DESIGN AND SIMULATION OF MICROSTRIP FILTERS

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Abstract: In this paper, by using the concept of microstrip lines we have designed parallel edge coupled band pass filter which can be implemented on various RF/microwave applications. The design is simplified by beginning with low-pass filter 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. Order of the filter determines the number of reactive elements needed for the filter design. As we go on increasing the order of the filter, it helps us to reach the ideal response of the filter. The choice of order of the filter is made to ease implementation. The implementation of transmission line filters is based on characteristics impedance changes. Higher the order of filter, the difficult the required changes in characteristics impedance become, however the performance of a filter improves with an order increase. Advanced design system (ADS) simulation software from Agilent technologies is used to simulate filters designed for different frequencies and using electromagnetic (EM) simulation tools, to predict the performance of the filter structure. The advantage of using microstrip line filter is that, as the frequency increases the reactance of the lumped components (inductors and capacitors) varies or not constant, so it is not possible to maintain the proper characteristics of the filter at higher frequencies. So, in order to overcome this difficulty, it's better to use microstrip line filter. A good way of designing microstrip filter aiding by ADS which shows feasible in practice and features in low cost, simple structure and applicability in radio receiver. The optimization function owing by ADS is an efficient tool to amend the drawback of the conventional method with theoretical formulas.

Index Terms – **Band pass filter, microstrip filters, lumped components, transformation, ADS, EM.**

I. INTRODUCTION

Filters are used as frequency selective devices in many RF and microwave applications [1]. Filters are realized using lumped or distributed circuit elements. The filters are one of the primary and necessary components of a microwave system. Microstrip line is a good candidate for filter design due to its advantages of low cost, good performance, compact size, light weight, planar structure and easy integration with other components on a single circuit board [1]. Conventional filter structures like equal ripple and butterworth low pass filters are requirement of special fabrication methods. Conventional low frequency techniques for fabrication does not fit at these frequencies due to the very high losses associated. Although microstrip is not the highest performance filter technology, still it is the preferred choice in many thin-films on ceramic and printed circuit board applications.

In this paper will present the design of parallel edge coupled microstrip band pass filters with different orders and comparing the resulted simulation responses with the theoretically calculated values. The filters are designed and simulated using Agilent technology, Advanced Design System (ADS) software tool and implemented on the FR4 substrate [17].

II. PROBLEM STATEMENT

At radio frequencies, the frequency responses of the lumped component filters are not going to match with the theoretically calculated frequency responses because, of change in the reactance of the lumped components at higher frequencies (at RF frequency). So, in order to overcome this problem of lumped components filter at RF frequency, we replace/convert lumped components filter to its equivalent microstrip filters. With lower order of filter, we are not able to obtain ideal response of the filter.

III. BASIC THEORY

A microwave filter is a two-port network by providing, transmission at frequencies within the pass band of the filter and attenuation in the stop band of the filter it can able to control the frequency response in a microwave system at certain point. A Band pass filter [1] is a device that passes frequencies within a certain range and rejects (attenuates) frequencies outside that range. Power can be coupled [4],[5],[6] between the two transmission lines when they are brought close to each other because of interaction of electromagnetic fields of each line and these are called as coupled transmission lines [9],[10]. Coupled transmission lines [12],[13] are usually assumed to operate in the TEM mode[7], which is rigorously valid for stripline structures and approximately valid for microstrip structures. [2], [4].
The structure of a coupled transmission line is shown in the figure 1.

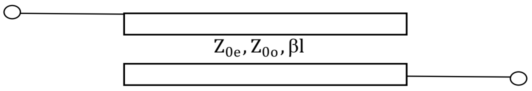


Figure 1: Structure of coupled transmission line

Z_{0e}: Even mode impedance
Z_{0o}: Odd mode impedance
βl : Electrical length

To map the low pass prototype to a band pass filter, the following frequency transformation is used [3],[9].

$$\omega' = \left(f_0/(f_2 - f_1)\right) * \left(\frac{f}{f_0} - \frac{f_0}{f}\right) \qquad \text{Eq.1}$$

$$f_0 = \sqrt{f_1 * f_2} \qquad \text{Eq.2}$$

Where, f_0, f_1 and $(f_2 - f_1)$ are the centre frequency, variable frequency and band-width respectively and f_1 and f_2 are the frequency band limits. Applying the frequency transformation [8] to series inductances and shunt capacitances of the low pass prototype gives,
Series-tuned series element:

$$C_k = 2\pi(f_2 - f_1)/(g_k * Z_L * (f_0)^2) \text{ farad} \qquad \text{Eq.3}$$

$$L_k = g_k * Z_L * \left(2\pi(f_2 - f_1)\right) \text{ henry} \qquad \text{Eq.4}$$

