

Development of 5.8 GHz Microstrip Parallel Coupled Line Bandpass Filter for Wireless Communication System

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Abstract—This paper aim to present the design technique, parameter analysis, real prototype fabrication and measurement results compare to simulation of 5.8GHz rectangular microstrip inset feed patch antenna. The antenna design calculation, simulation study and practical measurement results are well presented and compared. This study would be useful to realize low cost 5.8GHz rectangular microstrip patch antenna for any appropriate system developments and investigate the parameter study. The information shared is aimed to serve the similar scientific field and improve the system features.

Keyword—5.8 GHz, Microstrip, Parallel Coupled Line, Bandpass Filter

I. INTRODUCTION

The microwave filter is a two port network which used to control the frequency response at a specific point in a communication system by providing transmission at frequencies within the passband and attenuation in the stopband of a filter. Around the years preceding World War II, microwave filter theory and practice began by pioneers such as Mason, Sykes, Darlington, Fano, Lawson and Richards [1]. Today, most microwave filter designs are done with sophisticated computer-aided design (CAD) package based on the insertion loss method. The 5.8 GHz Industrial, Scientific and Medical (ISM) band filter is used in various wireless communications such as Wireless Local Area Network (WLAN) for short communication where the wireless communication system uses filters as frequency selective network, suppressing noise and manipulate output signal characteristic [2].

A bandpass filter only passes the frequencies within a certain desired band and attenuates others signals whose frequencies are either below a lower cutoff frequency or above an upper cut-off frequency. The range of frequencies that a bandpass filter let's to pass through is referred as passband. A typical bandpass filter can be obtained by combining a low-pass filter and a high-pass filter or applying conventional low pass to bandpass transformation [3]. For instance, an analogue electronic bandpass filter is an RLC circuit (a resistor–inductor–capacitor circuit). The ideal bandpass filter has a nearest flat passband which are no gain or attenuation and completely reject all frequencies outside the passband. In general condition, there is no ideal band pass filter. There is a frequency will be attenuated outside the pass band region. Thus, it can be said that the filter do not attenuate all frequencies outside the desired frequency range. This phenomena known as filter rolls off and usually expressed in dB of attenuation per octave or decade of frequency. The insertion loss, method allows a high degree of control over the passband amplitude and phase characteristic with the systematic way to synthesize a desired response [4].

The resonant series and parallel LC circuits combined to form a band-pass filter as shown in Fig. 1 below. In this circuit, the resonant series LC circuits are used to allow only the desired frequency range to pass while the resonant parallel LC circuit is used to attenuate frequencies outside the passband by shunting them towards the ground.

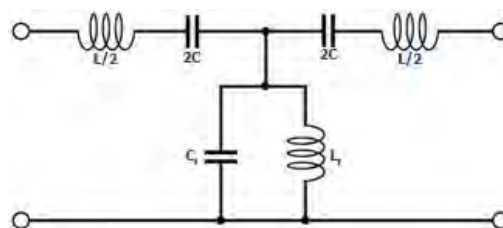


Fig. 1. Example of bandpass filter

Due to the growth in wireless communication and arrivals of new system nowadays caused an impact and demand in small and low cost filter with appropriate performance. It is a challenge for most designers, in design a miniaturization bandpass filter with low cost and high performance.

Nowadays, a microstrip transmission line or strip line is being made as a filter due to its behaviour as good resonator. This micro strip line gives better compromise in terms of size and performance rather other types of filter such as lumped element filters. In general, for manufacturing the microstrip circuit process, it is very similar to the processes used to manufacture printed circuit board. Other than that, its advantage would be of largely being planar. The microstrip transmission lines consist of a conducting strip of width (W) and thickness (t) and a wider ground plane, separated by a dielectric layer (ϵ_r) of thickness (h) as shown in Fig. 2 below.

