Design of a Butterworth bandpass filter in microstrip line technique

Group 3:

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1. Introduction:

   Nowadays, bandpass filters are important for any microwave system such as satelite communication. And with the technological developments, the size of the system components such as microwave filter become smaller. Microstrip line filters are more compact, smaller size than coaxial cable or waveguide filters. Therefore, these lead to using microstrip line as filter elements.

   In this paper, we will briefly give some backgrounds in microwave filters in Chapter 2, our Butterworth bandpass filter design and simulation in Chapter 3.

2. Background:

   2.1 Low-pass prototype filter:

   The low-pass filter component values are defined by:

$$L'_k = \frac{R_0 L_k}{\omega_c}, \qquad (4)$$

$$C'_k = \frac{C_k}{R_0 \omega_c}. \qquad (5)$$

   2.2 Bandpass filter transformations:

   Low-pass filter can be transformed to be bandpass filter. If ω_1 and ω_2 denote the edges of the passband, then we have:

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

$$\omega_0 = \sqrt{\omega_1 \omega_2}.$$

   Where Δ is the fraction bandwidth of the passband, and ω_0 is the center frequency. And the element transformations from a low-pass prototype to a bandpass filter are summarized in table 1.

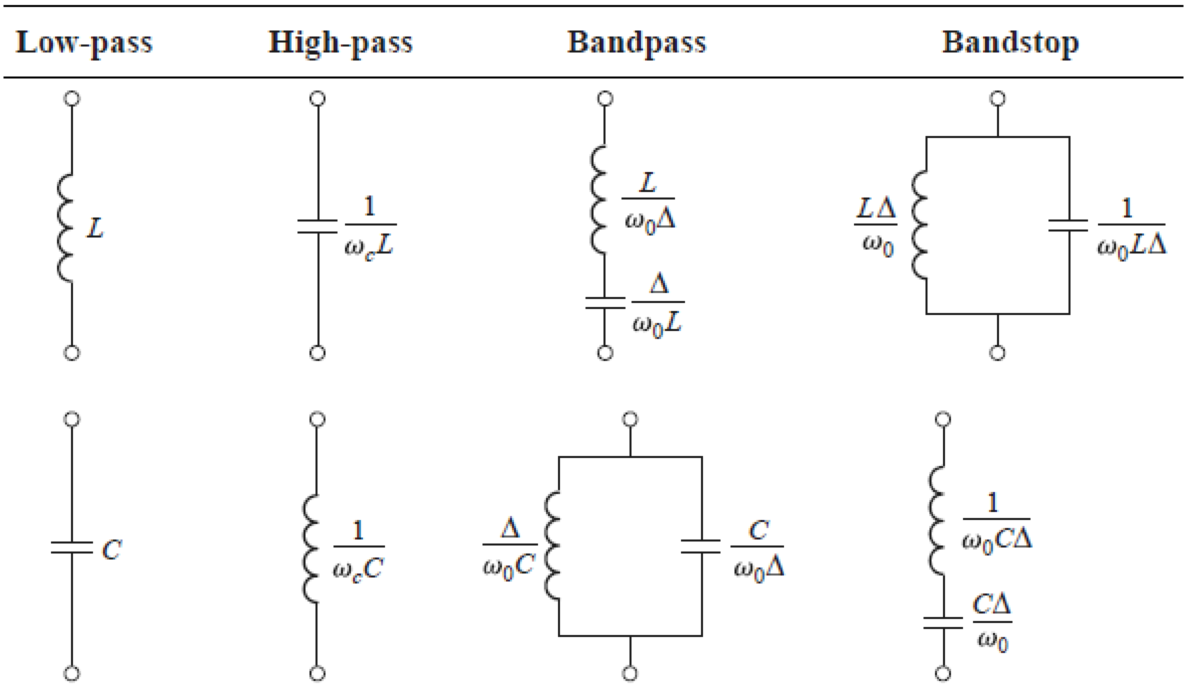

Table 1: Summary of prototype filter transform [1]

2.3 Coupled Line Filters:

The parallel coupled line filters are the most common microstrip filters. The design equations for the Butterworth filter are given by [1]

$$\frac{J_{01}}{Y_0} = \sqrt{\frac{\pi}{2}\frac{FBW}{g_o g_1}} \tag{1}$$

$$\frac{J_{j,j+1}}{Y_o} = \frac{\pi FBW}{2}\frac{1}{\sqrt{g_j g_{j+1}}} \quad ; j=1 \text{ to } n-1 \tag{2}$$

$$\frac{J_{n,n+1}}{Y_o} = \sqrt{\frac{\pi FBW}{2 g_n g_{n+1}}} \tag{3}$$

Where n is a number of filter order, in our case n = 3, and g0, g1,… gn are the prototype element value of the Butterworth filter, and FBW (Δ) is the fractional bandwidth of bandpass filter. J j,j+1 are the characteristic admittances of J-inverters and Y0 is the characteristic admittance of the terminating lines.

The even Zcen and odd Zcon mode impedance of the coupled line section n are determined by

$$(Z_{0e})_{j,j+1} = \frac{1}{Y_o}\left[1 + \frac{J_{j,j+1}}{Y_o} + \left(\frac{J_{j,j+1}}{Y_o}\right)^2\right] \text{j = 0 to n} \quad (4)$$

$$(Z_{0o})_{j,j+1} = \frac{1}{Y_o}\left[1 - \frac{J_{j,j+1}}{Y_o} + \left(\frac{J_{j,j+1}}{Y_o}\right)^2\right] \text{j = 0 to n} \quad (5)$$

3. Design and Simulation:

3.1 Simulators:

In this work Advanced Design Studio 2011 has been used.