Series-tuned shunt element:

$$C_k = g_k/(2\pi(f_2 - f_1)Z_L) \quad \text{farad} \qquad \text{Eq.5}$$

$$L_k = 2\pi * (f_2 - f_1)Z_L/g_k(f_0)^2 \text{ henry} \qquad \text{Eq.6}$$

$$\text{were, } (\omega_0)^2 = 1/(\ L_k * C_k)$$

Even and odd mode impedance calculation

$$\frac{J_{01}}{Y_0} = \sqrt{\frac{\pi}{2}\frac{FBW}{g_0 g_1}}$$

$$\frac{J_{j,j+1}}{Y_0} = \frac{\pi FBW}{2}\frac{1}{\sqrt{g_j g_{j+1}}} \qquad j = 1 \text{ to } n-1$$

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

$$(Z_{0e})_{j,j+1} = \frac{1}{Y_0}\left[1 + \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right] \qquad j = 0 \text{ to } n \qquad \text{Eq.7}$$

$$(Z_{0o})_{j,j+1} = \frac{1}{Y_0}\left[1 - \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right] \qquad j = 0 \text{ to } n \qquad \text{Eq.8}$$

IV DESIGN METHODOLOGY

Designing a 1st order parallel edge coupled band pass microstrip filter of chebyshev type with 0.5dB pass band ripple and the bandwidth factor is 0.1. The dielectric constant is 4.6 and the thickness of the substrate is 1.57mm and the centre frequency is 2 GHz.

Initially the low pass prototype of 1st order is chosen with chebyshev type of 0.5dB pass band ripple. The low pass prototype parameters given for a normalised cut-off frequency $\Omega_C = 1$ are,

$g_0 = g_2 = 1.00$, $g_1 = 0.6986$.

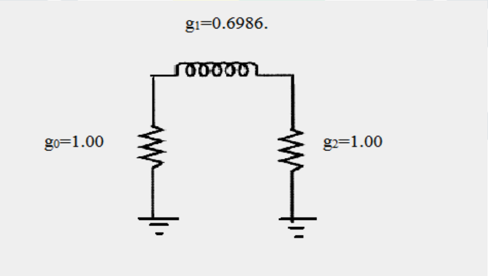


Figure 2: Circuit of band pass filter with low pass prototype

Lumped Components of series arm values of inductor and capacitor is 27.79nH and 0.2278pF. Band pass filter design using lumped components and optimization of the band pass filter using lumped components design is shown in the figure 3 and 4.

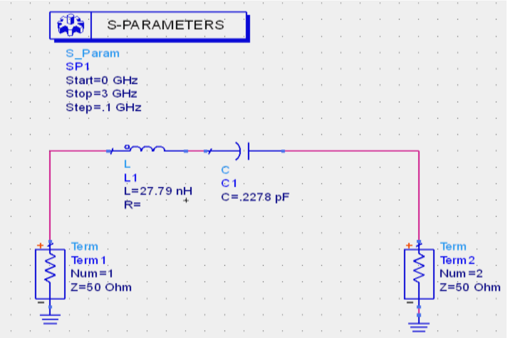


Figure 3: Circuit of band pass filter with low pass prototype

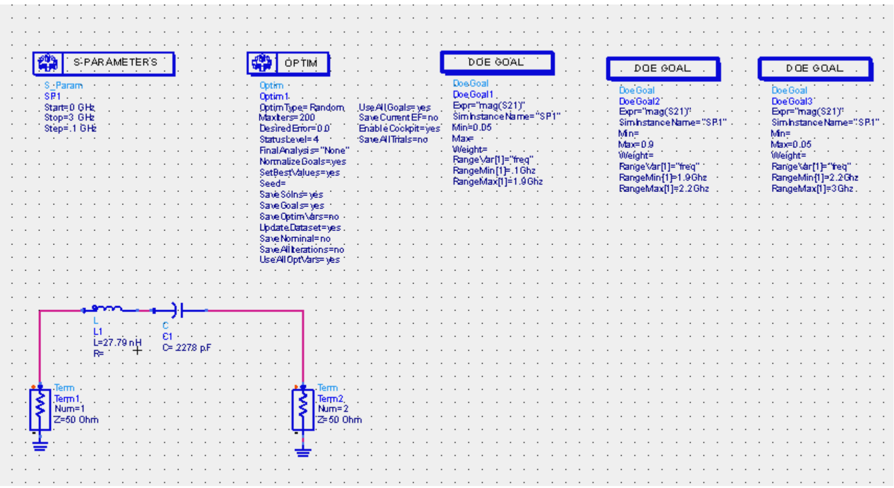


Figure 4: Optimization of the band pass filter using lumped components design

Tabulation of the coupled line even and odd mode impedance:

y,y+1	$J_{y,y+1}$	Z_{0e}	Z_{0o}
0,1	04741	84.94	37.53
1,2	0.4741	84.94	37.53

Width, length and gap calculation using Linc calc (ADS 2011.5 tool)

Z_{0e}	Z_{0o}	W_j(mm)	S_j(mm)	L_j(mm)
84.94	37.53	1.011525	0.6885	21.986424
84.94	37.53	1.011525	0.6885	21.986424

Band pass filter design using microstrip line components with its substrate FR4, thickness H 1.57mm and dielectric constant εr is 4.6 and its optimization is given in the figure 5 and 6.

