Coupled Ring Resonator for Dual Band Bandpass Filters

Muhamad Nur Fitry b Ab Jalil

Faculty of Electrical Engineering
Universiti Teknologi MARA Malaysia
40450 Shah Alam, Selangor, Malaysia
e-mail: fitry365@gmail.com

Abstract— This paper describes the design, simulation and analysis of a coupled ring resonator for dual bandpass filter for wireless application. The operating frequencies are 5 GHz and 8.25 GHz. Single bandpass approach was used in designing the filter and the simulation was carried out using CAD simulation software. The performance of the filter was simulated based on FR4 with dielectric substrate (εr) is 5.4 with substrate thickness of 1.6mm The filter was then fabricated and measurements were made using VNA. The measurement results show good agreement with the filter specifications.

Keywords- microstrip, dual bandpass filters, couple ring resonator, CAD simulation software.

I. INTRODUCTION

The wireless era start by two European scientists James Clerk Maxwell and Heinrich Rudolf Hertz leaves an enormous impact for a modern society. From commercial, to civil and military radar systems the applications of microwaves system is extremely crucial. In the field of communications, filter acts as an important function to specific frequencies that approved to pass with a little attenuation while the useless frequencies are attenuated. Microwave and RF filters are widely used in all these systems in order to discriminate between wanted and unwanted signal frequencies [7].

In the modern era, the increasing demand for wireless communication applications requires RF components to operate in multiple separated frequency bands in order to access different services with a single multimode terminal. In order to accommodate this multi-band RF signal reception and transmission into a single RF transceiver, a dual-band or multi-band RF front-end circuit is required[3].

A. Couple Ring Resonator

Microstrip ring resonators appear to offer attractive features such as compactness, dual response capability, and transmission zeroes in the frequency response. They found applications involving resonant structures at microwave and millimeter-wave frequency such as filters, measurement of dielectric constant, dispersion, and phase velocity [1].
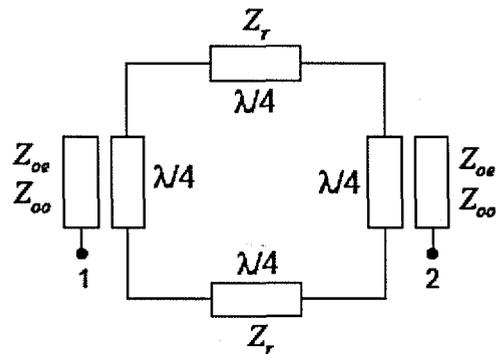

Figure 1. Couple Ring Resonator [1]

The resonator consists of a closed ring with a circumference equals the wavelength at the center frequency, and coupled by quarter wavelength lines as shown in Fig. 1. Z_{oe}, Z_{oo}, and Z_r are the even- and odd mode impedance of the coupled lines, and the line impedance of the ring, respectively. The global synthesis of the resonator was developed previously in [1] where the required impedances to achieve the desired specifications of the resonator [2].

B. Microstrip

Microstrip line is the most commonly used microwaves integrated circuit (MIC) transmission line. It has many advantages such as low cost, small size, absences of critical matching and cutoff frequency, ease of active device integration, ease of mass production, and compatibility with monolithic circuits [7].

Compared to the rectangular waveguide and coaxial line circuits, microstrip lines disadvantages include higher loss, lower power handling capability, and greater temperature instability [7]. The microstrip used in this project is FR4 with dielectric constant equal to 5.4 and thickness of 1.6mm.

II. SCOPE OF WORKS

The work was limited to a coupled ring dual band-pass filter using CAD commercial simulation software. The filter was designed based on the following specification:

TABLE 1. FILTER SPECIFICATION

Specification	Number of Band	
	First	Second
Centre frequency (f_c)	5.00GHz	8.2500GHz
High cutoff frequency (f_h)	5.25GHz	8.6625GHz
Low cutoff frequency (f_l)	4.75GHz	7.8375GHz
Bandwidth	500MHz	825MHz
Return Loss (S_{11})	More than 15dB	
Insertion Loss (S_{12})	Not exceed -3dB	

III. METHODOLOGY

Simulation on the effect of the substrate was also carried out to determine the effect of the physical shape and performance of the filter.

