo1}=26Ω, Z_{oe2}=49Ω and Z_{oo2}=39Ω. It can be seen that, the increment of Z_{oe1} influences a minimal effect on bandwidth and at the same time achieve the better return loss more than 20dB.

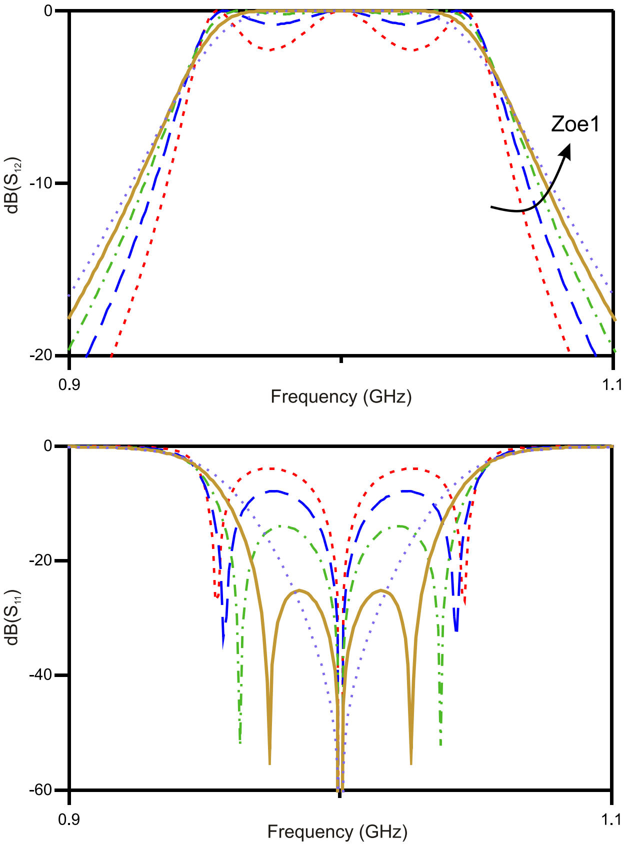

Fig. 5. Variation of electrical responses when Z_{oe1} is varies, with range of values from 45Ω to 65Ω.

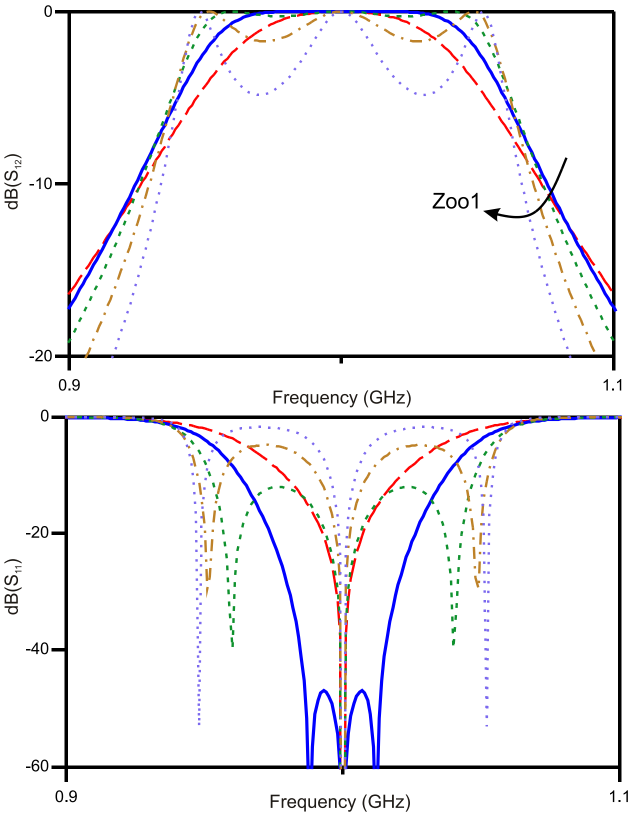

Fig. 6. Variation of electrical responses when Z_{oo1} is varies, with range of values from 20Ω to 40Ω.