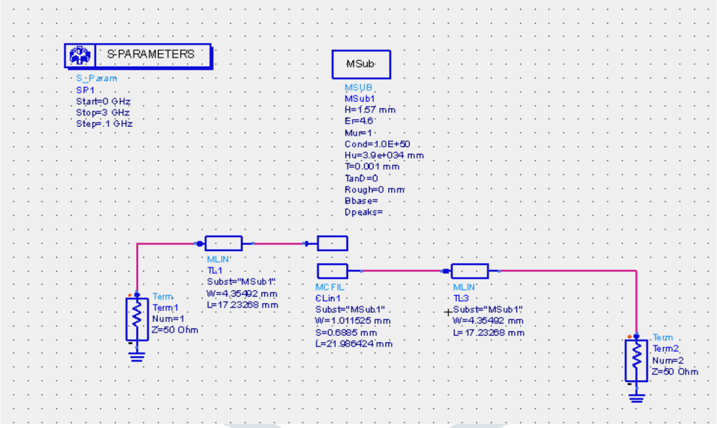


Figure 5: Band pass filter design using microstrip line components

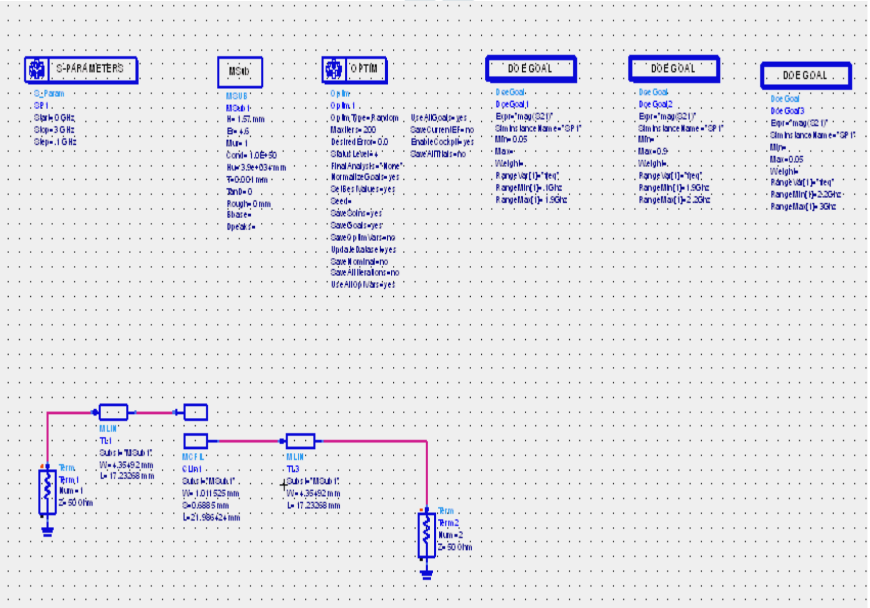


Figure 6: Optimisation of the band pass filter microstrip line design

Designing a 3rd order parallel edge coupled band pass microstrip filter of chebyshev type with 0.5dB pass band ripple and the bandwidth factor is 0.1. The dielectric constant is 4.6 and the thickness of the substrate is 1.57mm and the centre frequency is 2 GHz. Initially the low pass prototype of 3rd order is chosen with chebyshev type of 0.5dB pass band ripple. The low pass prototype parameters given for a normalised cut-off frequency $\Omega_C = 1$ are,

$g_0 = g_4 = 1.00$, $g_1 = g_3 = 1.5963$, $g_2 = 1.0967$

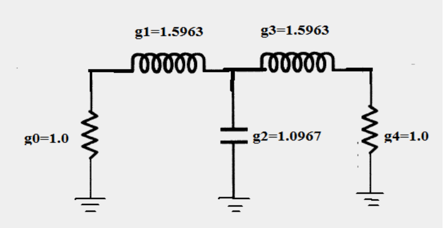


Figure 7: Circuit of band pass filter with low pass prototype

Lumped Components of series arm values of inductor and capacitor is 63.51nH and 0.0997pF and shunt arm values of inductor and capacitor is 0.362nH and 17.45pF. Band pass filter design using lumped components and optimization of the band pass filter using lumped components design is shown in the figure 8 and 9.