3.2 Design specification:

Filter Type	Butterworth
Number of order, n	3
Center frequency, f_0	2450 MHz
Bandwidth, B	100 MHz

The substrate parameters are as follows:

- Name: RT/Duroid 4350B
- Dielectric constant, Er = 3.48
- Substrates thickness, H = 0.762 mm
- Metal thickness, T = 17.5 um
- Tang D = 0.0046 at 10 GHz
- Conductivities = 5.8e7

3.3 Design:

3.3.1 Ideal lumped bandpass filter:

In theory, low-pass prototype filter designs can also be transformed to have the bandpass filter. Therefore we design a lumped low-pass prototype filter first. Using the design equations (4) and (5), we get the following value of L'_k and C'_k:

L'_k = 5.18 nH , C'_k = 1.425 pF

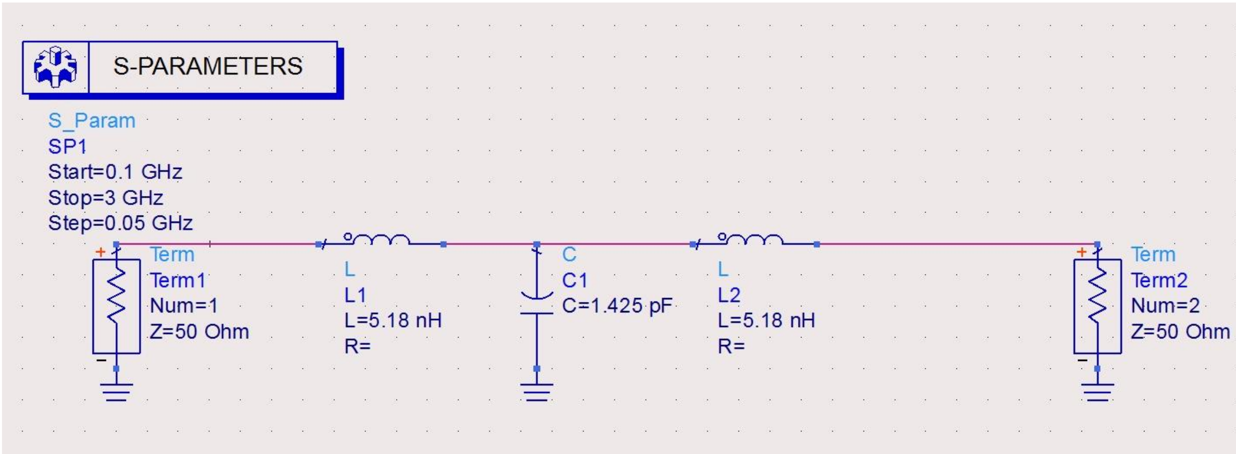

Figure 1: Ideal lump low-pass filter

Then, we transform the low-pass prototype to bandpass filter based on table 1. We get the following table and an ideal lump bandpass filter:

	L	C
Series Inductance	126.46 nH	0.033 pF
Parallel Capacitance	0.121 nH	34.75 pF

Table 2 : Filter elements value for the ideal lump bandpass filter

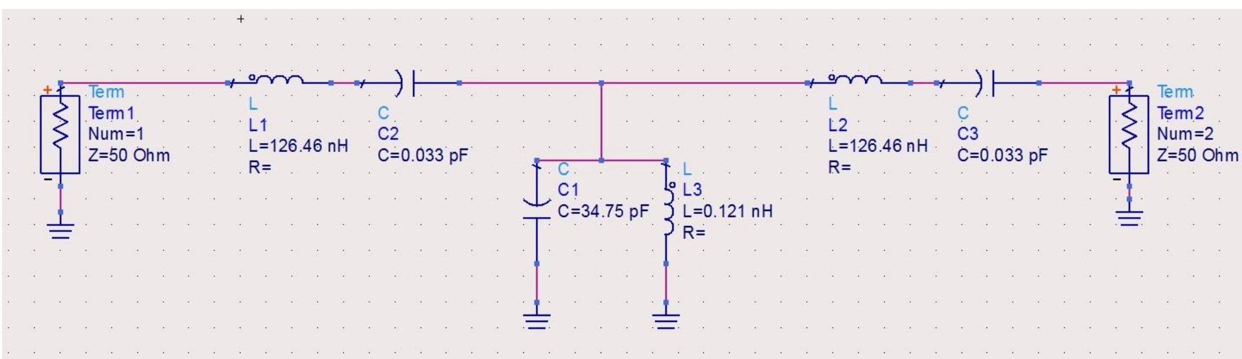

Figure 2: Ideal lump band-pass filter

3.3.2 Ideal couple line band pass filter:

It is hard for us to realize the lump elements band pass filter using Kuroda's identities method. Instead, we use the micro strip couple line technique to transform from the ideal lump element band pass filter directly to the ideal couple line band pass filter. Below is the picture of the band pass filter elements after using this technique in the ADS with CLIN components:

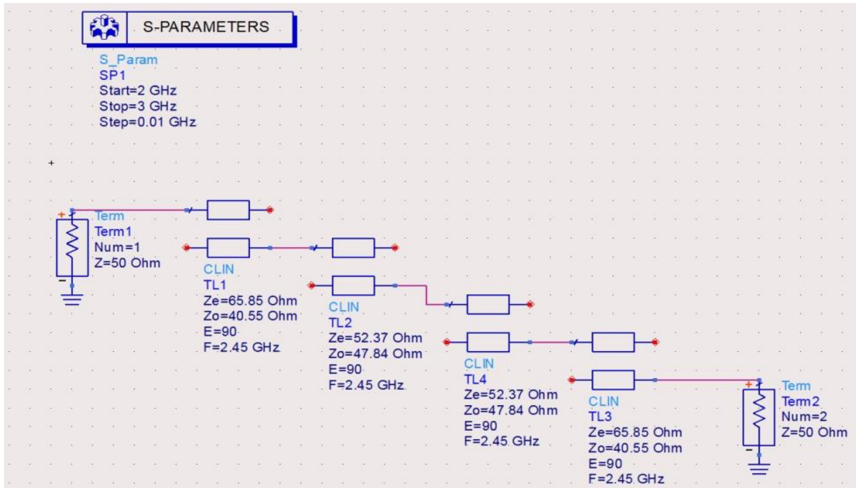

Figure 3: Ideal band pass filter micro strip line with CLIN components.

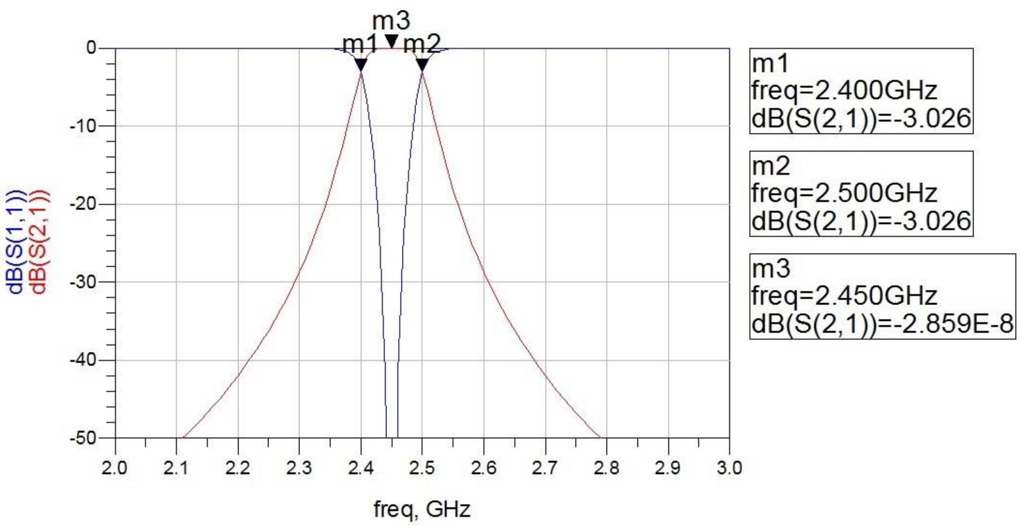

Figure 4: Simulated transmission and reflection coefficients of the CLIN

As you can see we achieve a very good result from the simulation. Now we use the LineCalc function in ADS to design the micro strip line with real parameters.

3.3.3 Ideal band pass filter with the real parameters:

In this part we change from the CLIN component to the MCLIN component which has the parameters of the micro strip line in real life. To simplify the process we will not include some of the real parameters of the given substrate RT/Duroid 4350B but with the idea parameters (set the Cond= 5.8e20 and TanD= 0.00). Figures below will show us the result of this transform.

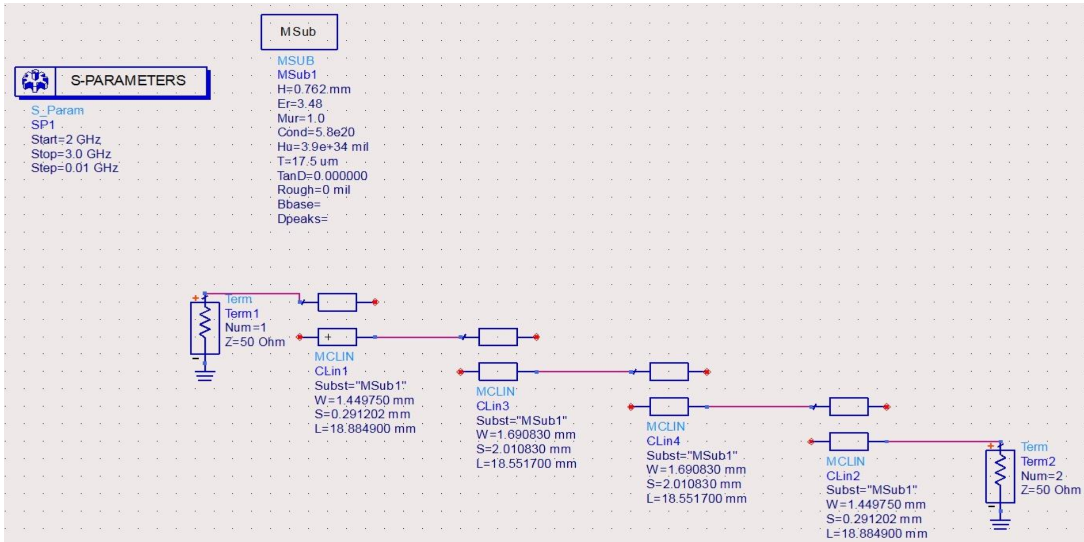

Figure 5: Ideal band pass filter micro strip line with MCLIN components.

