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Dual Band Microstrip Bandpass Filter Using Coupling Structure for Wi-Fi Application

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Abstract--*The Wi-Fi network connection is one of the largest network connection in world for a lot of telecommunication devices such as laptop and mobile phones. The design of a dual-band microstrip bandpass filter using coupling structure is proposed in this paper. The frequencies involved in for Wi-Fi application at frequencies of 2.4 and 5.8 GHz based on IEEE Regulation and Standard 802.11. The microstrip is used in filter design because of the low in cost and loss characteristics. The design of a microstrip bandpass filter that is created on coupling structure theory using end-coupled of quarter wavelength transmission line and parallel-coupled with a half-wavelenght resonators that operate at a dual-frequency band. Parametric analysis occur at open-stub condition, which involves the width, height and the gap to remove the harmonic frequency and obtain the good simulation results. Ansoft Designer Version 2.0 EM Simulator is used to design the filter. Simulations have been carried out to determine the filter's S-Parameters performance. The design comply at dual frequency at half-wavelength with a bandwidth of 300MHz at both frequency as stated. The filter is then fabricated on a TMM4 substrate from Rogers, dielectric constant of 4.50, dissipation factor of 0.0020, substrate thickness of 0.508 mm, copper thickness of 35 µm and the value of transmission line is 50Ω at both ports. The complete size of the filter is 55.4 × 3.52 mm². The process of simulation and measurement is been done to observed the S-Parameter performance of the filter for the return loss and insertion loss.*

Key words--*Bandpass filter; dual-band microstrip; coupling structure; Wi-Fi; end-coupled; parallel-coupled; dual-frequency band.*

I. INTRODUCTION

Nowa days, modern wireless communication has ubiquitiously become part of the human lifestyle. With the increase of users and applications come the challenge of higher bandwidth requirements. The current Wi-Fi network uses 2.4 GHz frequency to transmit and receive data among users[1]. The 2.4 GHz frequency is widely used and becomes congested easily and thus the alternative frequency of 5.8 GHz was introduced. Therefore, Wi-Fi network mechanism at 2.4 GHz and 5.8 GHz as defined in IEEE Regulation and Standards 802.11 [2], [3]. Both of this

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frequency is used for Wi-Fi connection either to downloading or uploading the data. The frequency of 5.8 GHz provides faster data rates at a shorter distance because of its higher bandwidth. Meanwhile, 2.4 GHz systems work at a slower speed but may travel further than higher frequency systems [2], [4].

A planar transmission line is one type of transmission line and comes in the form of microstrip, dielectric waveguide, slotline or stripline [5], [6].

The microstrip is normally used in filter design because of its characteristics of low cost and loss, high selectivity and compact in size [5], [7]. Fabrication wise, the microstrip is easier to fabricate and integrated with active devices [8], [9].

Dual-mode resonators are broadly used in microwave filter design because of its tuned circuit properties [10], [11]. Numerous research on the design of microstrip bandpass filter showed its tenability and rearrange in the context of bandwidth, centre frequency and transmission zero [12], [13].

A filter is aimed to accept a group of signals within required frequencies and discard other signals from unwanted frequencies. This project looks into the design of a dual-band frequency filter at Wi-Fi frequencies, 2.4 GHz and 5.8 GHz.

Several types of microstrip bandpass filter have been apply in electronic communication devices such as end-coupled and parallel-coupled of half-wavelength resonator filter, hairpin-line bandpass filter, interdigital bandpass filter, combline filters, pseudocombiline filter and stub bandpass filter [14], [15]. Moreover, multiband microwave filters have been broadly applied in wireless communication systems as can be seen in [16], [17].

In this paper, the coupling structure is introduced for design a microstrip dual-band bandpass filter. The properties of the planned filter are designed and established by full-wave simulation. The projected of dual-band bandpass for filter application is developed from end coupled of quarter wavelength transmission line and parallel coupled with a half-wavelength resonator. It will be illustrated in the design that a stub is used for removing the unwanted frequency and fabricated on a TMM4 Rogers substrate. The substrate has a large range of dielectric constant that is suitable for the single material system application. The substrate also has a low probability of being damaged during the fabrication because it has resistance to process chemical [18]. The dimension of this filter is 55.4 mm x 3.52 mm. The rest of this paper is ordered as follows. The material and method are proposed in section II. The results and discussion are given in section III. To conclude, the conclusion in section VI.