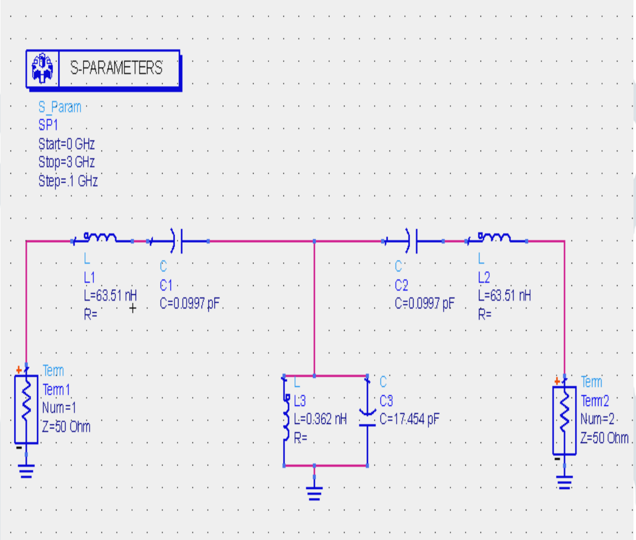
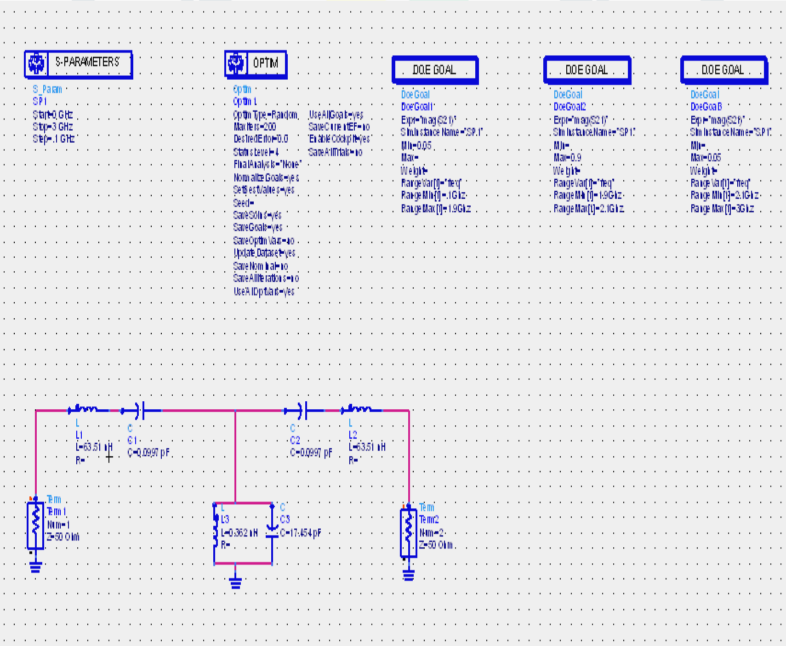

S-PARAMETERS
S_Param
SP1
Start=0 GHz
Stop=3 GHz
Step=.1 GHz

Figure 8: Circuit of band pass filter with low pass prototype


S-PARAMETERS
S_Param
SP1
Start=0 GHz
Stop=3 GHz
Step=.1 GHz

OPTIM
Optim
Optim1
OptimType=Random
MaxIters=200
DesiredError=0.0
StatusLevel=4
FinalAnalysis="None"
NormalizeGoals=yes
SetBestValues=yes
Seed=
SaveSolns=yes
SaveGoals=yes
SaveOptimVars=no
UpdateDataset=yes
SaveNominal=no
SaveAllIterations=no
UseAllOptVars=yes
UseAllGoals=yes
SaveCurrentEF=no
EnableCockpit=yes
SaveAllTrials=no

DOE GOAL
DoeGoal
DoeGoal1
Expr="mag(S21)"
SimInstanceName="SP1"
Min=0.05
Max=
Weight=
RangeVar[1]="freq"
RangeMin[1]=.1Ghz
RangeMax[1]=1.9Ghz

DOE GOAL
DoeGoal
DoeGoal2
Expr="mag(S21)"
SimInstanceName="SP1"
Min=
Max=0.9
Weight=
RangeVar[1]="freq"
RangeMin[1]=1.9Ghz
RangeMax[1]=2.1Ghz

DOE GOAL
DoeGoal
DoeGoal3
Expr="mag(S21)"
SimInstanceName="SP1"
Min=
Max=0.05
Weight=
RangeVar[1]="freq"
RangeMin[1]=2.1Ghz
RangeMax[1]=3Ghz