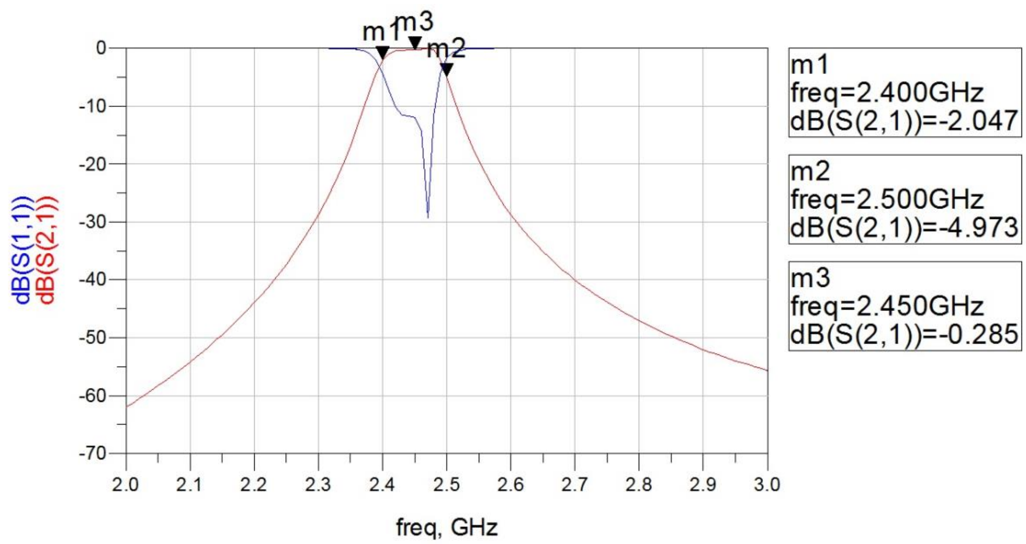

Figure 6: Simulated transmission and reflection coefficients of the MCLIN

As we can see, we have a little shift in center frequency and the loss in power of the coefficients in the simulated results. We cannot reduce the loss in power because it is the effect of the substrate but we can change the shifted center frequency back to the center frequency at 2.45 GHz and the different between the center frequency and the cut off frequencies back to nearly -3 dB by changing parameters of the MCLIN but must keep the E_Eff= 90 in LineCalc. Below is the optimized result.

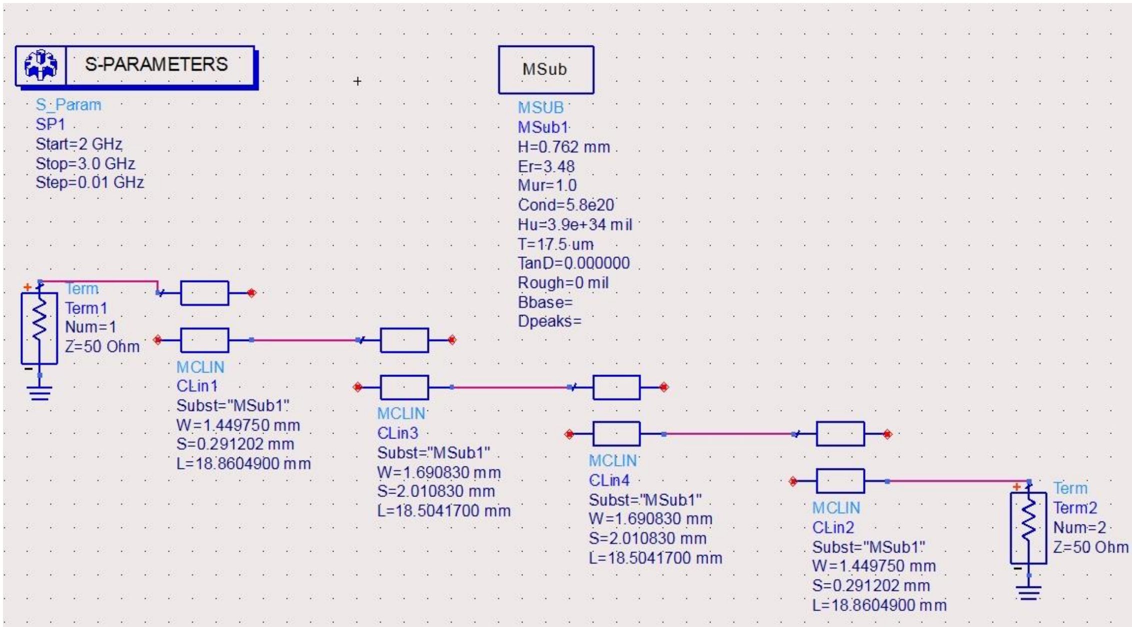

Figure 7: Optimized ideal band pass filter micro strip line with MCLIN components.

