A Diplexer Bandpass Filter for Dual Band RF Front-end Receiver at 2.4 GHz and 5.75 GHz

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***Abstract*—A new approach for designing a diplexer for dual-band bandpass filter (BPF) using a parallel coupled microstrip line filter is presented in this paper. The proposed diplexer consists of two fundamental resonant modes and the resonant characteristics has been investigated usingAdvanced Design System (ADS) 2011 software. To validate the design and analysis, two band-pass BPF were fabricated and measured. It shown that the measured and simulated performance are in good agreement. A dual-band response BPF that operates at 2.4 GHz and 5.75 GHz is designed and implement for IEEE 802.11a/b/g applications.**

Keyword-bandpass filter (BPF), Chebyshev filter, low pass filter (LPF), coupled microstrip line filter

I. INTRODUCTION

Bandpass filter (BPF) is a key component in RF receiver for wireless communication applications operating in multi-band, especially in the new developed wireless local area networks (WLANs) standards such as IEEE 802.11a (5.75 GHz) and IEEE 802.11b/g (2.4 GHz) specifications. Recently, different approaches have been introduced for the design dual-band BPFs. A dual-band BPF is achieved by a cascading of a BPF and bandstop filter [1]. In [2], an alternative approach with compact two-notched bands using open interconnected split ring resonator (OISRR) was proposed. Dual-band filters can also be realized by combining two sets of resonators with common input and output [3]. Besides utilizing two or more resonators, a dual-band filter can be designed by using a stepped-impedance resonator (SIR) [4].Nevertheless, the power capacity of BPF needs to be improved. In [5], resonator conducted in ground plane is proved to own a high power handling. Recently, various kinds of defects grounded structures have been presented with their applications in design of dual-band BPFs [6].

A diplexer circuit is basically a frequency multiplexer that splits a single channel carrying many frequencies into two channels carrying fewer frequencies. Usually the diplexer consist of filters to obtain the two passbandsthat can be expressed in wireless communication systems. Transmitted and receivered signals have to be filtered at the certaincenter frequency with specific bandwidth [7]. Typically filter types are classified into low pass filter, band pass filter, high pass filter and band rejection filter depending on pass characteristics.

This paper presents a parallel of5th and 9th order Chebyshev bandpass passive filter. In section II, the calculation of the filter design is described using Chebyshev lowpass filter (LPF) and transformed into a BPF. Section III, presents the simulation, measurement and testing for the results of the dual BPF design.

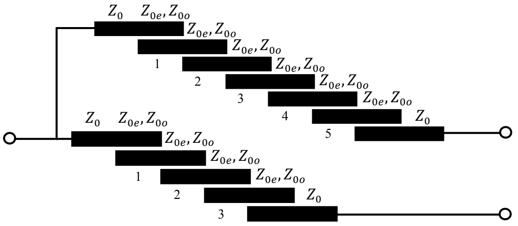


Fig.1.Parallelstructure of 5thand 9th order coupled line microstrip bandpass filter

II. DESIGN OF THE PROPOSED DUAL-BAND BANDPASS FILTER

The configuration of the proposed coupled line microstrip BPF filter is shown in Fig.1. There are two methods in designing filter which are image parameter method and insertion loss method. The insertion loss method applies in modern application network synthesis technique with desired frequency response [8]. The design is simplified by begin with LPF prototypes that are normalized in terms of impedance and frequency. Transformations are then applied to convert the prototype designs to the desired frequency range and impedance level [9].

Filter types also can classified into Chebyshev filter, Butterworth filter, Elliptic function filter and linear phase filter depending on frequency and phase response characteristics. The Chebyshev filter is a high Q filter that used when a steeper initial descent into stopband is required and the passband response is no longer required to be flat [10].

Choosing the type of filter is the initial process before proceeding to desired design, and then a filter specification is required to achieve goal and target design. Table I shows the Chebyshev BPF design specification for this project.From the specifications, we choose a Chebyshev filter design with ripple of 0.5 dB because the filter response has the steeper initial rate of attenuation beyond the cutoff frequency.According to [10], as more ripple is introduced in Chebyshev filter, the initial slope at the beginning of the stopband is increased and produce a more rectangular attenuation curve when compared to the rounded Butterworth response.