II. MATERIAL AND METHOD

Materials

Transmission lines are devices that can transfer energy from one point to the next point with a little amount of loss [5]. The types of transmission lines are planar, waveguide, and coaxial. Microstrip fabrication process uses printed circuit board (PCB) technology and can just be unified with other active microwave devices example, transistors [5].

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Microstrip structures are not dielectric above the strip, but often have field lines in the dielectric area that focus on the strip conductor and ground planes. The dielectric substratum with a very thin layer can reduce the microstrip line measurement in actual use[5]. In manufacturing costs, microstrip is cheaper than other types of planar transmission.It is also light, having larger out-of-band rejection and more compact [19], [20].

Transmission features of microstrip are constructed on parameters; effective dielectric constant, and characteristic impedance. The characteristics impedance of the transmission line is 50 Ω at both of the ports and others is determined by the width of the resonator. The design characteristics is described in the following equations.

The effective dielectric constant of the microstrip line is calculated by Equation (1) [21].

For $\frac{W}{h} \geq 1$:$\frac{W}{h} \geq 1$:

$$\varepsilon_{re} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\frac{h}{W}\right)^{-0.5} \varepsilon_{re} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\frac{h}{W}\right)^{-0.5} \quad (1)$$

The characteristic impedance, Z_c is calculated by Equation (2) [21].

$$Z_c = \frac{\eta}{\sqrt{\varepsilon_{re}}}\left\{\frac{W}{h} + 1.393 + 0.677\ln\left(\frac{W}{h} + 1.444\right)\right\}^{-1} \quad (2)$$

The height and width ratio is calculated by Equation (3) (4) [21].

For $\frac{W}{h} \leq 2$ and $Z_c \geq 50\,\Omega$ $\frac{W}{h} \leq 2$ and $Z_c \geq 50\,\Omega$

$$A = \frac{Z_c}{60}\left\{\frac{\varepsilon_r+1}{2}\right\}^{0.5} + \frac{\varepsilon_r-1}{\varepsilon_r+1}\left\{0.23 + \frac{0.11}{\varepsilon_r}\right\} \quad (3)$$

$$\frac{W}{h}\frac{W}{h} = \frac{8\times10^{A}}{10^{2A}-2}\frac{8\times10^{A}}{10^{2A}-2} \quad (4)$$

The dielectric loss attenuation is calculated by Equation (5) [21].

$$\alpha_d = \frac{k_0\varepsilon_r(\varepsilon_e-1)\tan d}{2\sqrt{\varepsilon_e(\varepsilon_e-1)}}Np/m\ \alpha_d = \frac{k_0\varepsilon_r(\varepsilon_e-1)\tan d}{2\sqrt{\varepsilon_e(\varepsilon_e-1)}}Np/m \quad (5)$$

The coupled resonators are designed on the technique of coupling coefficient of the inter-coupled resonator. The common concept of coupling is used to create the connection between the coupling coefficient and the physical assembly of the tuned coupled-resonator. The coupling coefficient of the coupling RF or microwave resonators may be different in structure and the frequencies of self-resonance are determined by the ratio of coupling energy to stored energy [5].

End-coupled microstrip arrangement is when there is a gap between the resonators, adjacently at the open ends, and it is capacitive [5].

The microstrip is situated in parallel or edge-coupled where it leads to resonators parallel to each other along half the length which provides comparatively big coupling for a specified spacing between resonators causing in a broader bandwidth compared to the end-coupled microstrip[5].

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Method

Transmission features of microstrip are constructed on effective dielectric constant, and characteristic impedance. Characteristics impedance for both ports are 50 Ω. The others characteristic impedance that needed is calculated by the width of the resonator itself.

The susbtrate material of TMM4. The substarte material in Table I [18] is used in the calculation process.

Table1: substrate Material

Substrate	**TMM4**
Dielectric Constant	4.50
Dissipation Factor	0.0020
Substrate Thickness	0.508 mm
Copper Thickness	35 µm

The quarter-wavelength transmission line is located next to the transmission line of the port. They are designed side by side to create the end-coupled type structure. This resonator is designed using the first band frequency, 2.4 GHz and characteristic impedance of 84Ω in quarter-wavelength form.

Table II shows the value used for design the quarter wavelength transmission line. The design of the end-coupled resonator is displayed in Fig. 1.