Figure 9: Optimization of the band pass filter using lumped components design

Tabulation of the coupled line even and odd mode impedance:

y,y+1	$J_{y,y+1}$	Z_{0e}	Z_{0o}
0,1	0.3137	70.605	39.235
1,2	0.1187	56.64	44.769
2,3	0.1187	56.64	44.769
3,4	0.3137	70.605	39.235

Width, length and gap calculation using Linc calc (ADS 2011.5 tool)

Z_{0e}	Z_{0o}	W_j(mm)	S_j(mm)	L_j(mm)
70.605	39.235	2.469210	.24377	20.185100
56.64	44.769	2.835510	1.71	20.059800
56.64	44.769	2.835510	1.71	20.059800
70.605	39.235	2.469210	.24377	20.185100

Band pass filter design using microstrip line components with its substrate FR4, thickness H 1.57mm and dielectric constant εr is 4.6 and its optimization is given in the figure 10 and 11.

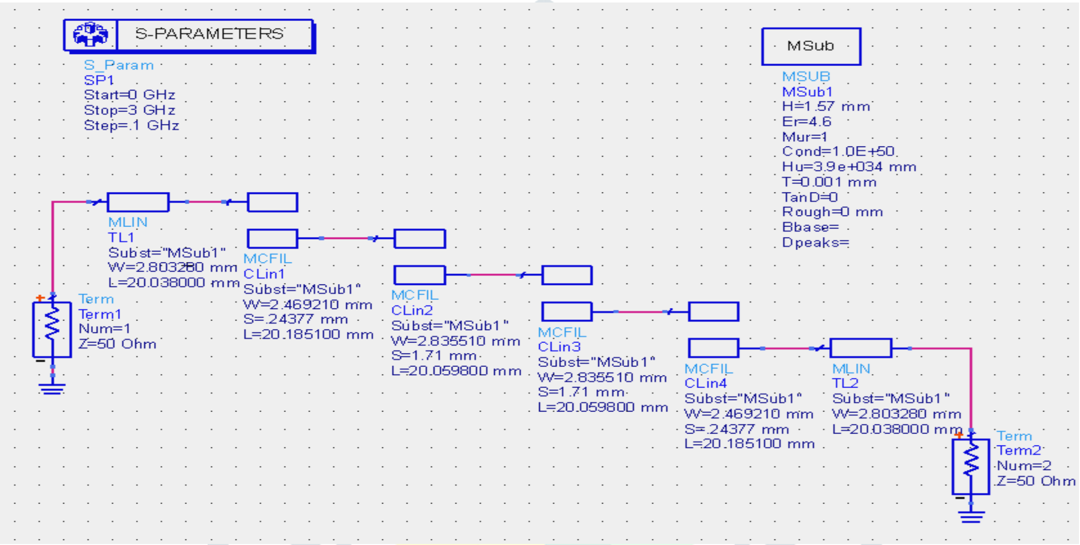


Figure 10: Band pass filter design using microstrip line components

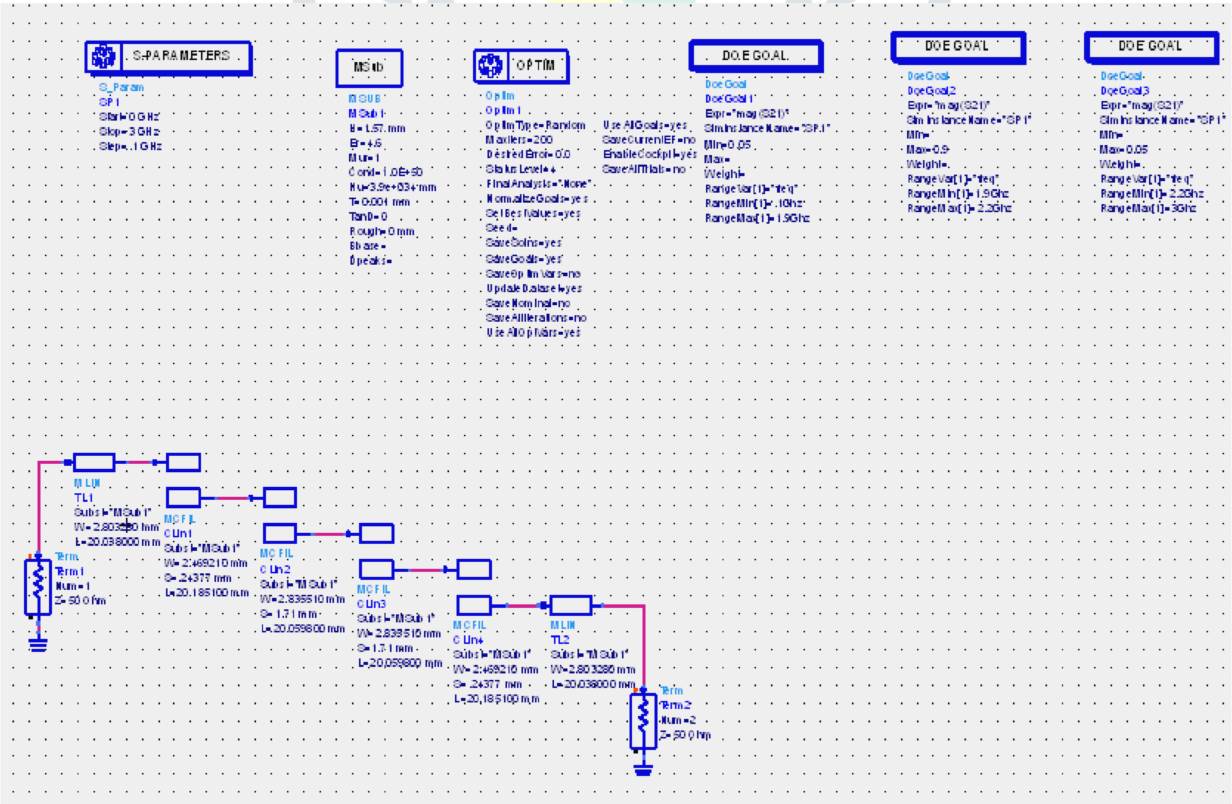


Figure 11: Optimisation of the band pass filter microstrip line design

IV. RESULTS AND DISCUSSIONS

The output for the 1st order parallel edge band pass filter using lumped design and microstrip line design is shown in the figure 12 and 13.