TABLE I. Band pass filter target design specification

Filter Specification	**Parameter**	
Center Frequency	2.4 GHz	5.75 GH
Filter Type	5th order Chebyshev	9th order Chebyshev
Transmission,S_{21}	<-10 dB	<-10 dB
Reflected, S_{11}	>-10 dB	>-10 dB
Stopband Attenuation	45 dB @ 2.5 GHz	25 dB @ 5.85 GHz
Bandwidth	100 MHz	100 MHz
Ripple	0.5 dB	0.5 dB

This project separate two Chebyshev BPFchannel into two desired frequency bands.Initially the order of the filter should be determined before designed the BPF with desired specification. The order of the filter can be determined by using attenuation versus normalized frequency graph as shown in Fig.2. The order of the filter also can be determined by using a calculation as mentioned in equation (1), [9].

$$n \geq \frac{cosh^{-1}X}{cosh^{-1}\omega} = \frac{\log\,(X + \sqrt{X^2 - 1}}{\log\,(\omega_s + \sqrt{\omega_s^2 - 1})} \tag{1}$$

Since, the pass band ripple (α_p) and stop band attenuation (α_s) also need to knowed when designed the filter.

$$X = \sqrt{(10^{0.1ap} - 1)^{-1}(10^{0.1as} - 1)} \tag{2}$$

If $\omega_1$and $\omega_2$denote the edges of the pass band, then a bandpass response can be obtained using the following frequency substitution as equation (3).

$$\omega = \frac{1}{\Delta}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right) \tag{3}$$

where, Δ is the fractional bandwidth of the pass band can be write as equation (4),

$$\Delta = \frac{\omega_2 - \omega_1}{\omega_0} \tag{4}$$

and the center frequency, ω_0 could be chosen as the arithmetic mean of $\omega_1$and ω_2, it is specifiy by equation(5).

$$\omega_0 = \sqrt{\omega_1 \omega_2} \tag{5}$$

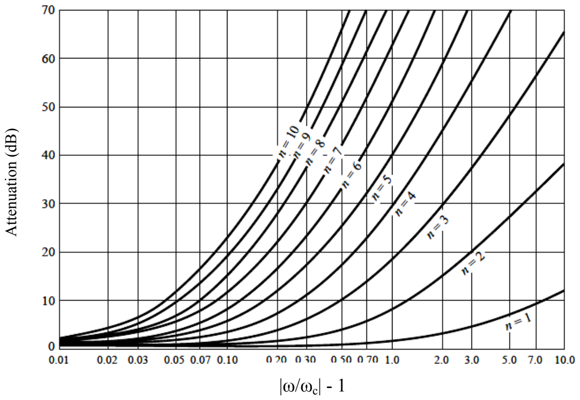


Fig.2. Attenuation curves for normalized frequecy of Chebychev (0.5dB ripple) filter prototype [9]

After the *n*-order filter is known, the ladder network for LPF prototype can be design by refering the table of element value. Table II which gives such element values for equal ripple LPF prototypes for *N*=1 to 10 (0.5dB ripple). The element values are numbered from g_0 at the generator impedance to g_{N+1} at the load impedance for a filter having *N* reactive elements. Notice that the load impedance $g_{N+1} \neq 1$ for even *N*.

TABLE II.Element values for equal ripple LPFprototype[9]
(g_0=1, c=1, N=1 to 10, 0.5 dB ripple)

N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	0.6986	1.0000									
2	1.4029	0.7071	1.9841								
3	1.5963	1.0967	1.5963	1.0000							
4	1.6703	1.1926	2.3661	0.8419	1.9841						
5	1.7058	1.2296	2.5408	1.2296	1.7058	1.0000					
6	1.7254	1.2479	2.6064	1.3137	2.4758	0.8696	1.9841				
7	1.7372	1.2583	2.6381	1.3444	2.6381	1.2583	1.7372	1.0000			
8	1.7451	1.2647	2.6564	1.3590	2.6964	1.3389	2.5093	0.8796	1.9841		
9	1.7504	1.2690	2.6678	1.3673	2.7239	1.3673	2.6678	1.2690	1.7504	1.0000	
10	1.7543	1.2721	2.6754	1.3725	2.7392	1.3806	2.7231	1.3485	2.5239	0.8842	1.9841

From Table II, the data is used to design the LPF prototype via ladder network. The ladder network have lumped circuit elements consists of shunt capacitors and series inductors. This ladder network have two types which can be designed beginning with shunt element or series element.