Fig. 2 shows the flowchart of the project. There are three main processes which are design, simulation and fabrication. Literature review was done to obtain information of coupled ring bandpass filter. CAD is used to design, simulate and evaluate the response of the band-pass filter at 5GHz and 8.25 GHz cut off frequency.

The design of a filter usually starts with a set of parameters that will satisfy the requirements of an application. These steps are call specification. Table 2 shows the specification of FR4 substrate used in the project.

TABLE 2. FR4 SUBSTRATE PROPERTIES

MICROSTRIP PROPERTIES	
Dielectric constant, ε	5.4
Permittivity	1
Height	1.6mm
Loss tangent	0
Roughness	0mm
Operating Frequency (GHz)	5& 8.25

A. Single Bandpass Couple Ring Resonator

The design start by converting the couple ring resonator circuit for single bandpass filter to dual bandpass. For single bandpass, the parameters involved in controlling the response of the ring are the characteristic impedance of the ring (Z_r), even-mode characteristic impedances (Z_{oe1} and Z_{oe2}), and odd-mode characteristic impedances (Z_{oo1} and Z_{oo2}) of the coupled lines[1]. Fig. 3 show the circuit diagram for couple ring bandpass filter using CAD software.
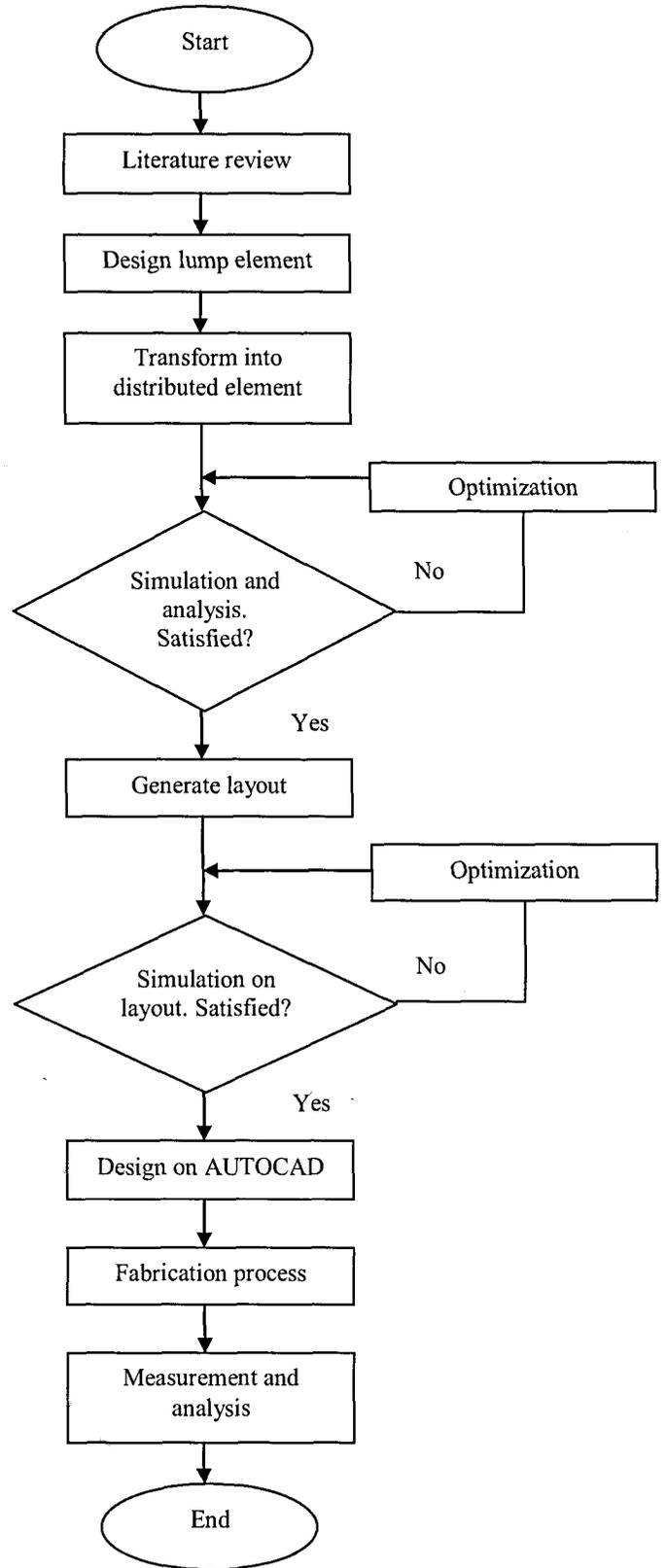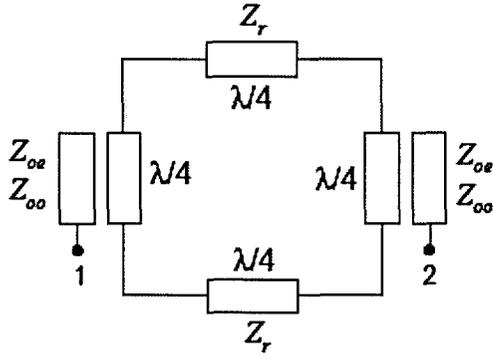