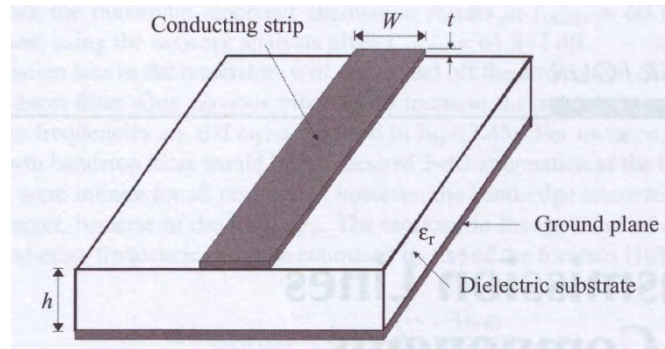


Fig. 2. General microstrip structure [9]

II. PARALLEL COUPLED LINE MICROSTRIP BANDPASS FILTER

A microstrip line filter type included stub, step impedance and coupled line filter [5]. Regarding to Fig. 3 below, a typical parallel coupled line bandpass filter which apply the half wavelength line resonators, whereas the resonators are parallel to each other along their length. This parallel coupled line structure with appropriate spacing between resonators caused a good coupling and provides desired bandwidth compared to other filter configuration [1]. The coupled line section for θ is equal to π divided by two, which will correspond to the center frequency of the bandpass response [6]. Based on the Fig. 3, the width, gap, length and impedance are labelled as (W), (S), (l), and (Y_0) consequently.

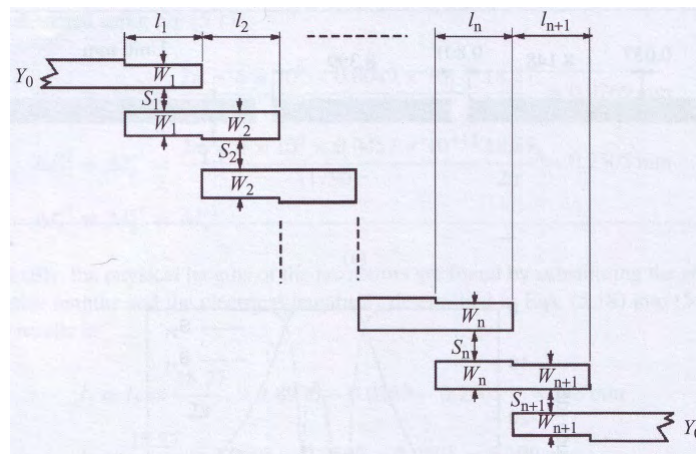


Fig. 3. Common structure of microstrip parallel coupled line bandpass filter [9]

The parallel coupling methods have certain advantages over the end coupling such as the length reduced approximately by half, a symmetrical insertion loss versus frequency response obtained with the first spurious response which occurred at three times center frequency, the larger gap between strips allows for higher power rating filter and permits a broader bandwidth for a given tolerance [7].

There are three main existing approaches to realize a bandpass filter. The first is micro strip or coplanar waveguide (CPW) multiple-mode resonator (MMR) with the assistance of a coupling mechanism. Secondly, a Broadside coupled micro strip line with a CPW at the back. Lastly, a direct or indirect combination of a low pass and high pass filter. However, there are many new developments in material and fabrication technologies. For example, high-temperature superconductors (HTS), low-temperature cofired ceramics (LTCC), monolithic microwave integrated circuits (MMIC), microelectromechanic system (MEMS), and micromachining technology [8].

III. DESIGN FLOW

Since the filter design is desired in small size and miniature, the coupled line filter with minimum order N equal to 1 with 0.5 equal-ripple responses are selected. On the other hand, based on the desired system operation and specification of filter such as operating frequency, bandwidth, insertion loss, and type of response, can lead to finding the appropriate filter order number. By using Fig. 4 and 5 below, a common 0.5 equal ripple parallel coupled line bandpass filter with order number can be identified. Normalized element value for 0.5 dB equal ripple low-pass filter have g_0, g_1 and g_2 are 1, 0.6986 and 1 consequently as shown in Fig. 5.

