A Parallel Coupled-Line Bandpass Filter

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Abstract – **In this paper, a bandpass filter using parallel coupled resonators was designed at centre frequency of 5.8 GHz using Butterworth method. The filter was implemented on the epoxy laminate with relative permittivity, $\varepsilon_r = 3.48$ with substrate thickness 1.524 mm. All the designing and simulation of the filter was carried out with the aid of electromagnetic simulator. *Comparisons between measured and simulated values of the* parameter of the filter were carried out and it was observed that all these values were very close with each other.**

Keywords- Microstrip , CST Microwave Studio (CST), Vector Network Analyzer (VNA), Advanced design system (ADS).

I.INTRODUCTION

The term microwaves may be used to describe electromagnetic (EM) waves with frequencies ranging from 300 MHZ to 300 GHz, which correspond to wavelengths (in free space) 1m to 1 mm. The frequency between RF and microwaves is depending on the particular technologies developed for the exploitation of that specific frequency range. These ranges of frequency are further divided into many frequency bands for convenience such as C-band and X-band.

Filters play an important role in many RF or microwaves applications. They are used to select or confine the RF or microwave signals within assigned spectral limits [1].

Bandpass filter is the device that passes frequency within certain range and removes any frequency outside that range. The most common filter in microwave application is parallel coupled line filter [2]. Coupling in the parallel coupled filter occurs between the edges of resonators. The coupling surface is much larger, so that the bandwidth of this filter is bigger than end coupled filter. The length of N resonators approximately half-wavelength to give resonance, and these lines are open ended and coupled with the adjacent resonator length for a quarter-wavelength portion of its length. Each resonator is affected by reactive loading from the adjacent couplings and open-ended capacitive fringing [3].

In a general filter design procedure, greater number of resonators is required to obtain a more rapid attenuation rate outside the passband. However an increase in the resonator number increases not only the insertion loss in the passband but also the filter size [1].

Work on PCBPF was carried out by various researches [4], [5], [6], [8], [9], [10]. Mudrik Alaydrus [4] had developed a PCBPF at 3.2 GHz of center frequency. The filter was designed using Butterworth method on Rogers Duroid, RO TMM10 with thickness 0.752 mm and relative permittivity of 9.2.

Jhin-Fang Huang etc all [5] had designed a compact bandpass filter using parallel coupled resonators. The filter was designed using Chebyshev method at 0.5 dB ripple. The center frequency of this filter at 5.8 GHz using Rogers Duroid, RO 4003 substrate with relative permittivity is $\varepsilon_r = 3.38$ which resulted in compact size filter.

F.Karshenas etc all [6] had proposed a miniaturized PCBPF. The filter was designed using FR-4 with thickness of 1.5 mm and the relative permittivity is $\varepsilon_r = 4.4$. This work based on slow-wave effect of the defected ground structures (DGS) to achieve size minimization without any critical deviation in center frequency and bandwidth.

I.I. SCOPE OF WORK

In this work, a parallel coupled bandpass filter was designed using Butterworth method at center frequency of 5.8 GHz. The filter was fabricated on Rogers Duroid, RO 4350 substrate that has 1.524 mm thickness and the dielectric constant is $\varepsilon_r = 3.48$. The simulation was performed using CST STUDIO SUITE 2009 (CST) and Advanced Design System (ADS) with the specification as indicated by Table 1.

TABLE 1. SPECIFICATION OF PCBPF

Parameter	Specification
Number of order (n)	3
Centre frequency	5.8 GHz
Low cut-off frequency	5.655 GHz
High cut-off frequency	5.945 GHz
Bandwidth	0.29 GHz
Return loss, S11	< -20 dB
Insertion loss, S21	0 dB