Table 2: Value of Quarter-Wavelength Transmission Line

Parameter	**Value**
W	0.3 mm
L	17.5 mm

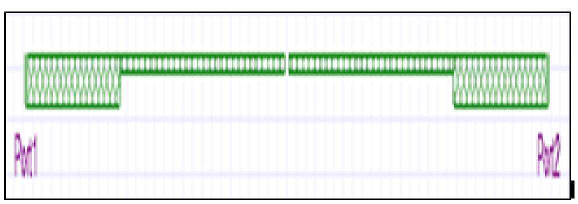

Figure 1. The end-coupled resonator

The resonator at 2.4 GHz is parallel-coupled between the transmission line and the quarter-wavelength resonator below it. The resonator is in half-wavelength form at the first band frequency, 2.4 GHz at 84 Ω of characteristic impedance and as in Table III and Fig. 2.

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Table 3: Value Of Half-Wavelength Resonator

Parameter	Value
W	0.3 mm
L	35 mm

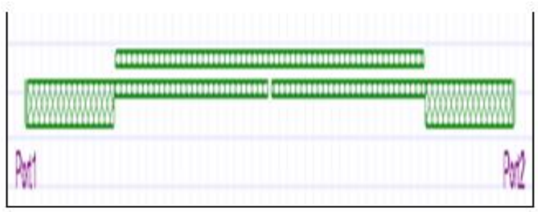

Figure 2: The end coupled, parallel-coupled and half-wavelength resonator

Half wavelength resonator is added to create the second band frequency, 5.8 GHz. The resonator is devised at the second band frequency, 5.8 GHz at 84Ω of characteristic impedance in half-wavelength form as in Table IV and Fig 3.

Table 4: Value Of The Half-Wavelength Resonator At 5.8 Ghz

Parameter	Value
W	0.3 mm
L	14 mm

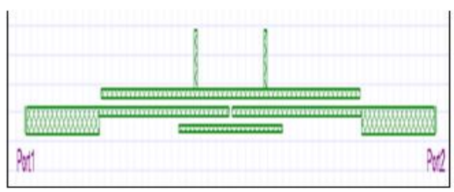

Figure 3: The resonator at 2.4 GHz and 5.8 GHz.

Open stub is needed to remove the harmonic frequency by creating two open stubs and the dimensions of the open stubs are varied by using the technique called parametric analysis. The two stubs are tapped with the 2.4 GHz half-wavelength resonator. This steps is important to achieved the right value of the center frequency.

The parametric analysis is carried out by varying the value of height and width for several conditions. The gap between the stubs is also observed. The parametric analysis is involving the value of height, width and gap of the open-stub as in Table V- VII.

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Varying the Length

Table 5: Vary Height For Dual Frequency

Parameter	Length (mm)	Value at 2.4 GHz		Value at 5.8 GHz	
		S_{11} (dB)	S_{21} (dB)	S_{11} (dB)	S_{21} (dB)
L_1	5	-4.48	-2.87	-6.43	-2.56
L_2	4	-7.41	-1.70	-2.20	-6.56
L_3	3	-12.95	-0.99	-4.88	-3.26
L_4	2	-24.48	-0.74	-15.48	-1.33
L_5	1	-14.87	-0.83	-19.52	-1.26

Varying the Width

Table 6: Vary Width For Dual Frequency

Parameter	Width (mm)	Value at 2.4 GHz		Value at 5.8 GHz	
		S_{11} (dB)	S_{21} (dB)	S_{11} (dB)	S_{21} (dB)
W_1	1.0	-10.60	-1.23	-4.33	-3.63
W_2	0.8	-13.80	-0.93	-7.87	-2.14
W_3	0.6	-18.34	-0.79	-11.95	-1.53
W_4	0.4	-24.48	-0.74	-15.48	-1.33
W_5	0.2	-21.08	-0.73	-18.41	-1.27

Varying the Gap

Table 7: Vary Gap For Dual Frequency

Parameter	Gap (mm)	Value at 2.4 GH		Value at 5.8 GHz	
		S_{11} (dB)	S_{21} (dB)	S_{11} (dB)	S_{21} (dB)
G_1	18.0	-3.81	-3.06	-19.66	-1.24
G_2	16.0	-4.95	-2.57	-19.15	-1.25
G_3	12.0	-12.31	-0.91	-1.35	-14.91
G_4	9.0	-24.48	-0.74	-15.48	-1.33
G_5	6.0	-15.25	-0.82	-18.85	-1.27

Parametric analysis at the open stub is needed for both frequency bands. This is to ensure to remove the harmonic frequency that will affect the measurement process of the center frequency. The dimension of the stub is compared as in Table VIII.