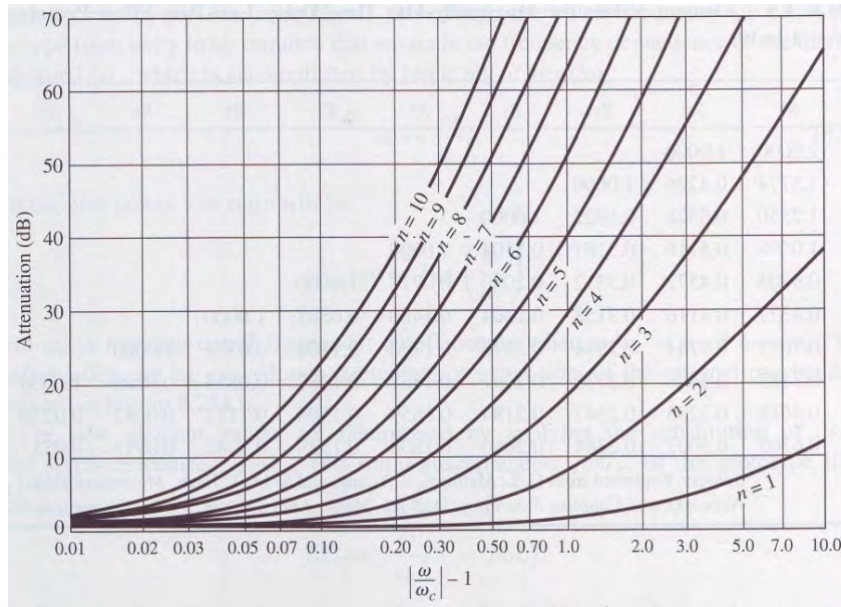


Fig. 4. Attenuation versus normalized frequency for 0.5dB ripple [6]

N	0.5 dB Ripple										
	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

Fig. 5. Table of Element values for 0.5dB ripple low pass filter prototypes [6]

Based on the filter application in system design, the fractional bandwidth (FBW) is calculated using equation (1) [6] below:

$$FBW = \frac{\omega_2 - \omega_1}{\omega_0} \tag{1}$$

where, ω_1 and ω_2 denote the edges of the passband frequency. Then the odd and even resistance calculated by using equation (2), (3) and (4) [9] below:

$$\frac{J_{01}}{Y_0} = \sqrt{\frac{\pi FBW}{2g_0g_1}} \tag{2}$$

$$\frac{J_{j,j+1}}{Y_0} = \frac{\pi FBW}{2\sqrt{g_jg_{j+1}}} \tag{3}$$

$$\frac{J_{n,n+1}}{Y_0} = \sqrt{\frac{\pi FBW}{2g_n g_{n+1}}} \tag{4}$$

where, g_0 , g_1 and $g_{(n+1)}$ are the elements of ladder type lowpass prototype, $J_{(j,j+1)}$ are the characteristic admittances of J inverters and Y_0 are characteristic admittance of terminating lines. By using the J inverters obtained above, the even and odd type characteristic impedance of the coupled micristrip line resonators is identified by using equation (5) and (6) [9] below:

$$(Z_{0e})_{j,j+1} = \frac{1}{Y_0} \left[1 + \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0} \right)^2 \right] \tag{5}$$

$$(Z_{0o})_{j,j+1} = \frac{1}{Y_0} \left[1 - \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0} \right)^2 \right] \tag{6}$$

where Z_{0e} is even characteristic impedance and Z_{0o} is odd characteristic impedance for j equals to 0 to n of elements. The calculated both even and odd characteristic impedance is shown in Table I below where i represent the stage order.

TABLE I
Dimensions of Width, Gap and Length

Stage (i,i+1)	Z0o(Ω)	Z0e(Ω)
0,1	38.95	71.90
1,2	45.87	54.94

IV. DESIGN FLOW

By using the Start LineCalc in Advanced Design System (ADS), Agilent Technologies version 2011 software, the dimensions of width, spacing and length of each stage are calculated by using even and odd characteristic impedance. The characteristic impedance Z_0 typically assumed as 50 Ohms. Each stage length chose to be guided wavelength (λ_g) whereas it corresponds to an electrical length (Eeff) as 90°. The calculated dimensions of width, gap and length of each stage are shown in Table II below.

TABLE II
Calculated Dimensions of Width, Gap and Length

Stage	Width (W)	Gap (S)	Length (l)
0	2.71	-	6.42
1	2.30	0.48	6.63
2	2.63	2.64	5.75

Next, for proceeds the optimization process in ADS, the optimization goal have setup properly. The involved parameters setup is such the substrate thickness, metal conductivity, dielectric loss tangent, surface roughness and so on. This all parameters have carefully set up based on the filter design specification. After that, the optimization and tuning proses carried on for the best results and performance. The finalized dimensions of width, gap and length of each stage are shown in Table III below.