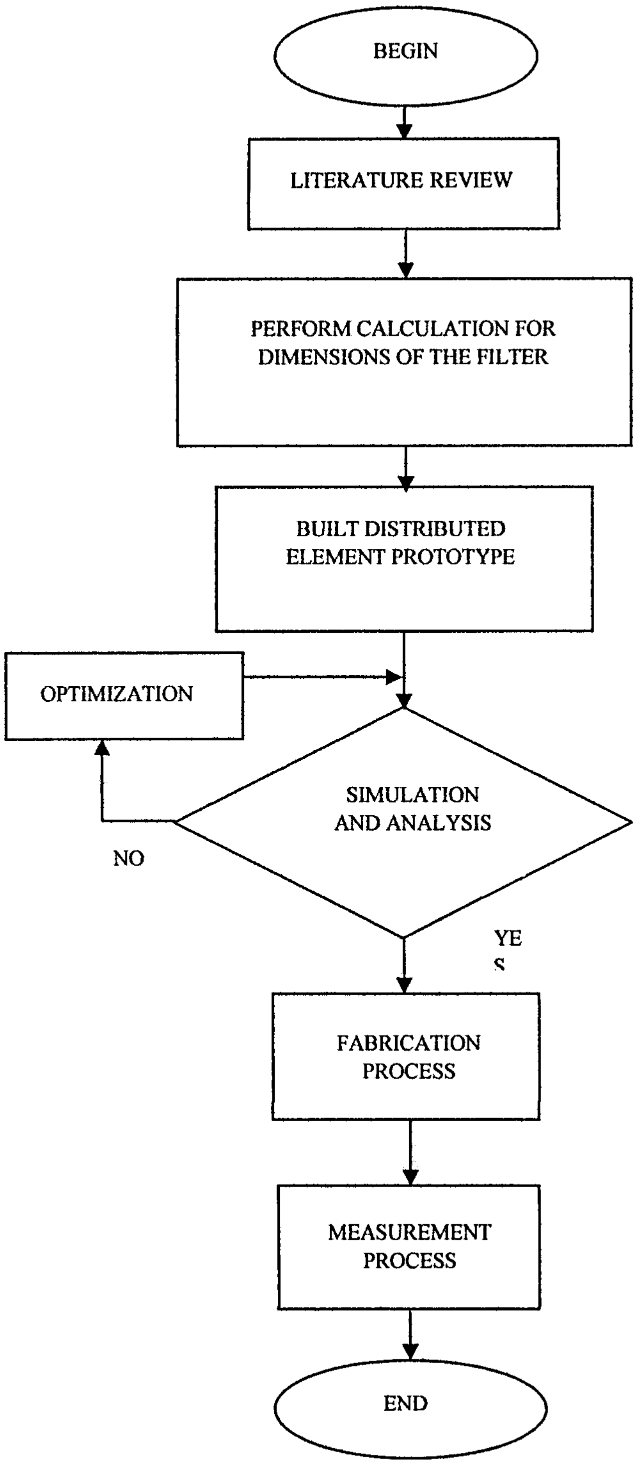

Figure 1. Flow chart.

Fig. 1 highlight the work done involved in realizing the prototype filter.

Basic design microwave filters were based from a prototype low pass filter design. In this technique, a physically realizable network is synthesized that will give the desired insertion loss versus frequency characteristic. In this work, a 3rd order bandpass filter was designed with center frequency of 5.8 GHz with fractional bandwidth of 5 % using parallel coupled resonators and maximally flat (Butterworth) method.

The first step to design the filter was to identify the frequency of the filter, the order of filter, and the impedance matching of the filter.

TABLE 3.3-1 ELEMENT VALUES FOR BUTTERWORTH FILTER.

ORDER	L1	C2	L3	C4	L5	C6	L7	C8	L9	← Type B
	C1	L2	C3	L4	C5	L6	C7	L8	C9	← Type A
1	2.000									
2	1.41421	1.41421								
3	1.00000	2.00000	1.00000							
4	0.76357	1.84776	1.84776	0.76357						
5	0.61803	0.61803	2.00000	0.61803	0.61803					
6	0.51764	1.41421	1.93185	1.93185	1.41421	0.51764				
7	0.44504	1.24698	1.80194	2.00000	1.80194	1.24698	0.44504			
8	0.39018	1.11114	1.66294	1.96157	1.96257	1.66294	1.11114	0.39018		
9	0.34730	1.0000	1.53209	1.87938	2.00000	1.87938	1.53209	1.00000	0.34730	

According to the table, third element values obtained are g0 = 1.00000, g1 = 1.00000, g2 = 2.0000, g3 = 1.0000, and g4 = 1.0000. The filter for this work was developed on Rogers Duroid, RO 4350 substrate with the specification as shown in Table 3.