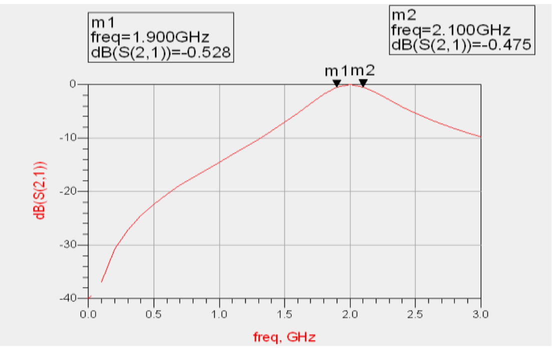


Figure 12: Output of band pass filter using lumped components design

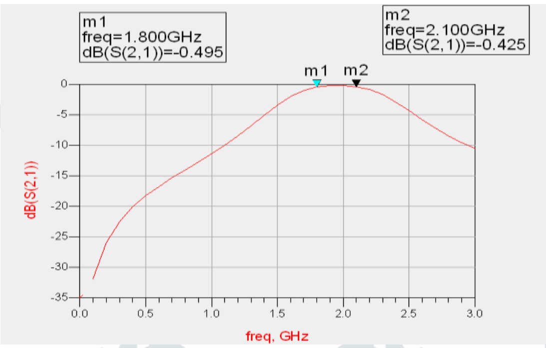


Figure 13: Output of the band pass filter microstrip line design

From the lumped component graph responses we, can see that the centre frequency of the filter is equal to 2GHz. So the designed band pass filter is able to pass signal between 1.8GHz to 2.2GHz with -3dB transmission coefficients and attenuate the signal outside the pass band frequency. From the graph we can observe that the centre frequency of the filter is equal to 1.9GHz. The designed band pass filter is able to pass signal between 1.6GHz to 2.4GHz with -3dB transmission coefficients and attenuate the signal outside the pass band frequency and there is slightly mismatch with the lumped components responses due to, non-accurate substrate modelling.

The 1st order parallel coupled band pass filter realization through layout design and its output response is shown in the figure 14 and 15.

