

Two Parallel-coupled Rings for Narrow Bandpass Filter Application

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Abstract— A 2nd order bandpass filter topology is presented. It employs two single mode ring resonators that coupled via a quarter-wavelength coupled-line to exhibit a pseudo-elliptic bandpass response. The advantage of the topology is that, having only one coupled-line in the structure has reduced the complexity of the circuit to obtain a narrowband response of less than 9% with high rejection level. Prototypes filters were realized to validate the concept using microstrip technology. It was proven that the measurement results had shown good agreement with those from the simulation.

Index Terms— Bandpass filter; Single mode ring resonators; Microstrip; Narrowband.

I. INTRODUCTION

Compact size bandpass filter with narrow bandwidth has been very significant in microwave communication systems for decades. These filtering features were favourable for spectral efficiency applications that imposed high performance, low insertion loss with sharp and high selectivity response. In addition to this, low cost, simple design and easy to manufacture may add more value to the construction of filters [1], [2], [3]. Most commonly structures based on quarter-wavelength resonators have been previously reported. Amongst this, the widely popular conventional parallel quarter-wavelength coupled-lines topology has received a lot of interest. Based on the quarter-wavelength coupled-lines, a resonator can be achieved by coupling two quarter-wavelength coupled-lines to give a half-wavelength resonator. However, this topology was subjected to large size and was normally increased with the order of filter; and the structures normally has poor rejection skirt due to coupling effect [4], [5], [6]. Furthermore, narrow bandwidth and high selectivity required larger coupling gaps between the coupled resonators and this may also increase the filter size [8], [9], [10], [11], [12]. The problem becomes more significant when dealing with topologies having too many coupling lines; the tuning process becomes tedious and more difficult to be realised [4], [7], [8], [13], [14], [15], [16].

Ring-based bandpass filter topology is well-known for its compactness and pseudo-elliptic bandpass response. To generate the dual resonance, most of the ring resonator topologies require coupling points and perturbation elements in the designs [4], [5], [6], [7], [8]. Work reported by Z. I. Khan *et.al.*, had introduced a ring resonator using quarter

wavelength coupled lines[11]. In this topology, the ring impedances need to be identical in terms of physical length, at such limit the freedom of control of the resonator. And the rigidity of the design is more significant when multiple rings need to be used to form higher order filters. It was found that the ring is difficult to control to achieve desired frequency response. Therefore, a simple resonator using ring topology was proposed as a base cell to form higher order filters [17]. This resonator is simple to control in obtaining higher order filters when multiple rings are introduced. This work had presented higher-order filter designs which were mainly in the range of 15% to 30% fractional bandwidth. The 2nd order filter designs of the work had reported the narrowest achievable fractional bandwidth of 18.93%. Therefore, using this concept in [17], a new coupling scheme of 2nd order filter is proposed to achieve fractional bandwidth of less than 9%. By coupling two single mode ring resonators via a quarter wavelength coupled-line, one may adjust the coupling gap between the two rings so that a narrow bandwidth may be realised. The proposed structure having only one coupled-line has reduced the complexity of the circuit to obtain the bandpass response. In terms of performance, the arrangement of the two ring resonators positioned at 180° to each other has reduced the radiation loss and improved the spurious effect. As a result, the position of higher stopband frequency can be easily obtained as predicted by its ideal circuit.

Investigations were performed on this new topology to analyse the characteristics of the controlled elements. In this context, a total of two bandpass filters were realized, designed at 2.0 GHz using microstrip technology to demonstrate the concept. The measurement and simulation results were then compared to validate the works.

II. DESIGN PROCEDURE OF TWO PARALLEL-COUPLED RINGS FILTER

In this section, a newly proposed single mode ring resonator in [17] is used as the base cell to form 2nd order filter. As shown is Figure 1, the ring was designed based on quarter-wavelength line impedance, Z_r placed at 90° each to give a total of three quarter-wavelength line impedance and a quarter-wavelength coupled-line with even- and odd-mode impedances of Z_{oe} and Z_{oo} respectively, forming a one-wavelength ring at a given center frequency f_o .