Figure 2. Flowchart Design

Figure 3. Circuit diagram ring resonator with identical coupled lines

1) *General Synthesis Formula*: First, assume that the coupled lines are identical, i.e $Z_{oe1} = Z_{oe2} = Z_{oe}$ and $Z_{oo1} = Z_{oo2} = Z_{oo}$.These formulas are the general synthesis formula for the ring resonator circuit [1]

$$Y_{oe} = \frac{1}{Z_{oe}} \tag{1}$$

$$Z_{oo} = \frac{1}{Y_{oo}} \tag{2}$$

$$r_f = 0.875 \tag{3}$$

$$y = 0.066 \tag{4}$$

$$Z_o = 50 \tag{5}$$

2) *Transmission Zeros Frequency*: Control the following formula shows the equation of frequency f_{tz} of lower transmission zero [1]

$$\theta = \frac{\pi f_{tz}}{2 f_0} \tag{6}$$

$r_f$ratio (<1) between the first transmission zero frequency and the center frequency [1]

$$f_{tz} = r_f \times f_0 \tag{7}$$

y passband ripple (in decibels) with [1]

$$x = 10^{\frac{-y}{20}} \tag{8}$$

3) *Passband Ripple Control*: the only parameters that control the resonator electrical response are Z_r and Y_{oe}. The central frequency and transmission zeros frequencies can be fixed while varying Z_r and Y_{oe} [1].

$$Z_r = \frac{2T_Z x + T_Z^2 Y_{oe} Z_0 + Y_{oe}(-Z_0 + S_Q) - x\sqrt{\frac{P+Q+R}{Y_{oe}x^2}}}{2xY_{oe}} \tag{9}$$

where

$$P = 4xZ_0 T_Z^3 - Y_{oe}Z_0^2 T_Z^4 (x^2 - 2) + 4T_Z x (S_Q - Z_0) \tag{10}$$

$$Q = 2T_Z^2 Y_{oe} - Z_0(Z_0(x^2 - 2) + S_Q) \tag{11}$$

$$R = -Y_{oe}Z_0(Z_0(x^2 - 2) = 2S_Q) \tag{12}$$

$$S_Q = \sqrt{(1 - x^2)(T_Z^2 - 1)^2 Z_0^2} \tag{13}$$

$$T_Z = \frac{\sin\left(\frac{\pi f_{tz}}{2f_0}\right)^2}{1 + \cos\left(\frac{\pi f_{tz}}{2f_0}\right)^2} \tag{14}$$

$$Y_{oo} = \frac{T_Z Y_{oe}}{Z_r\left(2Y_{oe} - \frac{T_Z}{Z_r}\right)} \tag{15}$$

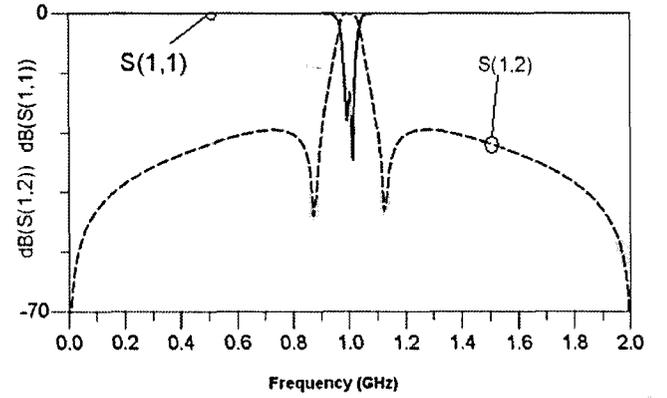By solving all the previous formulas listed, we can develop the frequency response of the circuit.