Table 8: The Comparison Before And After Parametric Analysis At Open Stub

Parameter	**Value at GHz**	**Value at 2.4 G and 5.8 GHz**
W	0.3 mm	0.4 mm
L	3.1 mm	2.0 mm
G	8.6 mm	9.0 mm

The final design is finalised after the S-Parameter is achieved at Fig. 4. The good results of return loss and insertion loss is achieved when its meets the requirements of good filter.

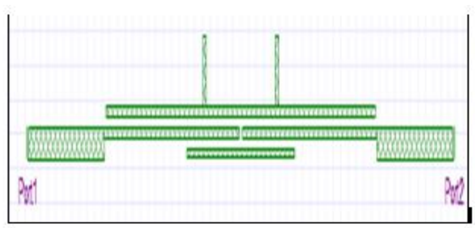

Figure 4: The complete design with specification of both frequency.

The gap between parallel-coupled is 0.3 mm meanwhile the gap for end-coupled is 0.4 mm. This gap is occur due to the parametric analysis in order to achieved the filter requirements. The gap also important to ensure there is no overlapping occur when fabrication process takes part. This will affect the filter measurements and performance.

III. RESULTS AND DISCUSSION

Simulation

A simulation study was carried out to look at the first band, i.e. at 2.4 GHz, without the half-wavelength resonator at 5.8 GHz, performance by varying the value of open-stubs to remove the harmonic frequency. The simulation result of first band is in Fig 5.

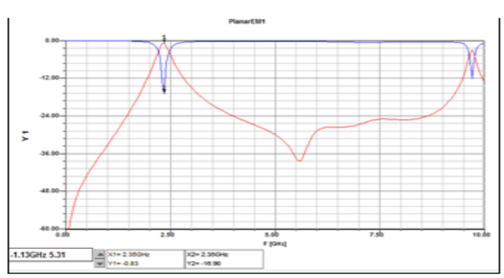

Figure 5: The simulation result at 2.4 GHz

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To create the second band, 5.8 GHz, the half-wavelength resonator is added to create the second band. The parametric analysis is needed to remove the harmonic frequency that occurs at other frequency. After varying the width, height, and gap of the open stub, the simulation results is in Fig 6.

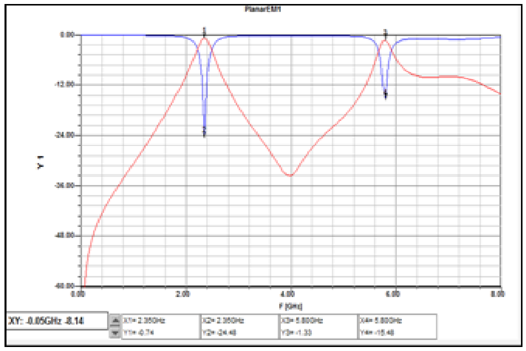

Figure 6: The simulation result at 2.35 GHz and 5.8 GHz

The parametric analysis process occur until optimizing points is achieved the good filter requirements; the return loss and insertion loss.

After the simulation achieved the specification, the S-Parameter is measured and tabulated in Table IX.

Table 9: The Value Of S-Parameter At 2.35 Ghz And 5.8 Ghz

Frequency	Value (dB)	
	Return Loss, S_{11}	Insertion Loss, S_{21}
2.35 GHz	-24.48	-0.74
5.8 GHz	-15.48	-1.33

As in good filter requirements, the bandwidth of the filter can be observed in simulation graphs as in Fig 7. At both center frequency; 2.35 GHz and 5.8 GHz, the bandwidth value is achieved 300 MHz, calculated by the value of the slope of the insertion loss.

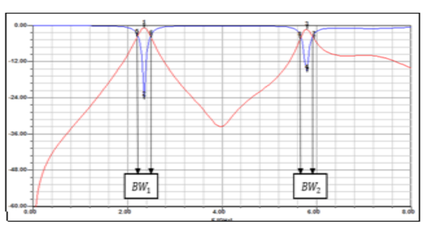

Figure 7: The bandwidth at dual frequency

Measurement

The design from Ansoft Designer Version 2.0 EM Simulator is generated and need to be converted into Gerber File using the GerbTool software as shown in Fig. 7. This step is needed to proceed with fabrication process.