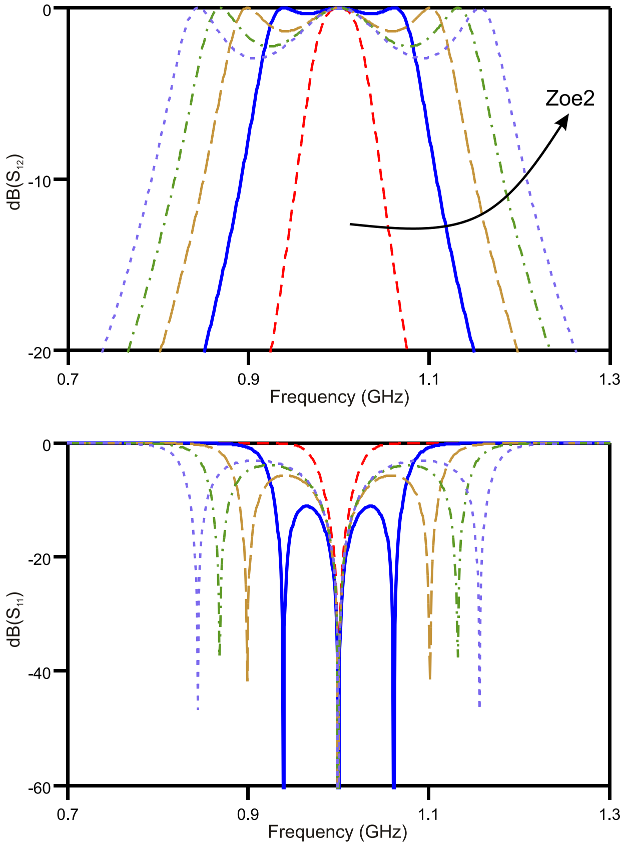

Fig. 7. Variation of electrical reponses when Z_{oe2} is varies, with range of values from 45Ω to 85Ω.

Fig. 6 shows the variation of Z_{oo1} from 20Ω to 40Ω while fixing other parameters at Z_{oe1}=61Ω, Z_{oe2}=49Ω and Z_{oo2}=39Ω. It can be seen that Z_{oo1} influences bandwidth, insertion loss and return loss too. Lower value of Z_{oo1} resulted to tight coupling effect causing minimum variation of bandwidth. Based on this observation, it can be anticipated that with suitable value of both parameters Z_{oe1} and Z_{oo1}, will achieve good impedance matching with minimal effect on filter bandwidth.

Next, observation is performed on Z_{oe2} and Z_{oo2} of the 2nd set of coupled-line. Variation of electrical responses for both parameters are shown in Fig. 7 and 8 respectively. The parameters are varies according to Table 1. It can be seen that, both parameters greatly controlled the bandwidth of the filter. The increment of Z_{oe2} or decrement of Z_{oo2} increased the bandwidth but at the same time degrade the return and insertion losses due to mismatched of impedances. Hence, desired FBW can be achieved by optimizing both Z_{oe2} and Z_{oo2} values. Based on this characteristic, one can say that this topology is suitable for narrow bandwidth bandpass filter application.

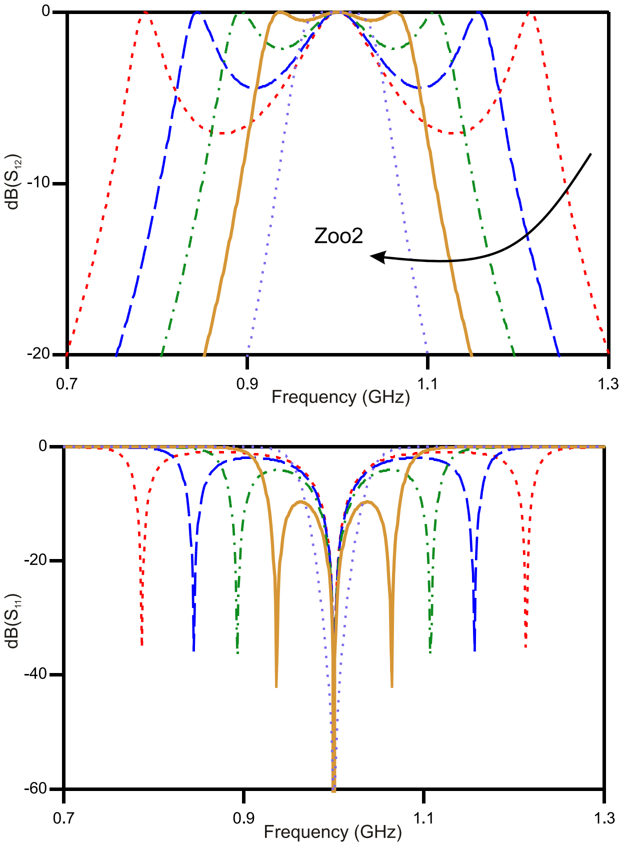

Fig. 8. Variation of electrical responses when Z_{oo2} is varies, with range of values from 20Ω to 40Ω.