TABLE III
Finalized Dimensions of Width, Gap and Length

Stage	Width (W)	Gap (S)	Length (l)
0	2.71	-	6.42
1	2.30	0.58	6.63
2	2.63	0.56	5.75

Fig. 6 below shows the simulated schematic. In order to match the microstrip line, both sides are added with 50 Ohm characteristic impedance which indicates as terminal “TERM”. The generated layout from drew schematic are shown in Fig. 7 below. The generated layout is simulated in Momentum RF environments. The total layout width, length and thickness of filter design in FR4 board are 8.8mm, 25.4mm and 1.6mm consequently. The bandpass filter is realized as a cascade of N+1 coupled line sections and the section numbered from left to right usually, as shown in Fig. 7 below. The layout section also can place reversely without affecting the response. The copper is used as a conductor and FR4 as substrate.

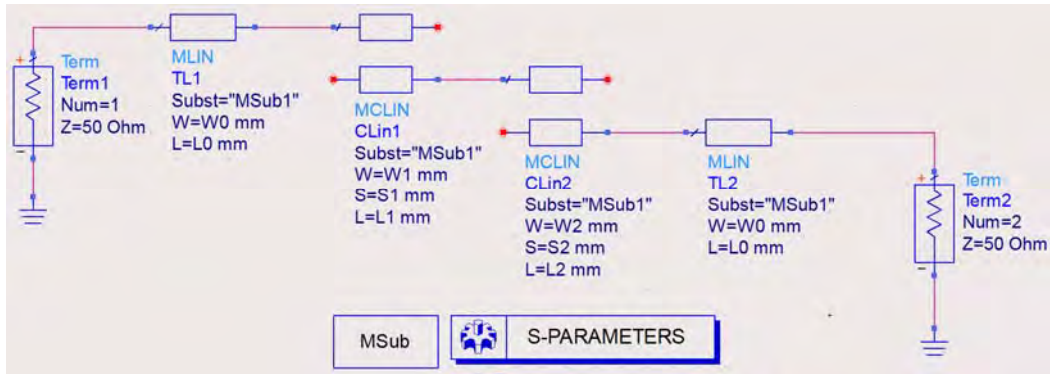


Fig. 6. Model of the band pass filter in ADS

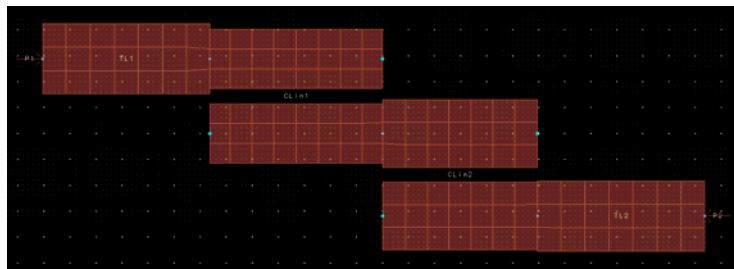


Fig. 7. Layout of the band pass filter in ADS

V. RESULTS ANALYSIS

The design filter was fabricated in FR4 as shown in Fig. 8 below. The total width, length and thickness is 1.3 cm, 4.8cm and 0.7cm consequently, including the (SubMiniature version A) SMA connector.

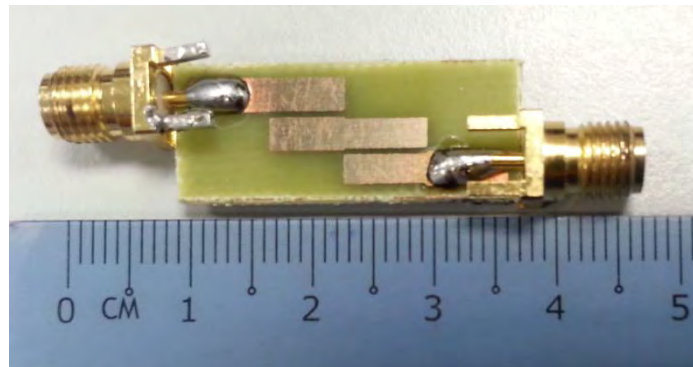


Fig. 8. Fabricated FR4 microstrip parallel coupled line bandpass filter

By doing a parametric study and analysis underway in designing an optimized filter, the length is varied by keeping the width and gap of elements constant. Based on Fig. 9 simulation results, the frequency band shifted to the right as the length are reduced from the original value. On the other hand, the frequency band shifted to the left as the length is increased from the original value. Based on this parametric analysis, it's proven an equation (7) [3], as guided wavelengths (λ_g) get shorter, the center frequency (f_0) will increase and shifted towards higher band. It means the guided wavelength (λ_g) is inversely proportion to center frequency (f_0). The changes of length dimension, did not effect the attenuation and insertion losses.