TABLE 2. SUBSTRATE SPECIFICATION

Specification	Value
Permittivity, ε_r	3.48
Substrate height	1.524 mm
Loss tangent, tan δ	0.0031
Copper thickness	0.035mm

The first step is to determined the center frequency, the fractional bandwidth and the impedance inverter values for parallel coupled band pass filter have to be calculated. These inverters convert the filter to a network of parallel resonators.

Fractional bandwidth

$$f_b = \frac{f_b(\%) \times f_c}{2} \quad (1)$$

Low cut off frequency

$$f_l = f_c - f_b \quad (2)$$

High cut off frequency

$$f_u = f_c + f_b \tag{3}$$

Lower angular frequency, $\omega_l = 2\pi f_l$ (4)

Upper angular frequency, $\omega_u = 2\pi f_u$ (5)

Centre frequency, $\omega_o = \sqrt{\omega_u} \times \sqrt{\omega_l}$ (6)

Fractional bandwidth

$$\Delta = \frac{\omega_u - \omega_l}{\omega_o} \tag{7}$$

First coupling structure

$$Z_0 J_{0,1} = \sqrt{\frac{\pi\Delta}{2 g_0 g_1}} \tag{8}$$

Intermediate coupling structure

$$Z_0 J_{i,j+1} = \frac{\Delta\pi}{2\sqrt{g_i g_{i+1}}} \tag{9}$$

Final coupling structure

$$Z_0 J_{0,1} = \sqrt{\frac{\pi\Delta}{2 g_0 g_1}} \tag{10}$$

The values of gn can be taken from table 3.3-1, $J_{i,i+1}$ is the characteristic admittance of J inverter and is the characteristic admittance of J inverter and Y_o is the characteristic admittance of the connecting transmission line.

The data of characteristic admittance of the inverter, we can calculate the characteristic impedances of even-mode and odd-mode of the parallel-coupled microstrip transmission line. The formula for both even and odd characteristic line impedance are;

$$a = J_{i,i+1} \tag{11}$$

For Even

$$(Z_{oe})_{i,i+1} = Z_0(1 + aZ_0 + a^2 Z_0{}^2) \tag{12}$$

For Odd

$$(Z_{oo})_{i,i+1} = Z_0(1 - aZ_0 + a^2 Z_0{}^2) \tag{13}$$

Second step is the calculation of the characteristic impedance and coupling structure factor in decibel (dB). The values of coupling inverters and the odd and even characteristic impedance were used to determine the width, length, and spacing in *Linecalc module.*

For electrical parameters;

$$Z_{i,i+1} = \sqrt{Z_{oe}} \times \sqrt{Z_{oo}} \tag{14}$$

For coupling

$$C_{i,i+1} = 20_{log}\left[\frac{(Z_{oe})_{i,i+1} - (Z_{oo})_{i,i+1}}{(Z_{oe})_{i,i+1} + (Z_{oo})_{i,i+1}}\right] \tag{15}$$

The third step was to convert the lumped elements of bandpass filter to distributed element in order on microstrip board. The element can be replaced either line impedance or line of stub. Usually, line impedance shows the value of series inductor and line of stub shows the value of capacitor [7].

The designed filter must satisfv with the theory which is the length of coupling re: L2 :1 C2 pproximate to λ / 4 while the resonator length is λ / ∠, ana au ıne lines are open-circuited at both end. The amount of coupling is increased instead by increasing the coupling length. It can be shown, that the coupling is maximum when the length of coupling is λ / 4 or some odd multiple of it [3].

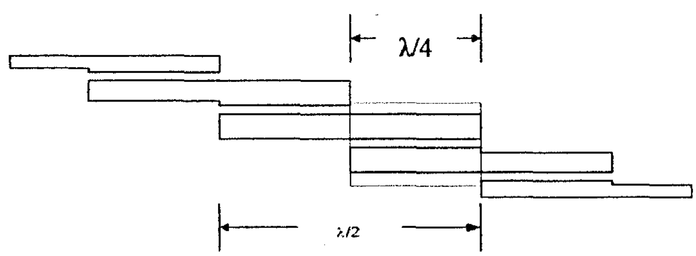

Figure 3. Third order edge-couple λ/2 ass filter-notice that the coupling resonators are λ/4 long (aepicted by gray area).