IV. 3RD ORDER FILTER REALIZATION

The 3rd order bandpass filter with four-fingers layout arrangement is simulated on microstrip technology, Roger RO3210 substrate (h = 1.27 mm, ε_r = 10.2, tan δ = $3\text{x}10^{-3}$. The layout of the filter is depicted in Fig.9, with area dimensions of 64.3 mm x 49.1 mm. Next, the filter size is reduced by meandering the coupled-lines. As shown in Fig. 10, the meandered design achieved overall size reduction approximately by 43% with dimensions of 44.4 mm x 40.5 mm. Both designs are simulated and the results are compared as shown in Fig. 11. The results show a good out-of-band rejection level beyond 40 dB while the cross-coupling between the adjacent couple-lines in four-fingers arrangement has created a transmission zero on the lower-side of passband within range of 800-825 MHz. There are no major defect on simulation results between meandered-lines and straight-lines filter designs.

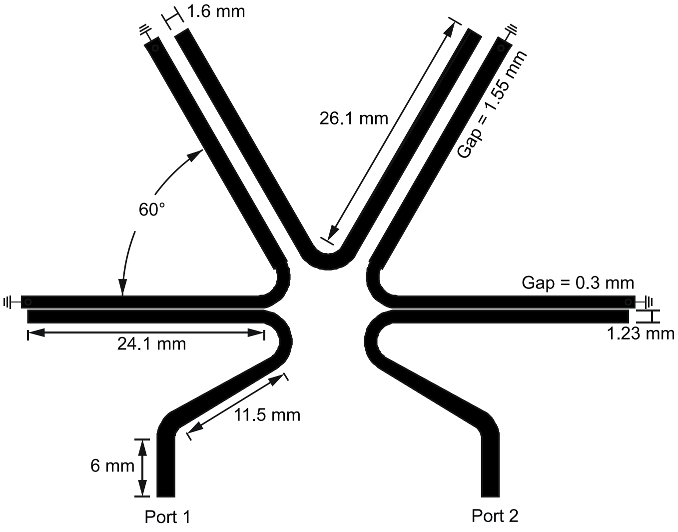

Fig. 9. Schematic layout 3rd order four-fingers straight-lines bandpass filter

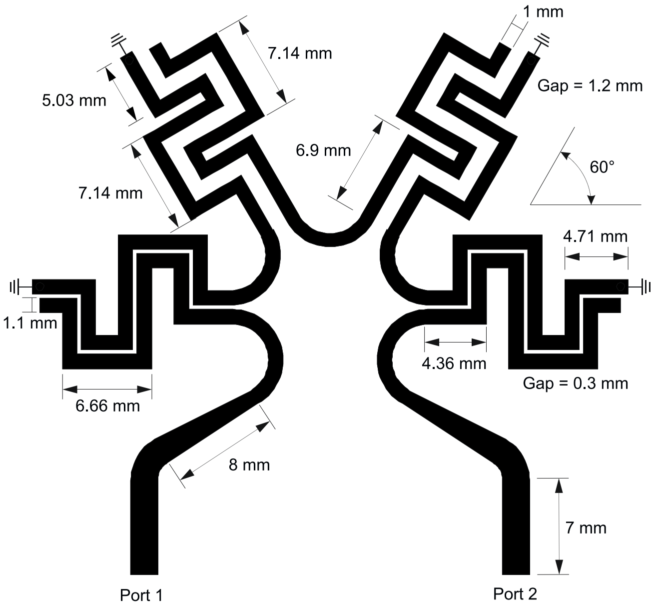

Fig. 10. Schematic layout of 3rd order meandered-lines bandpass filter

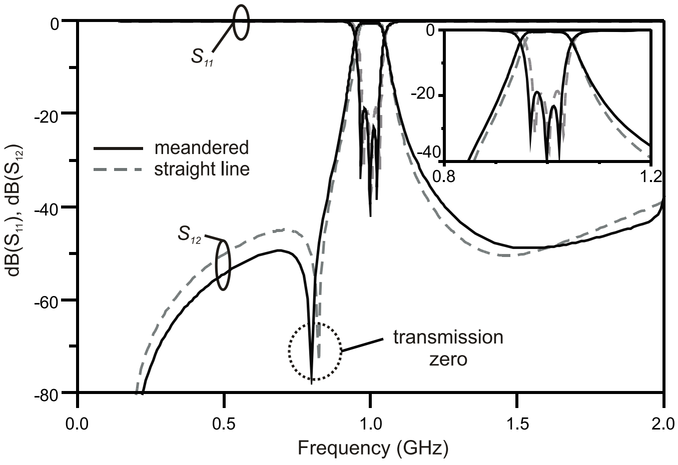

Fig. 11. Comparison output of simulation for straight-lines and meandered-lines filter designs