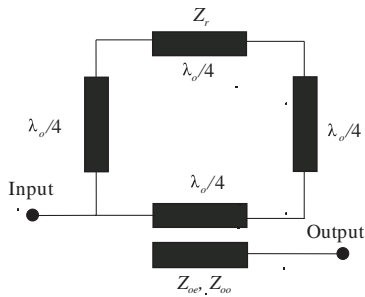


Figure 1: Topology of a single mode ring resonator with a $\lambda/4$ wavelength coupled-line, designed at f_o .

With a set of chosen values of the impedances given by: $Z_r = 90 \Omega$, $Z_{oe} = 70 \Omega$ and $Z_{oo} = 35 \Omega$ at center frequency $f_o = 1$ GHz, the ring resonator is simulated using EM fullwave simulator to observe the electrical response. As can be seen in Figure 2, the ideal response of the ring resonator had produced a single resonant frequency, f_o with two transmission zeros were found at both sides of the passband.

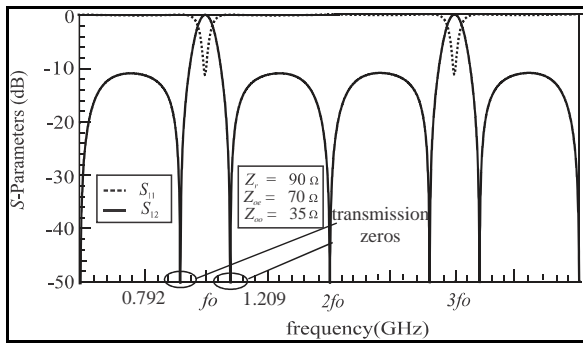


Figure 2: Ideal response of a single mode ring resonator

Based on this concept, the single mode ring is arranged in such a way that two rings are coupled in parallel with its quarter-wavelength coupled-line to give a total ring perimeter of one-and-a-half-wavelength as illustrated in Figure 3.

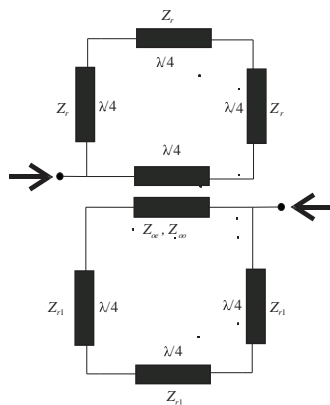


Figure 3: Ideal circuit of 2nd order bandpass filter using two parallel-coupled rings topology

This new 2nd order filter can be obtained by following several steps as follow:

Step 1: Identify the required filter specifications such as center frequency, f_o and position of transmission zero, f_{tz} .
 Step 2: Set even-mode impedance, Z_{oe} to the highest possible value that can be realised.

Step 3: Choose odd-mode impedance, Z_{oo} to give sufficient coupling effect to realize the bandpass response.

Step 4: Based on the given specifications, tune the ring impedances, Z_r and Z_{r1} accordingly to obtain the desired f_o for f_{tz} .

Following to this design procedure, a set of impedances were chosen as shown in Table 1 for filter designed at $f_o = 2.0$ GHz.

Table 1
 Impedances of the 2nd order filter for two parallel-coupled rings

| Impedances | Value |
|---|--------------|
| Even-mode impedance of the coupled-line, Z_{oe} | 113 Ω |
| Odd-mode impedance of the coupled-line Z_{oo} | 75 Ω |
| Impedance of the first ring, Z_r | 162 Ω |
| Impedance of the second ring, Z_{r1} | 56 Ω |

The circuit was simulated using fullwave EM simulator to depict a pseudo-elliptic 2nd order bandpass filter frequency response with two poles in the passband region and two transmission zeros at the stopbands as depicted in Figure 4.