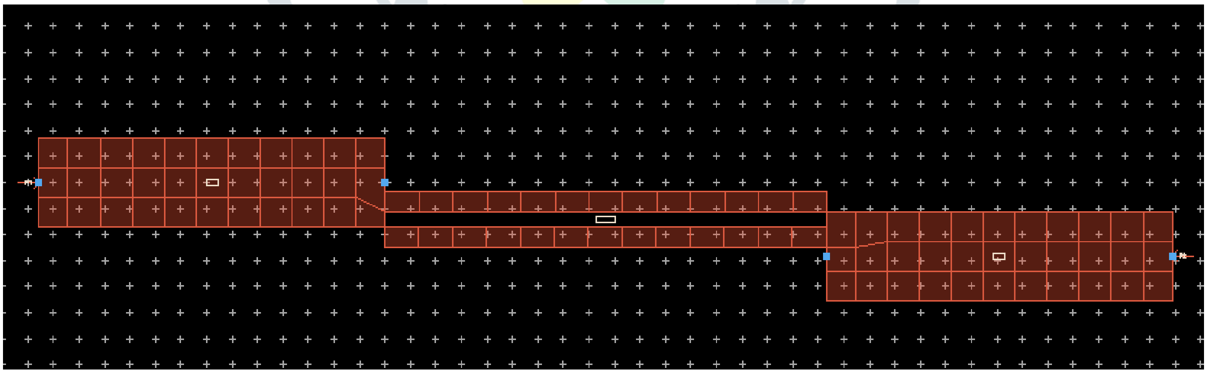


Figure 14: Band pass filter realisation through layout design

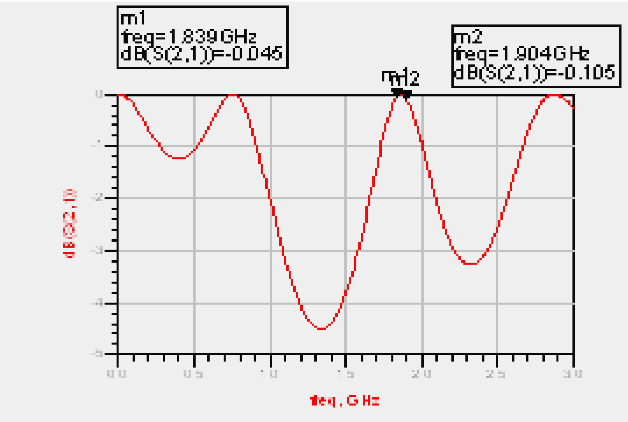


Figure 15: Output of band pass filter layout design

From the graph we can observe that the centre frequency of the filter is equal to 1.8GHz. The designed band pass filter is able to pass signal between 1.6GHz to 2.2GHz with -3dB transmission coefficients and attenuate the signal outside the pass band frequency. The slight difference between frequency response of the band pass filter in EM simulation and schematic strip line simulation because, during EM simulation (using the method of movements technique), the number of division per wavelength are 20. Therefore the accuracy of the EM simulation can be enhanced just by increasing number of divisions per wavelength (in method of movement simulation technique) and also by the accurate modelling of the substrate.

The output for the 3rd order parallel edge band pass filter using lumped design and microstrip line design is shown in the figure 16 and 17.

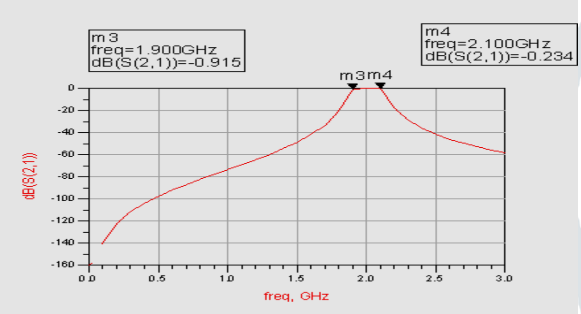


Figure 16: Output of band pass filter using lumped components design

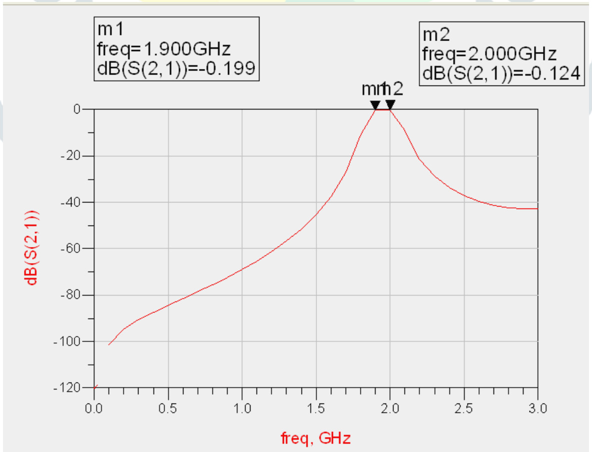


Figure 17: Output of the band pass filter microstrip line design

From the lumped component graph responses, we, can see that the centre frequency of the filter is equal to 2GHz. So the designed band pass filter is able to pass signal between 1.9GHz to 2.1GHz with -3dB transmission coefficients and attenuate the signal outside the pass band frequency. From the microstrip line graph response, we can observe that the centre frequency of the filter is equal to 1.9GHz. The designed band pass filter is able to pass signal between 1.89GHz to 2.1GHz with -3dB transmission coefficients and attenuate the signal outside the pass band frequency and there is slightly mismatch with the lumped components responses due to, non-accurate substrate modelling.
The 3rd order parallel coupled band pass filter realization through layout design and its output response is shown in the figure 18 and 19.