For validation, a prototype of 3rd order filter with meandered-lines was realised on microstrip substrate, Roger RO3210 substrate, designed at 1 GHz. The characteristics of the substrate are h = 1.27 mm, $\varepsilon_r = 10.2$, tan $\delta = 3\text{x}10^{-3}$. The photograph of the meandered-lines filter is shown in Fig. 12 and the comparison output of simulation and measurement results is depicted in Fig. 13.

Fig. 12. Photograph of the 3rd order meandered lines bandpass filter.

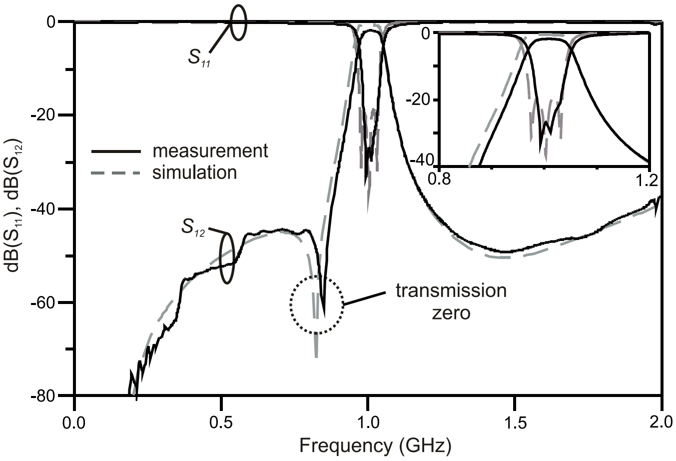

Fig. 13. Comparison output of simulation and measurement result of the 3rd order meandered-lines bandpass filter.

As can be seen in Fig. 13, the results are in good agreement, with insertion loss at 1.83 dB and return loss attenuated more than 20 dB. A transmission zero located at the lower-side of the passband is found at 0.85 GHz. The measured 3 dB bandwidth is from 0.979 GHz to 1.042 GHz, representing a FBW of 6.3%.

Finally, the performance of the proposed resonator is compared with previous works using coupled-lines as tabulated in Table 1. In terms of high selectivity, the proposed resonator exhibits a transmission zero at the lower sideband which is an advantage as compared to the topologies in [12]–[14]. Furthermore, the bandwidth of the filter is narrow and therefore it is suitable for narrow bandwidth bandpass filter applications. Adding to this, the shorted coupled-lines which are arranged side-by-side in 180° layout, has achieve the overall electrical length of ½ λ. Therefore, the overall size of the proposed resonator is smaller compared to the size of the parallel coupled-lines arrangement that has 3½ λ [15]. In fact, the size of the proposed resonator is further reduced by 43% from it's original size by using meandered technique.

TABLE I
Comparison with Other Related Works

Ref.	Transmission Zero	Bandwidth
[12]	No	10%
[13]	No	15%
[14]	No	50%
This work	Yes	6.3%

V. CONCLUSION

A topology of inter-connected two shorted coupled-line resonator as a base cell was presented. Based on this topology, a 3rd order bandpass filter was constructed. The 3rd order filter was designed on planar technology and the response showed single transmission zero for high selectivity with narrow bandwidth. Controlling parameters of the 3rd order resonator were investigated and it was found that the characteristics of the resonator can be controlled in terms of insertion and return losses by varying all the impedances of the coupled-line sections while the bandwidth was greatly controlled by the impedances of the second coupled-line. Meander technique was applied to the 3rd order filter and had successfully reduced the size by more than 40%, while the responses of the filter maintained the same. This included the position of transmission zero which was found at the lower side of the passband. Finally, the prototype of the 3rd order filter with meander-lines was realized using microstrip technology for validation. It was found that, the measurement results of the fabricated filters were in good agreement with the simulation results with FBW of 6.3%. Based on the results, the new 3rd order bandpass filter with meandered-lines maybe found to be suitable for narrowband bandpass filter applications besides enriched the filter banks.

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