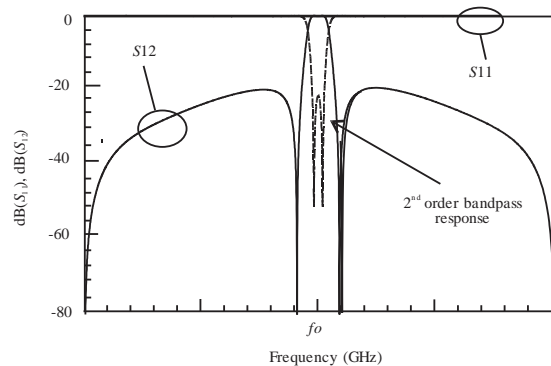



Figure 4: 2nd order bandpass filter simulated ideal response of the two parallel-coupled rings topology

As seen here, two poles in the passband were resonating at 1.960 GHz and 2.039 GHz to exhibit a separation of 79 MHz. Two transmission zeros frequencies were found to be very close to the cut-off frequencies, which are 1.818 GHz at the lower-side stopband and 2.182 GHz at the upper-side stopband to give a narrow passband bandwidth of 0.364 GHz. The cut-off frequencies of the passband occurred at 1.913 GHz and 2.089 GHz result to the fractional bandwidth of 8.80 % which made the response very sharp and selective. The simulated response of the 2nd order filter are summarized in Table 2 for location of poles, transmission zeros frequencies, bandwidth and fractional bandwidth.

Table 2
Simulated ideal response of the two parallel-coupled rings, designed at $f_0 = 2.0$ GHz

| | |
|--|---|
| Topology |  |
| Resonant frequency (GHz); f_1, f_2 | 1.960, 2.039 |
| Frequency separation (GHz) | 0.079 |
| Transmission zeros (GHz); f_{tz1}, f_{tz2} | 1.818, 2.182 |
| Bandwidth (GHz) | 0.364 |
| Fractional Bandwidth; $FBW = \frac{f_{tz2} - f_{tz1}}{f_0}$ | 8.80 % |

III. CHARACTERISTIC OF THE TWO PARALLEL-COUPLED RINGS TOPOLOGY

At this stage, the characteristic of the two parallel-coupled rings topology was investigated to analyse the influence of the controlling parameters on the frequency response. As shown in Figure 5(a) to 5(c), the graphs illustrate the variation of simulated frequency responses according to the variation values of impedance Z_r of the first ring, impedance Z_{r1} of the second ring and coupling coefficient, k of the quarter-wavelength coupled-line.

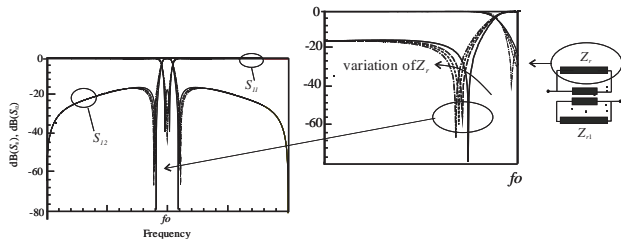


Figure 5(a): Simulated frequency response, designed at 2 GHz for impedance Z_r varies from 162 Ω to 200 Ω

In Figure 5(a), the 1st ring impedance, Z_r is varied from 162 Ω to 200 Ω while the second ring, Z_{r1} is fixed at 56 Ω , $Z_{oe} = 113 \Omega$ and $Z_{oo} = 75 \Omega$ respectively. It can be noted that the variation of the 1st ring impedance influenced the magnitude of the in-band, out-of-band and the position of transmission zero.

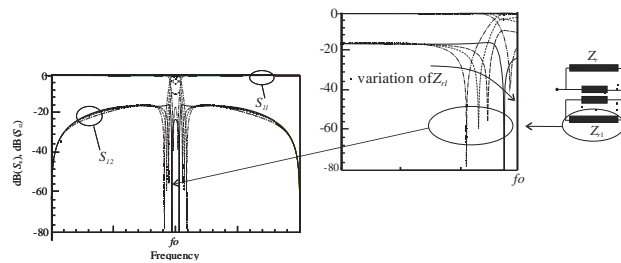


Figure 5(b): Simulated frequency response, designed at 2 GHz for impedance Z_{r1} varies from 56 Ω to 96 Ω