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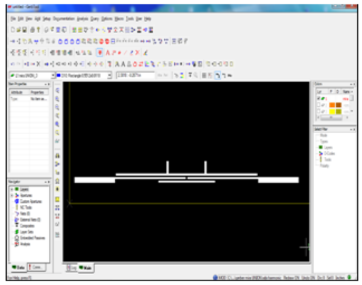

Figure 8: The design view in GerbTool

The fabrication substrate used TMM4 material. After fabrication, the two port is connected using soldering technique at end to end of the filter as in Fig. 8.

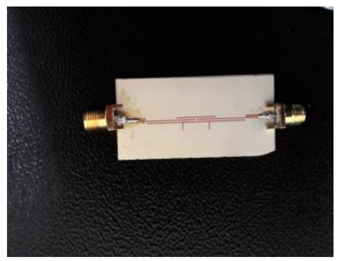

Figure 9: The filter after fabrication

The measurement of the S-Parameter is analysed using the Vector Network Analyzer (VNA) as in Fig. 9.

Figure 10: The display measurement on VNA

The measurement results shows the return loss that achieved at less than -10 dB for dual frequency as shown in Fig. 10.

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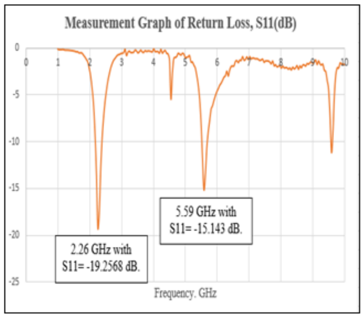

Figure 11: The display measurement of Return Loss at Dual frequency

Next, the measurement results in Fig. 10 shows the insertion loss that achieved at more than -2 dB for dual frequency as shown in Fig. 11.

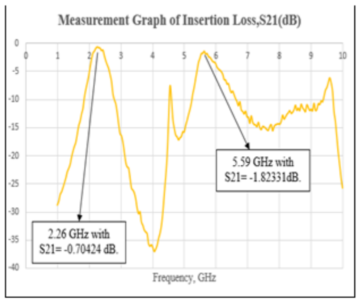

Figure 12: The display measurement of Insertion Loss at Dual frequency

The S-Parameter resuls is combined in Fig 12 and the data tabulated as in Table X.

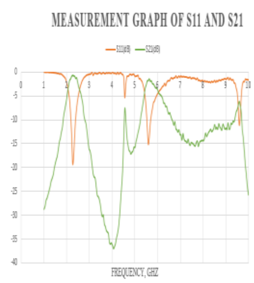

Fig. 12 The measurement of S-Parameter

Table 10: The Measurement Of S-Parameter

Frequency	**Value (dB)**	
	Return Loss, S_{11}	**Insertion Loss, S_{21}**
2.26 GHz	-19.2568	-0.70424
5.59 GHz	-15.143	-1.82331

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The measurement results and simulation results is slightly different at the center frequency as in Table IX and Table X. This is because of the tolerance during the fabrication process. The prototype is works at dual frequency with diffrent type of resonator and each are being specified lengths.

IV.CONCLUSION

The filter is designed based on microstrip bandpass filter theory. The design implements the coupling structure to create a dual-band bandpass filter. The bandpass filter is designed based on two resonators that are half-wavelength at 2.4GHz and 5.8GHz with a bandwidth of 300MHz. From the simulation and measurement of S_{11}, the return loss is less than -10 dB for both frequencies and the insertion loss is more than -2 dB for both frequencies.

From the design, the centre frequency is determined by the length of the resonator. As the frequency is increased, the length of the resonator is decreased. The value of width is determined by the value of characteristics impedance.

The other part of the design work is the parametric analysis that has been done to determine dimensions of the open-stubs element. By changing the value of elements at open stub, the emergence and suppression of the harmonics frequencies were made. Thus, the open-stubs are used to remove the unwanted harmonic frequencies that occur at frequencies other than 2.4 GHz and 5.8 GHz.

The value of gap spacing among the resonators and the transmission line was found to affect the performance of the bandpass filter since the coupling increases as the gap spacing decrease. For this design, all gap spacing is set to 0.3 mm to improve the filter performance. A smaller value may cause fault in the fabrication procedure.

Fabrication of the filter occurred on the TMM4 Rogers substrate. The manufacturing and measuring method was performed to assess the outcome of the results of the S-parameter and assessed by comparing the simulation with the outcome of the test.

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