Figure 4. Frequency response of the ring resonator at cut off frequency of 1 GHz

B. *Dual Bandpass Couple ring Resonator*

Based on the single band circuit diagram, we can produce the dual band by mirroring the circuit. Fig. 4 shows the frequency response of the dual band ring resonator at cut off frequency of 5 GHz and 8.25 GHz for $Z_r = 112\Omega$, $Z_{oe1} = 90\,\Omega, Z_{oe2} = 46\,\Omega, Z_{oo1} = 39\,\Omega$ and $Z_{oo2} = 34\,\Omega$. The cut off frequency is at 6.625 GHz and it is simply can be obtained at the middle of two bandpass operating frequency.
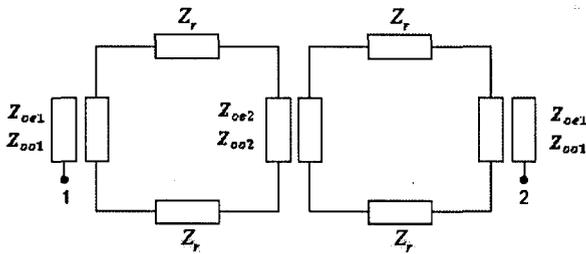
Figure 5. Circuit diagram of couple ring dual bandpass filter

The next step is developing the frequency response of S_{11} and S_{12}. By using *CAD*, the frequency response for the dual band ring resonator shown in Fig. 5.

f1=5.0GHz
S(1,1)=30.747
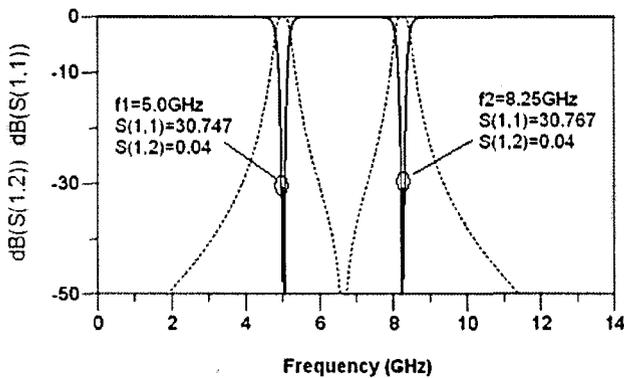S(1,2)=0.04

f2=8.25GHz
S(1,1)=30.767
S(1,2)=0.04

Figure 6. Frequency response of couple ring dual bandpass filter.

From the lump element, the circuit is transform into distributed element by calculating all the values of the width and length of all the elements. This calculation is done by the *CAD* simulation software.

TABLE 3. WIDTH AND LENGTH OF ELEMENTS

Elements	Width (μm)	Length (μm)
Z_r	304	5798.353
Z_{c1}	1332.75	5574.448
Z_{c2}	2001.907	5574.448
Z_o	2759.51	4828.24

From Fig. 7, we can see that the couple ring has a gap between odd and even element. For the Z_{c1} the gap is 235 μm and label as S_1 and for the gap of Z_{c2} is 1039.7 μm and label as S_2.
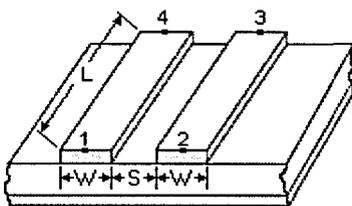