The distributed elements are designed based on even and odd mode impedance of the coupled lines [8] and can be optimized by using Advanced Design System (ADS) software. Fig. 4 show the ideal PCBPF that was tuned by using ADS and Fig. 5 shows the top view of the simulated microstrip parallel coupled bandpass filter. This top view was done by using CST Microwave Studio.

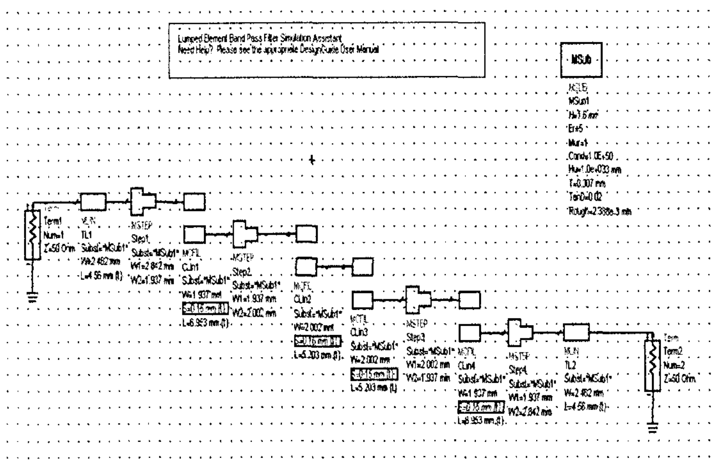

Figure 4. Ideal parallel coupled bandpass filter.

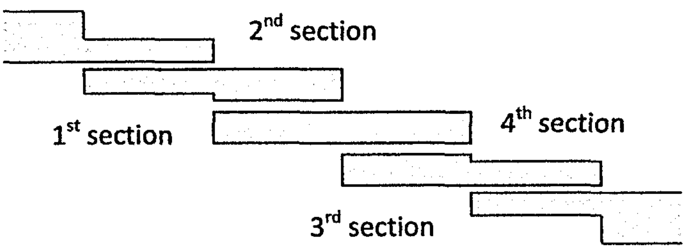

Figure 5. Top views of simulated parallel coupled microstrip bandpass filter structure.

The filter required even and odd mode characteristic impedance (Z_{oe}, Z_{oo}) of 97.9204 Ω and 69.9816 Ω, respectively for the 1st coupled line section which represent the line width (w) of 2.123 mm and line spacing (s) of 0.5 mm. The 2nd coupled line section requires Z_{oe} and Z_{oo} of 80.3525 Ω and 62.6728 Ω respectively which represent the line width (w) of 1.587 mm and line spacing of 0.77 mm.

The last two coupled line section are symmetrical to the 1st and 2nd coupled line section, thus having the same dimension as stated earlier. The dimensions of input and output port are corresponding to 50Ω microstrip line which could be considered as subminiature version A (SMA) connector. The comparisons between simulation and ideal filter design were carried out to distinguish the result after manual fabrication.

III. RESULTS AND DISCUSSION

The filter was designed at centre frequency at 5.8 GHz. Based on the simulation and measurement result as indicated by Fig. 6, the insertion loss, S21 is -0.72 dB and -1.529 dB respectively.

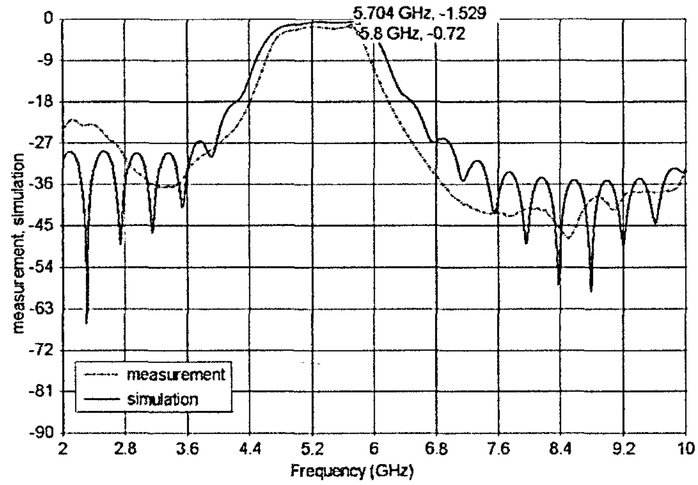

Figure 6. Simulated and measured of insertion loss, S21.