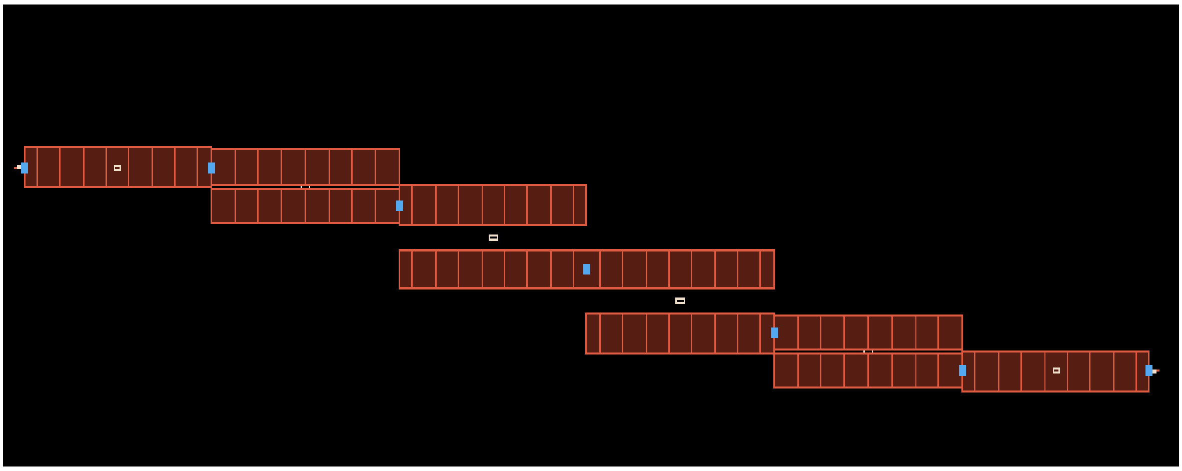


Figure 18: Band pass filter realisation through layout design

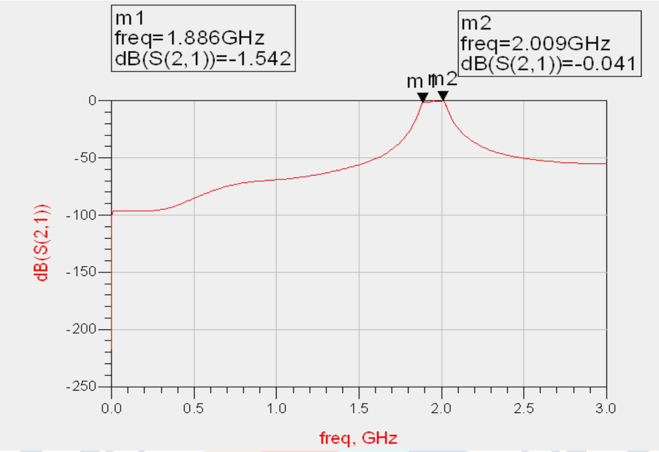


Figure 19: Output of band pass filter layout design

From the graph we can observe that the centre frequency of the filter is equal to 1.9GHz. The designed band pass filter is able to pass signal between 1.85GHz to 2.01GHz with -3dB transmission coefficients and attenuate the signal outside the pass band frequency. The slight difference between frequency response of the band pass filter in EM simulation and schematic strip line simulation because, during EM simulation (using the method of movements technique), the number of divisions per wavelength are 20. Therefore, the accuracy of the EM simulation can be enhanced just by increasing number of divisions per wavelength (in method of movement simulation technique) and also by the accurate modelling of the substrate.

V. CONCLUSION

In this paper, we have studied the frequency responses of lumped components and microstrip line parallel edge coupled band pass filters with 1st order and 3rd order.

Order of the filter determines the number of reactive elements needed for the filter design. From the design we noticed that the 1st order filter the centre frequency is equal to 1.8GHz and with 3rd order filter the centre frequency is equal to 1.9GHz. Therefore, by increasing the order from 1st to 3rd the centre frequency is approximately equal 2GHz and it helps us to reach the ideal response of the filter. Higher the order of filter, the difficult the required changes in characteristics impedance become, however the performance of a filter improves with an order increase.

From the frequency responses of filters of lumped components, we have come to know that reactance of the lumped components varies with respect to frequency. So, from this behaviour, it has been come to the conclusion that lumped component filters not suitable for high frequency applications. So, in order to fulfil the high frequency applications demands, microstrip line filters of parallel edge coupled band pass has been studied using Advanced Design System tool and results of microstrip line filters matching with lumped components filters and these structures are fabricated on FR4 substrate.

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