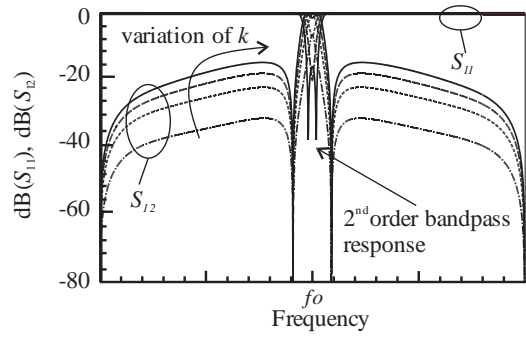


Figure 5(c): Simulated frequency response, designed at 2 GHz for coupling coefficient, k of the coupled-line varies from 0.03 to 0.20

Next, the 2nd Z_{r1} is varied from 56 Ω to 96 Ω , while the 1st ring impedance, Z_r is fixed at 162 Ω , $Z_{oe} = 113 \Omega$ and $Z_{oo} = 75 \Omega$ respectively. As seen in Figure 5(b), the 2nd ring impedance also influenced the magnitudes of the in-band, out-of-band and the transmission zeros. Next, the effect of coupling coefficient, k , of the coupled-line was investigated. In this case, the coefficient, k , was varied and simulated. As shown in Figure 5(c), with variation of coefficient k from 0.03 to 0.20, while the 1st ring impedance, Z_r and 2nd ring impedance, Z_{r1} were fixed at 162 Ω and 56 Ω respectively, the position of transmission zeros was not affected. The coupling coefficient, k , of the quarter-wavelength coupled-line actually has the influence on the magnitude of in-band and out-of-band performances.

IV. IMPLEMENTATION OF 2ND ORDER PARALLEL COUPLED RINGS FILTER

In this section, the proposed two parallel-coupled rings filter was implemented to demonstrate the concept of microstrip substrates. The proposed concept was materialized by using two different type of tangential loss substrates, which were given by 2×10^{-2} and 3.5×10^{-3} . The filters were designed at center frequency of 2 GHz, simulated and measured to observe the performance and validate the concept.

A. Filter implementation of 2nd order parallel-coupled rings filter

In this section, the 2nd order of the two parallel-coupled rings filter was realized on FR-4 substrate with characteristic given as follows; $\epsilon_r = 4.1$, $h = 1.6$ mm and $\tan \delta = 2 \times 10^{-2}$. The overall layout with dimensions and the fabricated photo of this resonator are depicted in Figure 6 to demonstrate the work. The simulated and measured frequency responses of the 2nd order bandpass filter are depicted in Figure 7. Measured results had shown that the two resonance frequencies were found at 2.115 GHz and 2.193 GHz while center frequency positioned at 2.154 GHz. Meanwhile, two transmission zeros were found at lower stop-band, 1.956 GHz and upper stopband, 2.273 GHz attenuate above 25 dB which gives a passband bandwidth of 317 MHz. The fractional bandwidth of this filter is 5.48 %. An additional of transmission zero on the higher rejection band was found to give extra stop band at the rejection band. Unfortunately, the circuit exhibits high

insertion loss due to high tangential loss of the substrate and this can be improved by using a low loss tangential loss substrate.

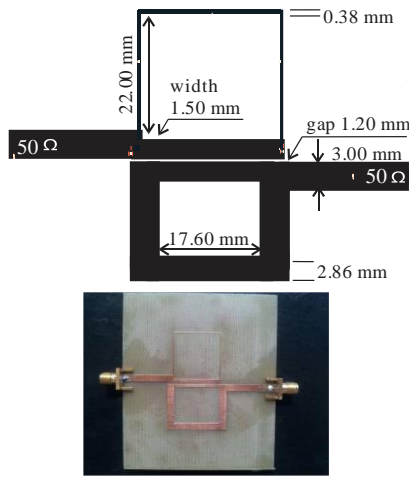


Figure 6: Layout and photo of the fabricated filter using FR-4 microstrip substrate