$$\lambda_g(mm) = \frac{300}{f_0(GHz)\sqrt{\epsilon_{eff}}} \tag{7}$$

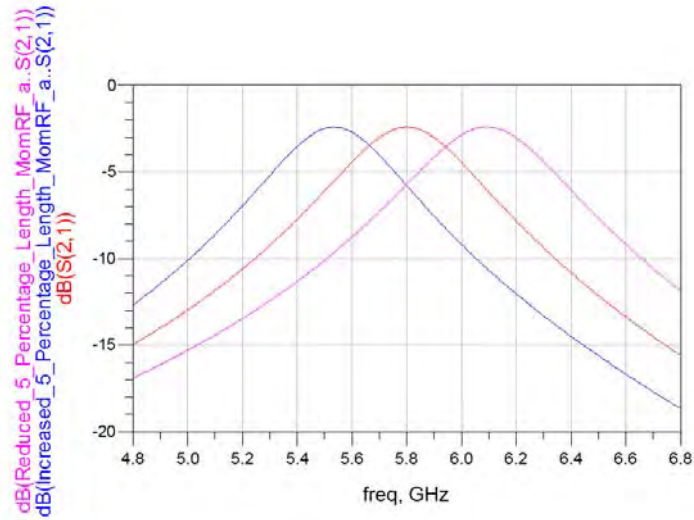


Fig. 9. Parameter analysis of the coupled line length of bandpass filter

By referring Fig. 10 below, the effect of changing coupled line width is analysed by keeping constant the length and the gap parameters. Based on the simulation results response, as the width increases, insertion loss also increases and vice versa.

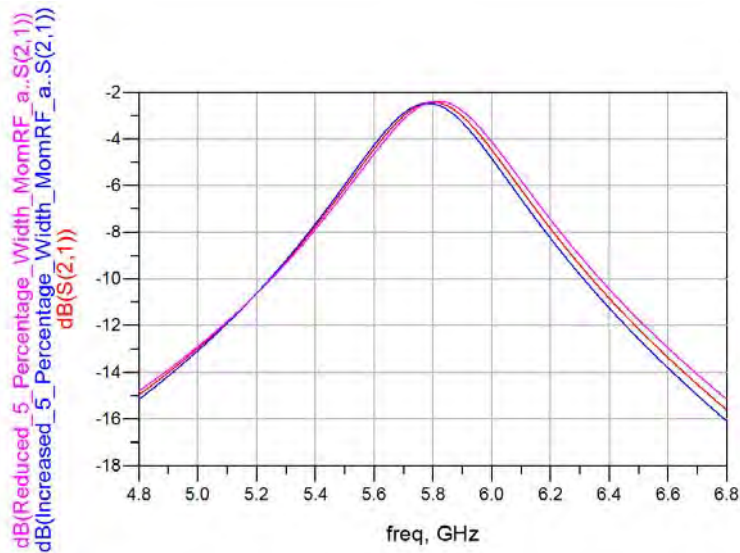


Fig. 10. Parameter analysis of the coupled line width of bandpass filter

By referred Fig. 11 below, the effect of changing coupled line gap is analysed by keeping constant the length and the width parameter. Based on simulation results, as the gap increased, it approximately similar to original simulation results, but a bit decreased in term S21 transmission loss. However, went decreased the gap of coupled line, the simulation results shifted in term of frequency overall, increased in S21 and bandwidth became wider. By this fact, it clearly shows that the good gap matching is required in parallel coupled line bandpass filter.