Figure 7. Microstrip structure for couple lines

The filter is then simulated and it is being optimized to achieve the best response. The layout of the filter is illustrated in Fig. 8 with dimension (in mm) using *AutoCAD* software.
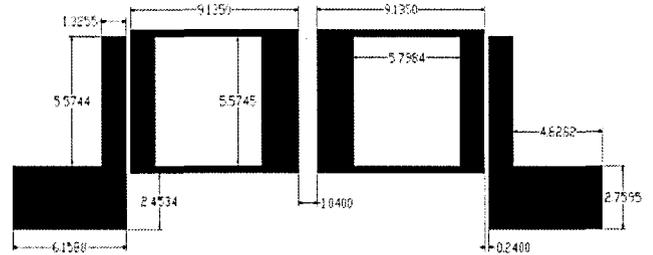

Figure 8. Couple ring bandpass filter physical layout

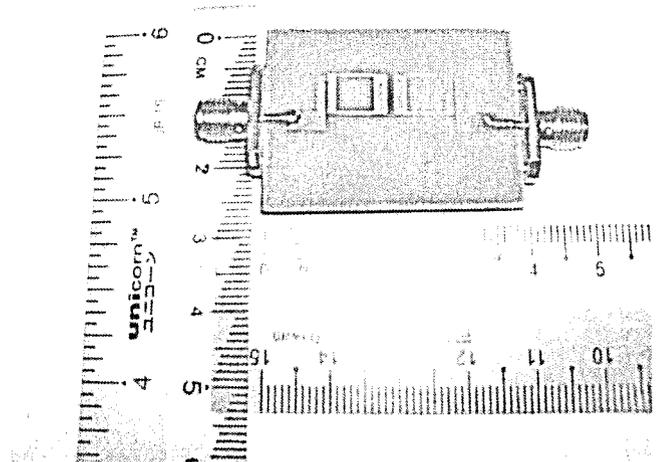The final dimension of the filter layout and the fabricated filter is shown in Fig.9

Figure 9. Fabricated filter with physical dimension

IV. RESULT AND DISCUSSION

From Fig 10, it can be observed that for final simulation on layout, the insertion loss (S_{12}) of the second band does not meet the design specification.

This error is unavoidable since it is difficult to optimize while meeting all the desired specifications. However, the percentage relative error is very small which only 8.43% and still can be accepted.

After fabrication process, the filter is measured using ZTR40 Vector Network Analyzer (VNA). The comparison results between measurement and simulation for insertion loss and return loss were shown in Figure 11.
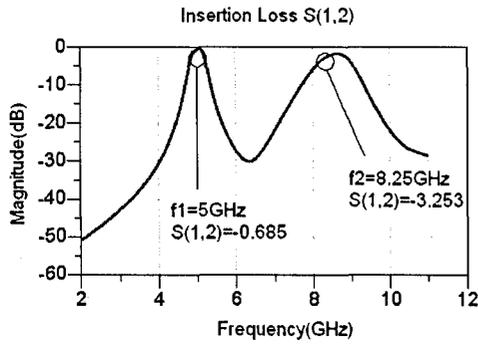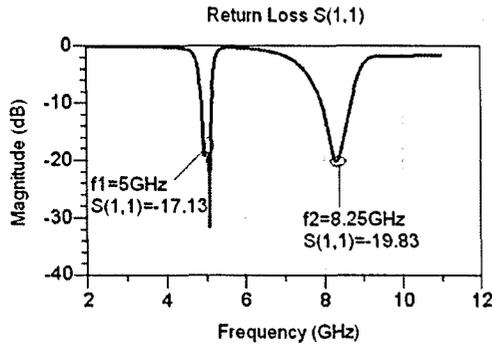
Figure 10. Simulation of insertion loss

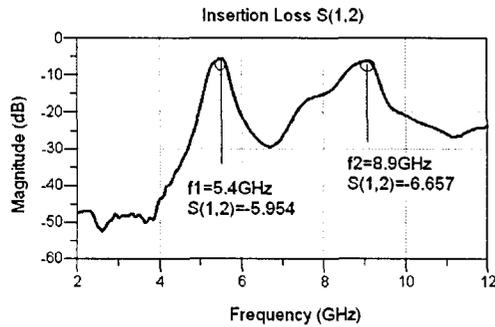Figure 11. Simulation of return loss

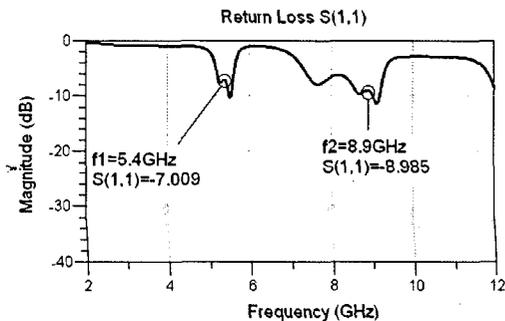

Figure 12. Measurement of Insertion Loss

Figure 13. Measurement of Return Loss

Table 4 shows the results of the simulation and measurement. It can be observed that there are variances when compared between both the simulated and measurement. These are due to the following factors:

- While doing simulation, the thickness of the length and width do not take into consideration. However the limit for fabrication process is only 150µm.

- The losses due to the connector are not considered while making simulation.

- The etching process that too long contribute to losses especially to the element that close to the minimum limit of fabrication.

- The substrate is poor quality and lossy resulting differences between measurement and simulation result.

TABLE 2. COMPARISON OF SIMULATION AND MEASUREMENT RESULT

Parameters	Simulation		Measurement	
	first	second	first	second
Centre frequency	5.00GHz	8.2500GHz	5.4GHz	8.9GHz
Return Loss (S_{11})	-17.133dB	-19.830dB	-7.09dB	-8.985
Insertion Loss (S_{12})	-0.685dB	-3.253dB	-5.954	-6.567
Bandwidth (MHz)	500	600	-	-

V. CONCLUSION

This paper has presented the design and development of the coupled ring resonator for dual band-pass filter for wireless application. The operating frequencies are 5 GHz and 8.25 GHz. The design procedures are also presented in this paper. Objectives to design and measure the characteristics were achieved in this project. By using the CAD simulation, the results obtained had met the design specifications. However, the performance of the fabricated filter does not meet the specifications. These can be further improved if the fabrication process is performed in the laboratory and the dielectric of the substrate can be verified before etching process to ensure the quality of the finished product.

VI. FUTURE RECOMMENDATION

The results can be improved in future in many ways. Firstly, is to use different substrate that has different microstrip properties. Secondly, to further study and analyse on how to achieve narrow bandwidth for the dualband bandpass filter. Generally, the design of a filter seeks to make the roll-off as narrow as possible, thus allowing the filter to perform as close as possible to its intended design Finally, to further study and analyze the effect to the filter response when the even and odd mode (Z_{oe} and Z_{oo}) are varies.

REFERENCES

[1]   M.K. Mohd Salleh, G. Prigent, O. Pigaglio, and R. Crampagne,"Quarter-Wavelength Side-Coupled Ring Resonator for Bandpass Filters" *Microwave Theory and Techniques, IEEE Transactions on*, vol. 56, pp. 156-162, 2008.

[2]   Z. Ismail Khan, M.K Mohd Salleh "Achievable Bandwidyh of a Quarter Wavelength Side-Coupled Ring Rconator" Symposium on Industrial Electronics and Applicatios (ISIEA), 2009

[3]   Sheng-Fuh Chang, Yng-Huey Jeng, and Jia Liang Chen, "Dual – band Step Impedance Bandpass Folter for Multimode Wireless LANs" *Electronics Letter*, vol. 40, No. 1,2004

[4]   Norhana Bt mohamad Nordin, *"Design a Teschebyshev Hairpin Band-pass Filter fo Unlicensed WiMAX,"* Final Year Thesis, Bachelor of Electrical Engineering, UiTM. (Oct 2009

[5]   Siti Azidah Binti Abidin, *"Butterworth Band-pass Filter (BBPFUsing Parallel Coupled Lines for WiMAX),"* Final Year Thesis, Bachelor of Electrical Engineering, UiTM. (Oct 2009)

[6]   D.M. Pozar, Microwave Engineering, c.d.Wiley,Newyork

[7]   Kai Chang *"RF and Microwave Systems"* John Wiley & Sons, 2000

[8]   Hong,J.S and Lancaster ,M.J,"Microstrip Filters for RF/Microwaves Applications", Wiley-Interscience publication, Canada, 2001.

[9]   Ian Huter " Theory and Design of Microwves Filters" The Institution of Ecctricals Engineers,1988