In practice, it would be extremely difficult to compare the performance and evaluate the usefulness of two filter networks if operating under different sets of circumstances and not standardized. Thus, the concept of normalization is merely tool to assure the capability of comparing the performance of any filter types when given the same operating conditions. For a normalized equal ripple low pass design, the source impedance is 1Ω and the cutoff frequency is $\omega_c = 1$rad/sec.

A. Impedance and Scaling Conversion

Once the specify LPF prototype has been design, the next step is to transform the prototype circuit into a BPF. The transformation configuration is accomplished by resonating each low pass element with an element of the opposite type and the same value. All shunt elements of the LPF prototype become parallel-resonant circuit and all series-elements become series-resonant circuit.When a prototype circuit is transformed into BPF, the attenuation bandwidth ratio also will remain the same.

After transforming the band pass circuit, then to complete the BPF design, both impedance and frequency have to scailing into new element value using the following formula. For the parallel-resonant branches as in equations(6) and (7), [9].

$$C' = \frac{g_i}{\omega_0 \Delta Z_0} \tag{6}$$

$$\mathrm{L}' = \frac{\Delta \mathrm{Z}_0}{\omega_0 \mathrm{g}_\mathrm{i}} \tag{7}$$

and,for the series-resonant branches can be given in equations(8) and (9).

$$\mathrm{C}' = \frac{\Delta}{\omega_0 \mathrm{g}_\mathrm{i} \mathrm{Z}_0} \tag{8}$$

$$\mathrm{L}' = \frac{\mathrm{g}_\mathrm{i} \mathrm{Z}_0}{\omega_0 \Delta} \tag{9}$$

The Z_{oo} and Z_{oe}impedance can be calculated using equations (10) to (11), while the length (L), width (W) and the separation (S) can be determined using the ADS 2011 software.

$$Z_{oe} = Z_o[1 + JZ_o + (JZ_o)^2] \tag{10}$$

$$Z_{oo} = Z_o[1 - JZ_o + (JZ_o)^2] \tag{11}$$

and

$$Z_o J_1 = \sqrt{\frac{\pi\Delta}{2g_1}} \tag{12}$$

$$Z_0 J_n = \frac{\pi\Delta}{2\sqrt{g_{n-1} g_n}} \tag{13}$$

The calculation of W, S and L at 2.4 GHz and 5.75 GHz can be referred at Table III and Table IV respectively. These data will be used to design the BPFs by using the ADS 2011 software. Based on the simulation results, both BPFs are shifted and not at the centerdesiredfrequency. Therefore, the optimization was carried outin section III (*Results*) to tuned the BPFs signal into desired frequency required.

TABLE III.5th Order Chebyshev Odd (Z_{oo}), Even (Z_{oe}) Impedance and Dimension of W, S and L

N	Z_{oe} (Ω)	Z_{oo} (Ω)	W (mm)	S (mm)	L (mm)
1	60.30	42.78	1.07	0.33	19.32
2	51.87	48.26	1.15	1.50	19.14
3	51.53	48.56	1.15	1.72	19.13
4	51.53	48.56	1.15	1.72	19.13
5	51.87	48.26	1.15	1.50	19.14
6	60.30	42.78	1.07	0.33	19.32

TABLE IV.9thOrder Chebyshev Odd (Z_{oo}), Even (Z_{oe}) Impedance and Dimension of W, S and L

N	Z_{oe} (Ω)	Z_{oo} (Ω)	W (mm)	S (mm)	L (mm)
1	57.03	44.53	1.52	0.48	9.89
2	50.94	49.10	1.58	2.62	9.85
3	50.75	49.27	1.58	3.02	9.85
4	50.73	49.29	1.58	3.09	9.85
5	50.72	49.30	1.58	3.11	9.85
6	50.72	49.30	1.58	3.11	9.85
7	50.73	49.29	1.58	3.09	9.85
8	50.75	49.27	1.58	3.02	9.85
9	50.94	49.10	1.58	2.62	9.85
10	57.03	44.53	1.52	0.48	9.89

Fig.3(a) and (b) shows the designed schematic of the BPF.Fig.3(a) shows six resonators built by five pairs of parallel-coupled microstrip. Meanwhile Fig.3(b) shows ten resonators built by nine pairs of parallel-coupled microstrip.The advantages of microstrip technology include simple, small size, light weight and durable finish as compared to a conventional design. These advantages are significant to reduce the size of RF components design.