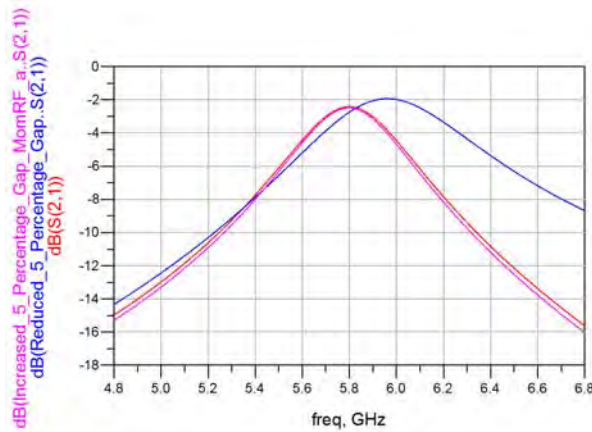


Fig. 11. Parameter analysis of the coupled line gap of bandpass filter

Furthermore, a comparison study is carried out by comparing the ADS simulation results with practical measurement of microstrip parallel coupled line bandpass filter. The Fig. 12 and 13 below show the scattering parameters of S11 return loss and S21 transmission loss for simulation and measured results consequently. The filter is tested with the Vector Network Analyzer (VNA) from Agilent Technologies N5242A (PNA-X Network Analyzer). The intersection point bandwidth and return loss below -10 dB over the passband was simulated. Fig. 14 and 15 shows that the filter is almost matched in characteristic impedance (Z_0) 50Ohms for simulation and measurement. The Fig. 16 shows the phase varied linearly with frequency simulated and it approximately reach near to 0° .

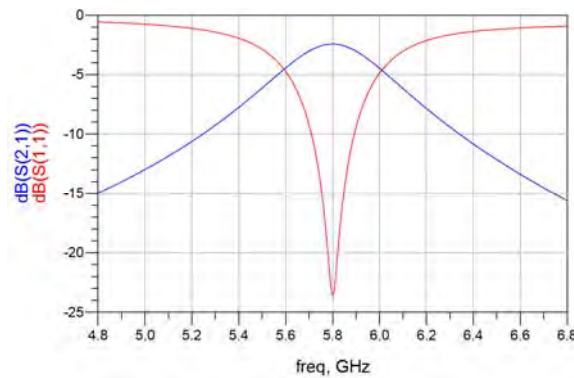


Fig. 12. Simulation results of scattering parameters for microstrip parallel coupled line bandpass filter

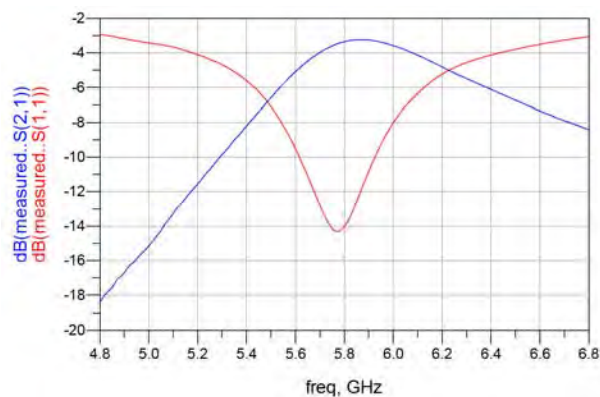


Fig. 13. Measurement results of scattering parameters for microstrip parallel coupled line bandpass filter

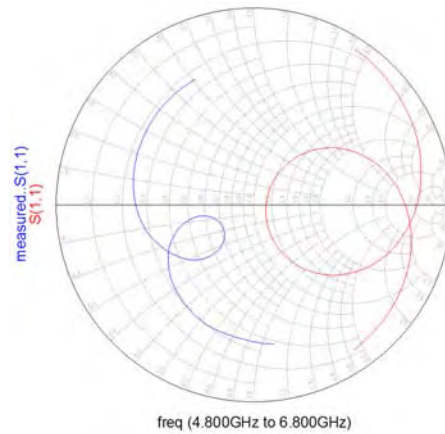


Fig. 14. Simulation and measurement results in Smith chart for S21 microstrip parallel coupled line bandpass filter