Fig. 7 shows the simulation and measurement result of return loss, S11 is -24.958 dB and -24.082 dB respectively. There was slightly discrepancy between simulated and measured results. The return loss and the insertion loss had shifted from 5.8 GHz to 5.704 GHz. Table 4 shows the comparison of the simulation and the measurement result of the insertion loss and return loss. Measurements of all the parameters of the prototype filter were carried out using VNA.

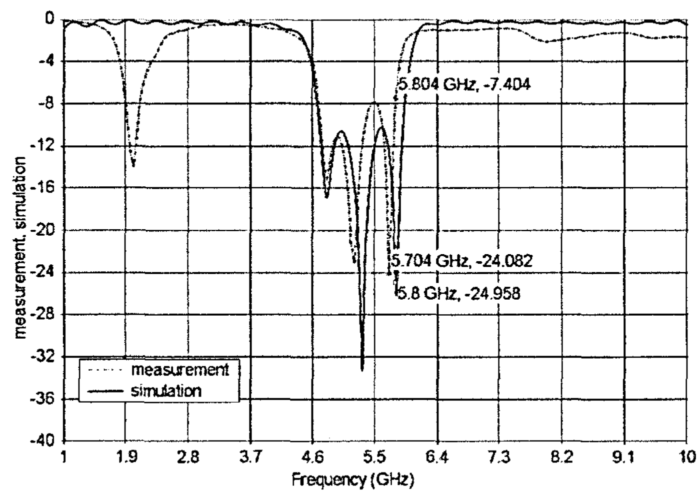

Figure 7. Simulated and measured of return loss, S11.

TABLE 4. Comparison between simulated and measured values

Parameter	S11(dB)	S21(dB)
Simulation	-24.958	-0.72
Measurement	-24.082	-1.529

The slight discrepancy between measured and simulated values may be due to many reasons such as the variation in values dielectric constant of the substrate, parasitic and stray elements, which it may reduce the performance of the filter [9] or imperfect ground plane of the devices. In the simulation of the band-pass filter, it is found that the center frequency (fc) is very sensitive to the length of the parallel-coupled lines and the frequency response profile is sensitive to the spacing and width of the coupled lines [5].

As a consequence, if the implementation process of the PCB can be well controlled, a good band-pass filter can be actually realized.

Fig. 8 represents the fabricated parallel couple bandpass filter that has been designed according to the specification. The fabrication process was carried out prior to the simulation process. The filter dimension is 42.13 mm length and 29.35 mm width.

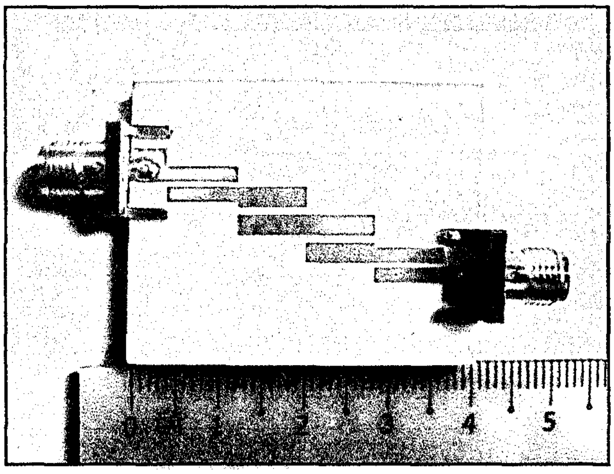

Figure 8. Prototype of PCBPF

IV. CONCLUSION

In this work, a parallel coupled bandpass filter was successfully designed, simulated, and analyzed by using Rogers Duroid, RO 4350 with relative permittivity, $\varepsilon_r = 3.48$ and thickness, h is 1.524 mm. The filter is compact in size, light and very low cost of fabrication. However, there is some difference between simulation and measurement values.

V. RECOMMENDATION

In future, this approach can be modified to improve the performance of the filter. The substrate that has high permittivity can be used to improve performance at high frequency and reduce the size of filter. Besides that, this design can use the defected ground surface to achieve size minimization, while the spurious responses are eliminated by the band-rejection property. These features offer the classical parallel coupled-line bandpass filter simultaneous compactness and wide stopband performance.

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