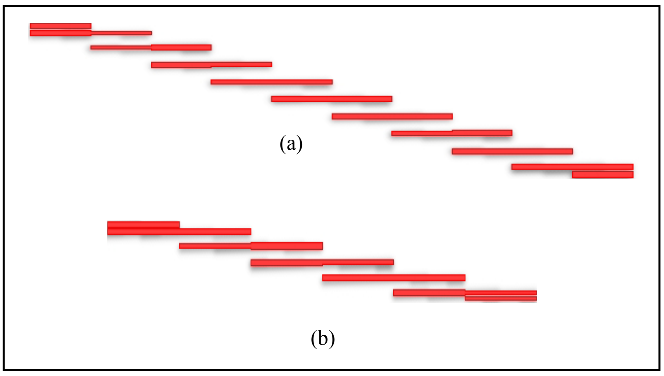


Fig.3. Fabricated of bandpass filter. (a) 5.75 GHz BPF. (b) 2.4 GHz BPF

III.RESULTS

According to [12], the deviation of the strip width (W) gives effects of changes in resonator of W. The characteristics of the filter are shifted in tolerances about 50 MHz with almost unchanged contour to lower or higher the frequency. With the optimization and tuning the width of parallel coupled microstrip lines at Table V and Table VI, the best resultsof both BPFs can be achieved. It shows that when reduce the value by half at the strip width calculation, it alsoimproved the results of the BPFs output of S_{11} and S_{21}drastically.

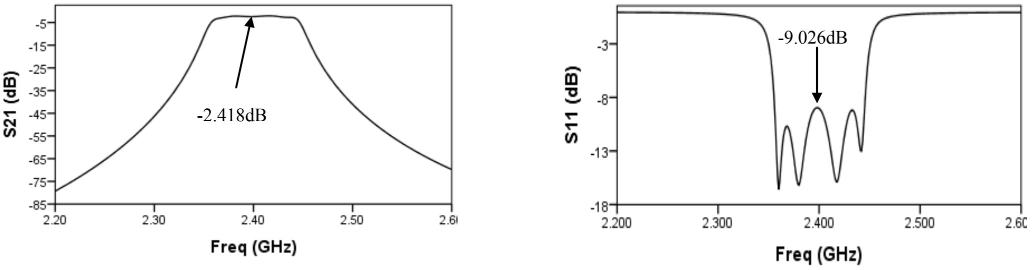
TABLE V.Optimization and tuning the width (W) for 2.4 GHz BPF

N	W (mm)
1	0.82
2	0.84
3	1.02
4	0.79
5	0.93
6	0.59

TABLE VI.Optimization and tuning the width (W) for 5.75 GHz BPF

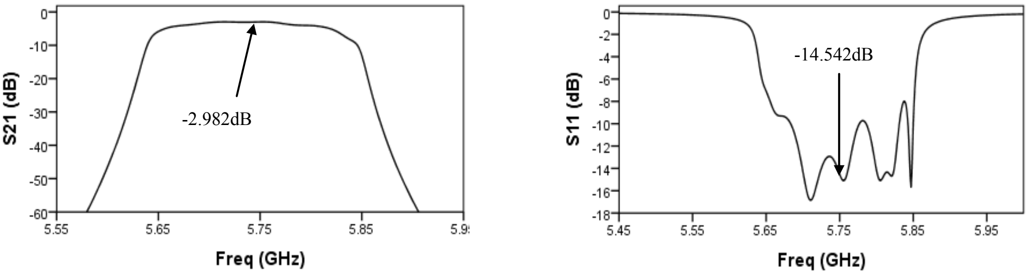
N	W (mm)
1	0.75
2	0.53
3	0.80
4	0.71
5	0.69
6	0.77
7	0.67
8	0.84
9	0.80
10	0.86

The simulations graphfor 2.4 GHz BPF are depicted in Fig.4(a) and (b). The results shows that the transmission and reflected factor obtained –2.418 dB and –9.026dB respectively. Fig.5(a) and (b) shows the transmission and reflected factor at 5.75 GHz with -2.982 dB and –14.542 dB respectively.From Fig. 4(a), it is seen that the filter has a bandwidthof 90 MHz within2.35 ~ 2.4 GHz. While Fig.5(a) shows that the bandwidth measured within 3 dB of the response at its peak from 5.65 ~ 5.83 GHz andobtained 180 MHz.