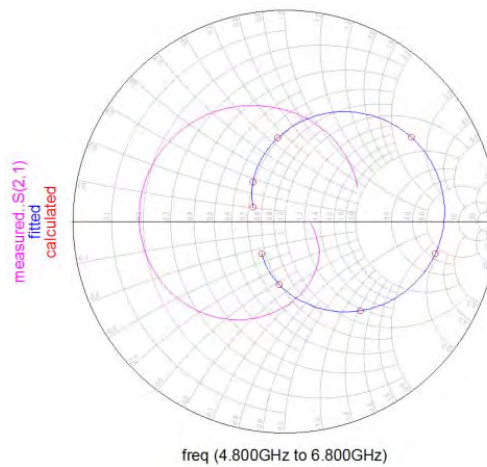


Fig. 15. Simulation and measurement results in Smith chart for S21 microstrip parallel coupled line bandpass filter

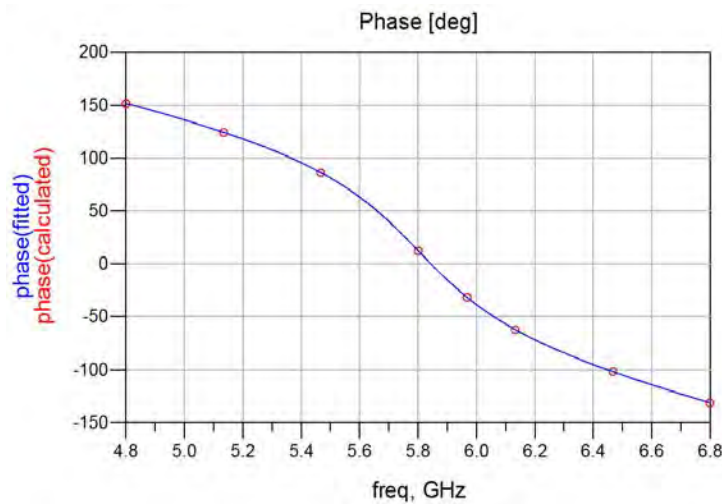


Fig. 16. Simulation results for phase versus frequency of microstrip parallel coupled line bandpass filter

The comparison of simulated and measured parameter as well detailed in Table IV below. The difference between simulation and measured S11 return loss is almost in the range of tolerance 9.56 dB. On the other hand, the difference between simulation and measured S21 transmission loss is almost in the range of 0.812 dB. The bandwidth of the intersection point of both signals is almost double than simulation results which increased from 416MHz (5.592 GHz to 6.008 GHz) to 750MHz (5.480 GHz to 6.230 GHz).

TABLE IV
Comparison Results of Simulated and Measured Parameter

Description	Simulation Results		Measurement Results	
	S ₁₁	S ₂₁	S ₁₁	S ₂₁
Magnitude (at 5.8GHz)	-23.612 dB	-2.424 dB	-14.502 dB	-3.2361 dB
Frequency Range (GHz)	5.592 to 6.008		5.480 to 6.230	
Bandwidth (MHz)	416		750	

In the filter designing and fabrication proses, the reverse engineering technic was carried out in order to find the correct dielectric constant (ϵ) by varying dielectric constant only in ADS simulation to match the measurement results. It is because there are various types of substrate in use for microstrip filter design and usually the dielectric constant (ϵ) in the range of $2.2 \leq \epsilon \leq 12$ [10]. The Flame Retardant and Type 4 (FR4) dielectric constant, typically in the range 4.4 to 5.2, depends on glass-resin ratio [11].

VI. CONCLUSION

In conclusion, an FR4 microstrip parallel coupled line bandpass filter is well designed and simulated by using the ADS software tool from Agilent Technologies version 2011 software. The filter is well fabricated and tested using VNA from Agilent Technologies N5242A (PNA-X Network Analyzer). The tuning and optimization is well carried out to get better performance of filters. The parametric study allowed to better understanding or the parallel coupler filter design and parameter affects. In the filter designing and fabrication proses, the reverse engineering technic was carried out in order to find the correct FR4 dielectric constant (ϵ) by varying dielectric constant only in ADS simulation to match the measurement results. A microstrip parallel coupled line bandpass filter was fabricated on FR4 with one order 0.5 ripple with center frequency 5.8 GHz for wireless communication system. The measured S₁₁ return loss and S₂₁ transmission loss of fabricating filter is -14.052 dB and -3.2361 dB consequently. The bandwidth of the intersection point of both signals is almost double than simulation results which is from 750MHz (5.480 GHz to 6.230 GHz). From the measuring and simulation results, it can be concluded that for fabricating, a lot of factors must be taken to overcome the skew in spite the human error and machine malfunction.

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