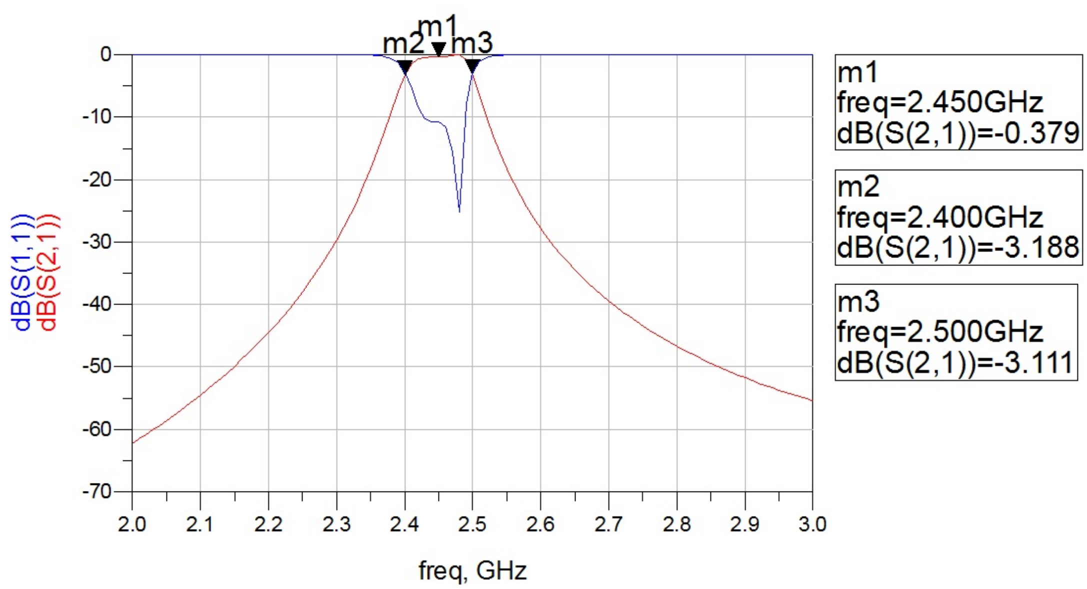

Figure 8: Simulated transmission and reflection coefficients of the optimized MCLIN

3.3.4 Band pass micro strip coupled line filter section:

The next step is to transform the ideal micro strip coupled line to the micro strip coupled line filter section. We substitute the MCLIN components with the MCFIL components. Below is the schematic and the simulated result.

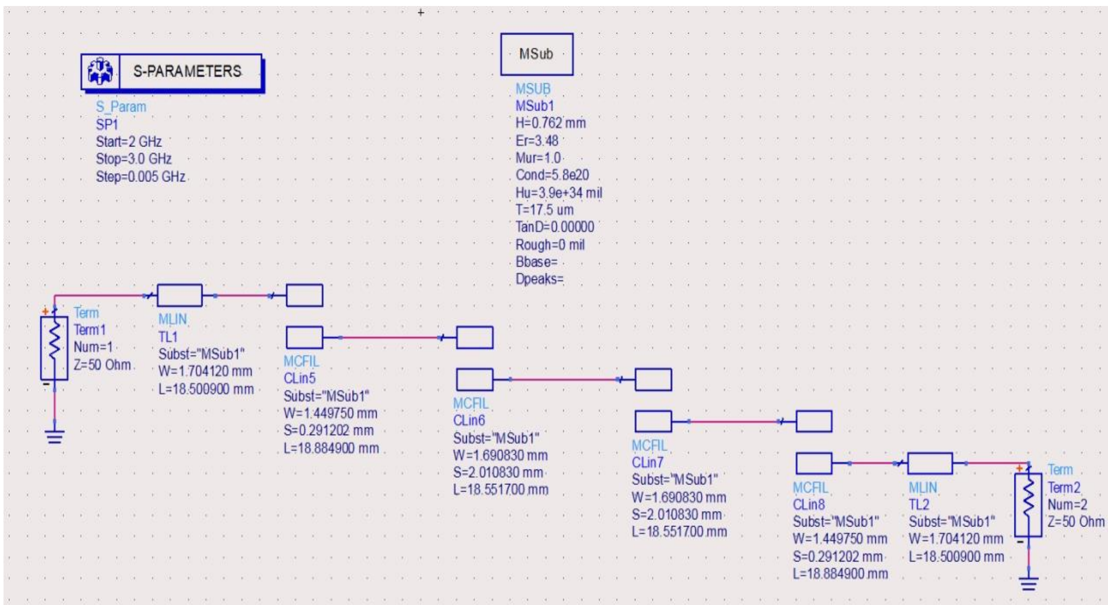

Figure 9: Band pass filter with MCFIL components.

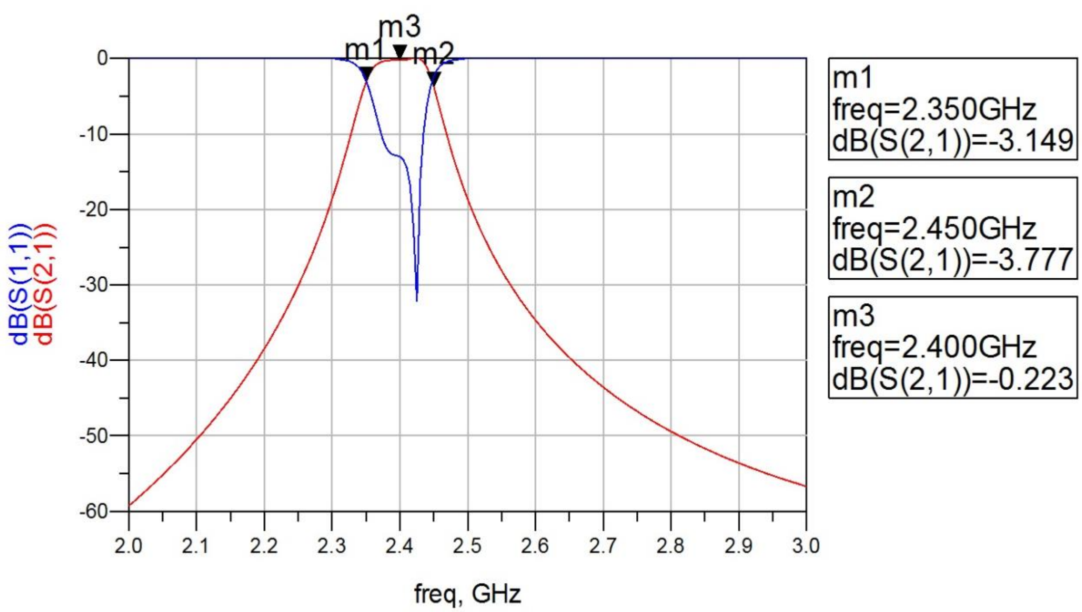

Figure 10: Simulated transmission and reflection coefficients of the MCFIL.