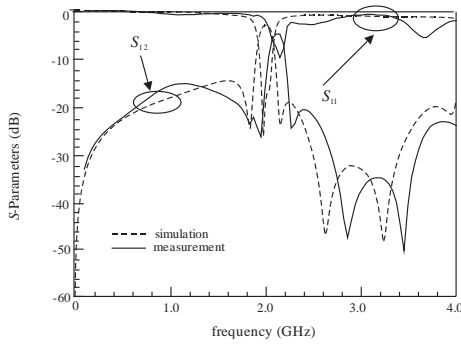


Figure 7: Simulated and measured response on FR-4

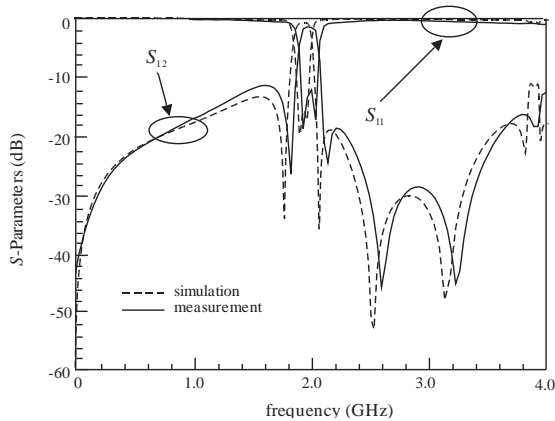


Figure 8: Simulated, measured responses and photo of fabricated filter using Taconic microstrip substrate

Next, the filter was implemented on Taconic with characteristics given by: $\epsilon_r = 4.5$, $h = 1.63$ mm and $\tan \delta = 3.5 \times 10^{-3}$. The filter was simulated and measured and the performance is illustrated in Figure 8. From the measurement, two resonance frequencies were found at 1.945 GHz and 2.050 GHz while center frequency was positioned at 1.998 GHz giving a fractional bandwidth of 8.76 %. Meanwhile, two transmission zeros were found at the lower stop-band; 1.840 GHz and 2.155 GHz at the upper stopband. The rejection level at the stopbands has improved tremendously, which exceeded 24dB while the insertion and return loss were found at 1.55dB and 13.65dB respectively.

Finally, the measurement results of 2nd order filters are compared with the initial 2nd order filter in [17] and the responses are summarised in Table 3. It can be concluded that the new filter had shown great reduction in terms of fractional bandwidth and great improvement of rejection level at $1.5f_o$.

Table 3
Comparison of the 2nd order bandpass filters measured performance

| | Ref [17] | This Work | |
|-----------------------------------|--|--|--|
| Microstrip substrate | FR-4 | FR-4 | Taconic |
| Transmission zeros frequency(GHz) | $f_{tzl} = 1.779$ $f_{trh} = 2.798$ | $f_{tzl} = 1.956$ $f_{trh} = 2.273$ | $f_{tzl} = 1.840$ $f_{trh} = 2.155$ |
| Passband bandwidth (GHz) | 1.019 | 0.317 | 0.315 |
| Fractional BW (%) | 18.93 | 5.48 | 8.76 |
| Attenuation at $1.5f_o$ (dB) | 26.95 | 39.02 | 30.15 |

V. CONCLUSIONS

In this paper, a 2nd order bandpass filter topology was proposed, showing an advantage of having a response suitable for narrowband applications. This topology was proposed as another option for the 2nd order filter in [17]. This structure comprised of two single mode rings, coupled via a quarter-wavelength coupled-line. The ring impedances of the two rings were non identical in order to allow flexibility of the design. Investigation of the filter's characteristic was carried out. It was found that the transmission zeros at the stopbands can be controlled by varying the ring impedances of the filter i.e. Z_r , Z_{r1} and the coupling gap leading to the possibility to control the bandwidth of the filter. The prototypes of the filters were realized using microstrip technology and measurement results had shown good agreement with the simulation. The filters demonstrated sharp rejection skirts, stopband attenuation levels above 24dB with improved spurious response. More specifically, it was found that the fractional bandwidth were less than 9% and transmission zeros greater than 24dB for high selectivity. In view of the experimental results, this new arrangement scheme realized a filter not only with narrow bandwidth and sharp skirt but also compact size, high selectivity and simple design using a low cost technology which is suitable for advance microwave communication applications that require high spectral efficiency applications.

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