(a) (b)

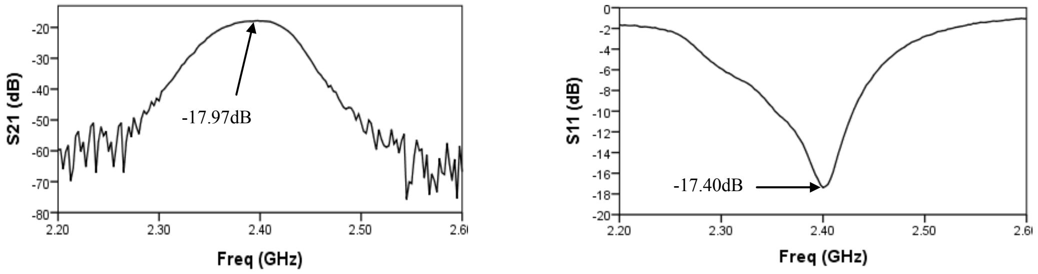
Fig.4. After optimization and simulaton for 2.4 GHz BPF, (a) Transmission, S_{21} and (b) Reflected, S_{11}



(a) (b)

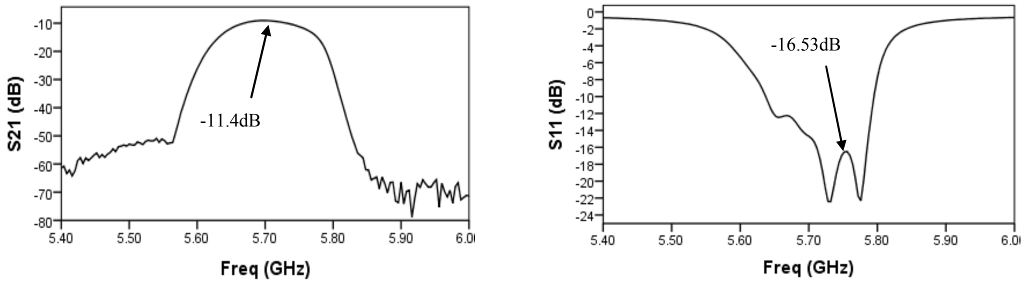
Fig.5. After optimization and simulaton for 5.75 GHz BPF, (a) Transmission, S_{21} and (b) Reflected, S_{11}

The BPFs measurement are shown in Fig.6 and Fig.7 at 2.4 GHz and 5.75 GHz respectively. The design measured using PNA-X Network Analyzer from Agilent Technologies. Fig.6(a) and (b) shows that the transmission and reflected factorobtained are –17.97 dB and –17.40 dB respectively. The bandwidth in Fig.6(a) measuredwithin 3 dB of the response at its peak andobtained 70 MHz at 2.4 GHz. The results at Fig.7(a) and (b) shows the transmission and reflected factor for 5.75 GHz as center frequency with the outputs are –11.4 dB and –16.53 dB respectively. Fig.7(a) also depicted the bandwidth achievedby 150 MHz at 3dB response at its peak.



(a) (b)

Fig.6. Measurement for 2.4 GHz BPF, (a) Transmission, S_{21} and (b) Reflected, S_{11}



(a) (b)

Fig.7. Measurement for 5.75 GHz BPF, (a) Transmission, $S_{21}$and (b) Reflected, S_{11}

Both simulation and measurement achieved the target specification. Table VII shows the comparison of simulation and measurement parameters for dual-band BPFs.By comparing the measurement with the simulation bandwidth results, the differencesare 22% for 2.4 GHz and 16.7% for 5.75 GHz.

TABLE VII.Dual Band BPFSimulationand Measurement Results

Parameter	**Simulation**		**Measurement**	
Frequency (GHz)	2.4	5.75	2.4	5.75
Bandwidth (MHz)	90	180	70	150
Transmission (S_{21}) dB	-2.42	-2.98	-17.97	-11.40
Reflected (S_{11}) dB	-9.03	-14.54	-17.40	-16.53

IV. CONCLUSIONS

BPF play a significant role in wireless communication systems. Transmitted and received signals have to be filtered at a certain center frequency with a specific bandwidth. In designing of microstrip filters, the first step is to carry out an approximated calculation based on using of concentrated components like inductors and capacitors. After getting the specifications required, we realized the filter structure with the parallel-coupled technique.In this paper, the experimental verification gives comparison, how close the simulation results and measurements look like.Both results have been compared with the output of transmission (S_{21}) and reflected (S_{11}). This project contribution is to build a part of the dual-bandconcurrent RF front-end receiver with a two channels parallel output.

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