Compare the coefficients result of the MCFIL components to the MCLIN components:

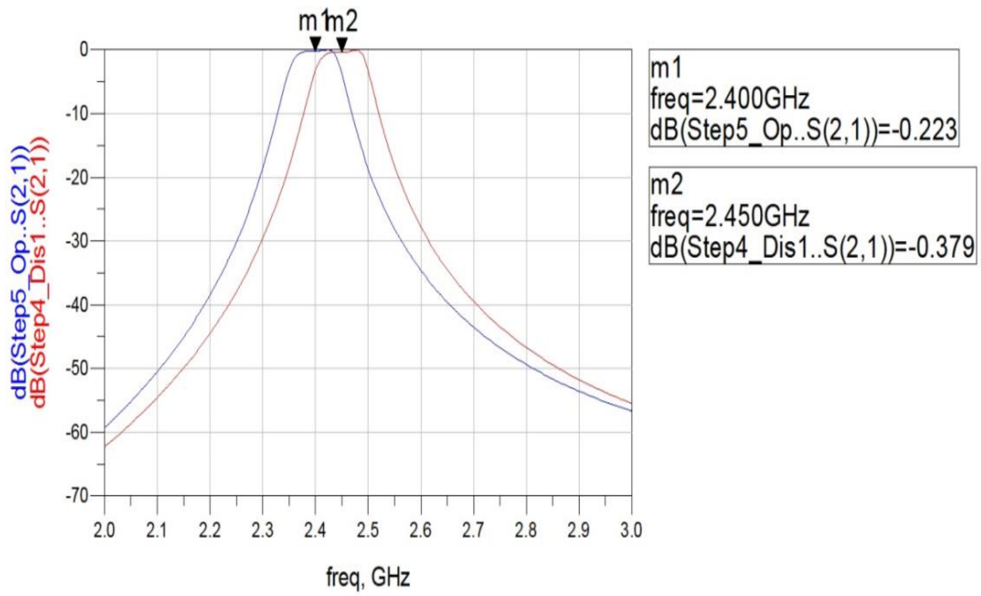

Figure 11: Transmission coefficients of the MCFIL and MCLIN.

As we can see from the result there is a very large shift of the center frequency when you change the components from MCLIN to MCFIL because when we use MCFIL, we take account the fringing affect thus make the center frequency shifted.

It is very hard for us to shift back the graph to the desired center frequency by changing parameters of the MCFIL to get the unchanged shape and E_Eff angle get from the LinaCalc. So instead we try to calculate the shifting effect of the transformation from MCLIN to MCFIL then design a new MCLIN schematic to get rid of this affect. We can see that the graph is shifted to the left with the center frequency from 2.45 GHz to 2.4 GHz with the shift about 0.05 GHz, so then if we design a MCLIN schematic with the center frequency about 2.5 GHz then when we change it to MCFIL schematic we will have the graph with the wanted frequency and shape. Below is the result we get from the MCLIN schematic with the frequency at 2.495 GHz:

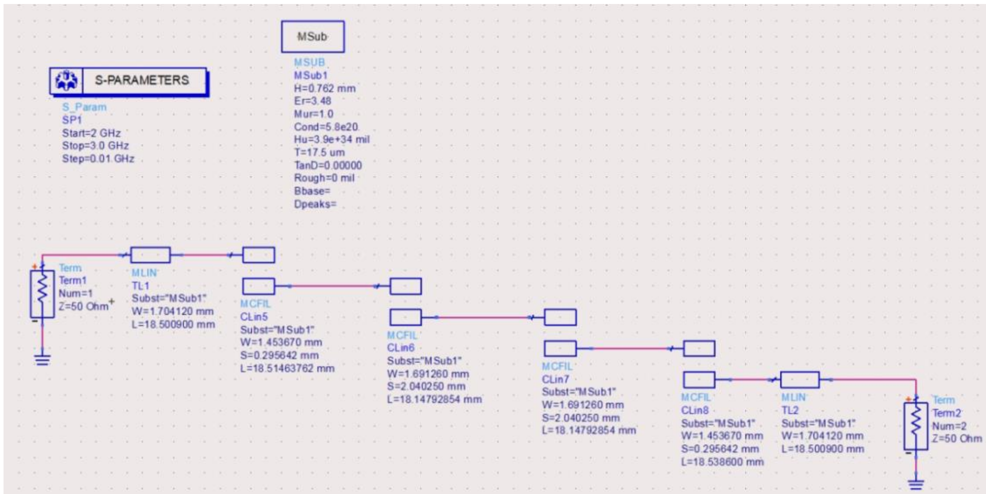

Figure 12: Band pass filter with center frequency at 2.495 GHz

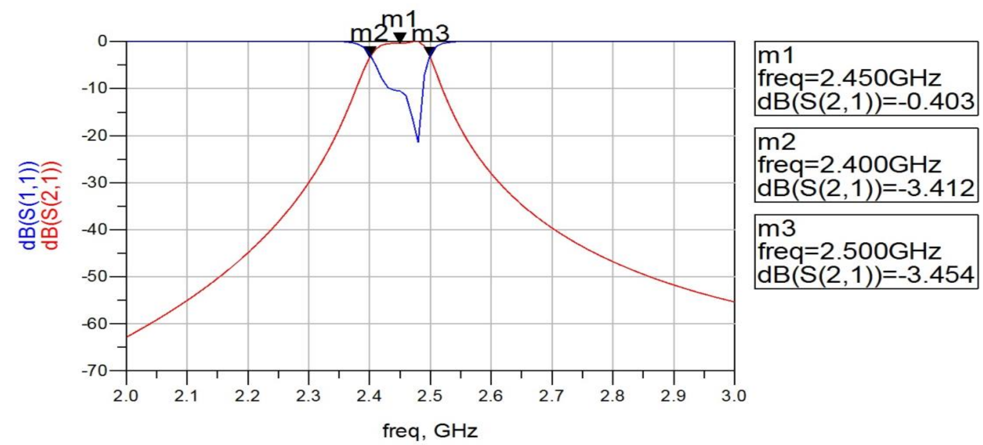

Figure 13: Simulated transmission and reflection coefficients at 2.495 GHz

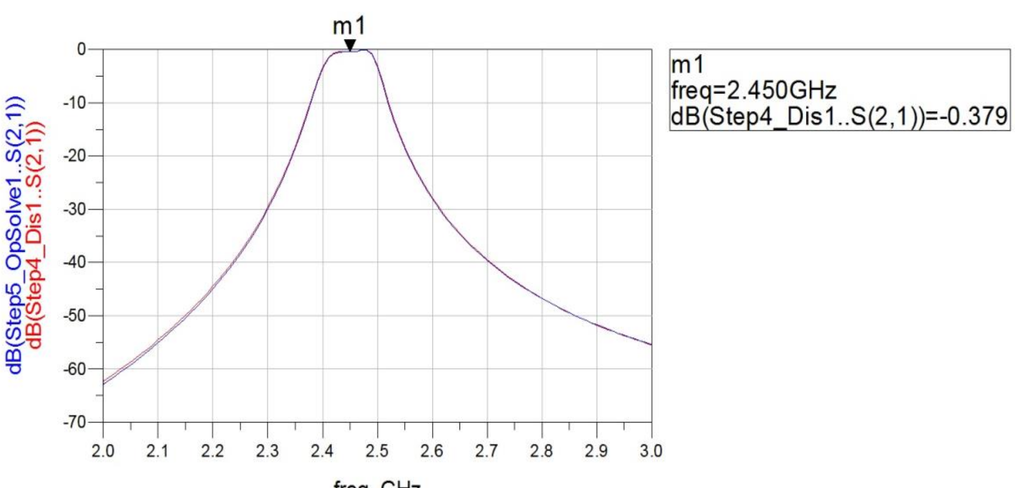

Figure 14: Transmission coefficient result of the MCLIN at 2.45 GHz and MCFIL at 2.495 GHz

As we can see we get the very good coefficient result with nearly the same graph between the ideal MCLIN components schematic at 2.45 GHz and MCFIL components schematic at 2.495 GHz. Thus with this we can move to the next part of the design process is to make a discontinuities micro strip coupled line.

3.3.5 Discontinuities micro strip coupled line:

To make the discontinuities micro strip coupled line we add the MSTEP components to serve as simulation of the difference in width between components then 2 ports at the end of the transmission line. The result is shown below:

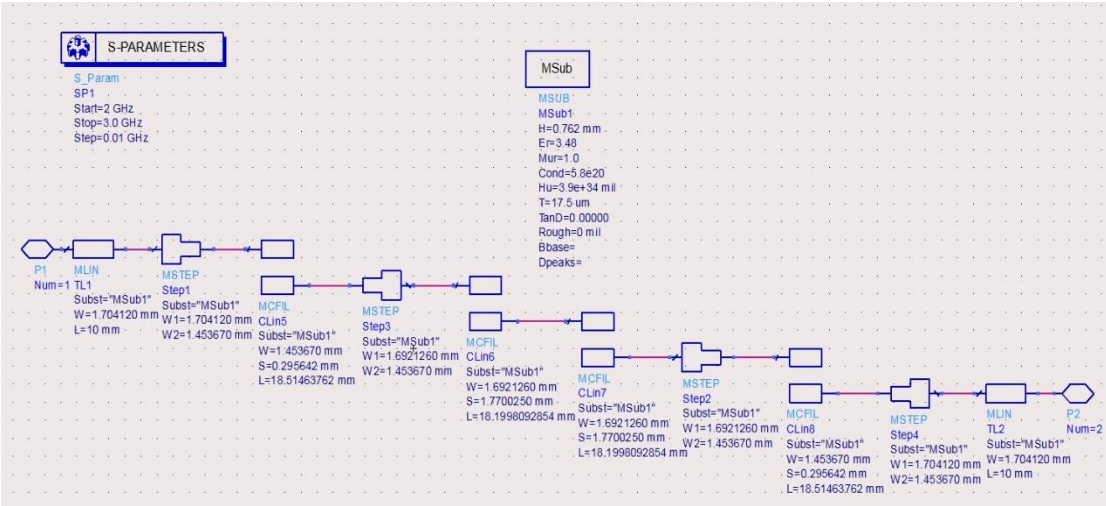

Figure 15: Discontinuities micro strip coupled line schematic

With the discontinuities micro strip coupled line schematic we then can run the momentum stimulation. In the substrate part of the stimulation, we add the missing parameters of the given substrate RT/Duroid 4350B which is the Cond= 5e7 and TanD= 0.0046. Thus we get the result shown below:

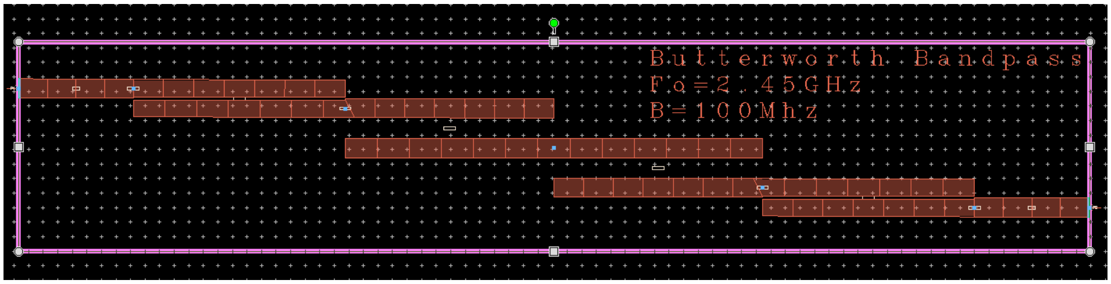

Figure 16: The band pass board layout

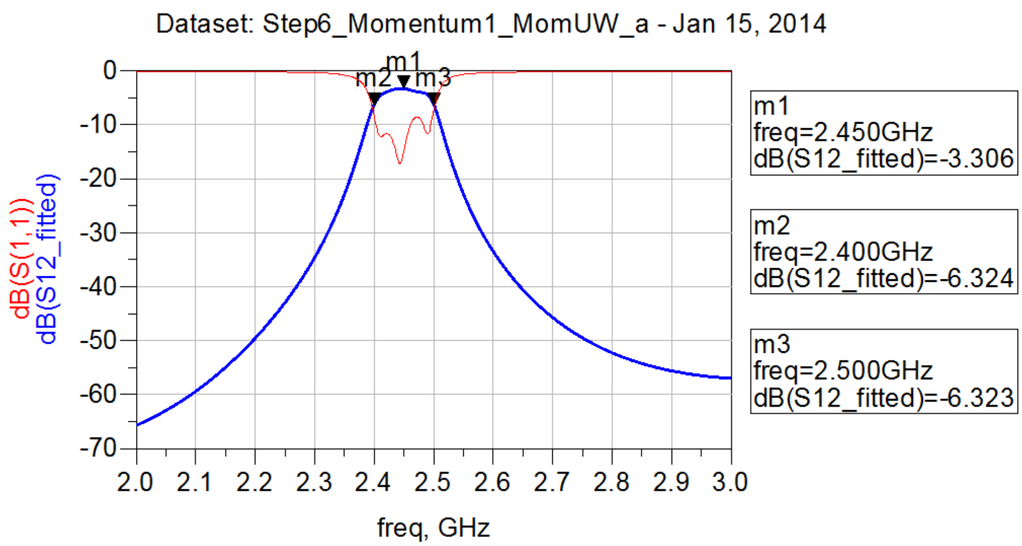

Figure 17: Simulated transmission and reflection coefficients of the layout.

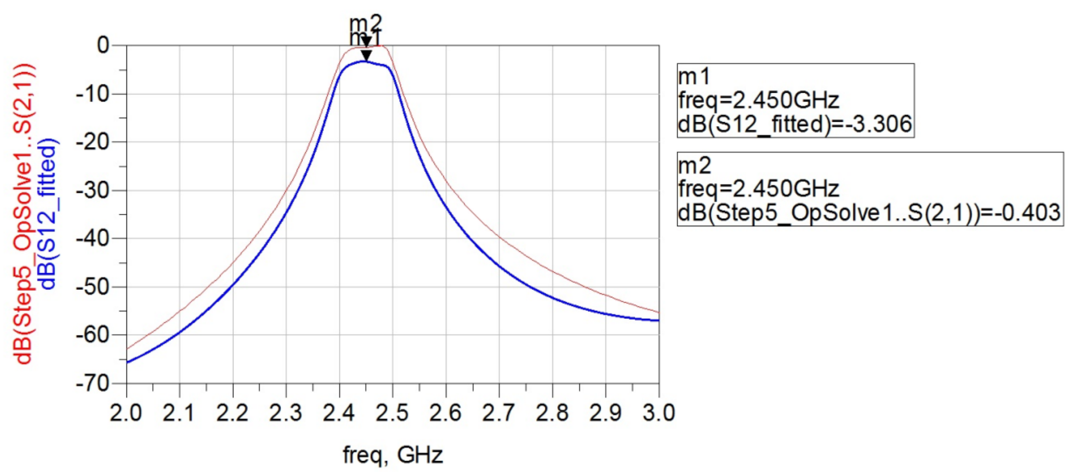

Figure 18: Transmission coefficients of the MCFIL schematic and the layout board

From the graph we see that after transfer from MCFIL to layout we have a dramatic loss in the power of the filter, the main cause of this loss come from when we add the real parameters Cond and TanD to the substrate instead of using ideal parameters.

With the layout schematic finally we can make the real band pass filter. In the next section we will see and compare the results we got from the actual band pass filter and the stimulated one.

3.4 The result of the actual bandpass filter in real life:

After measure the real band pass filter, this is the graph we create from the data get from the measurement.

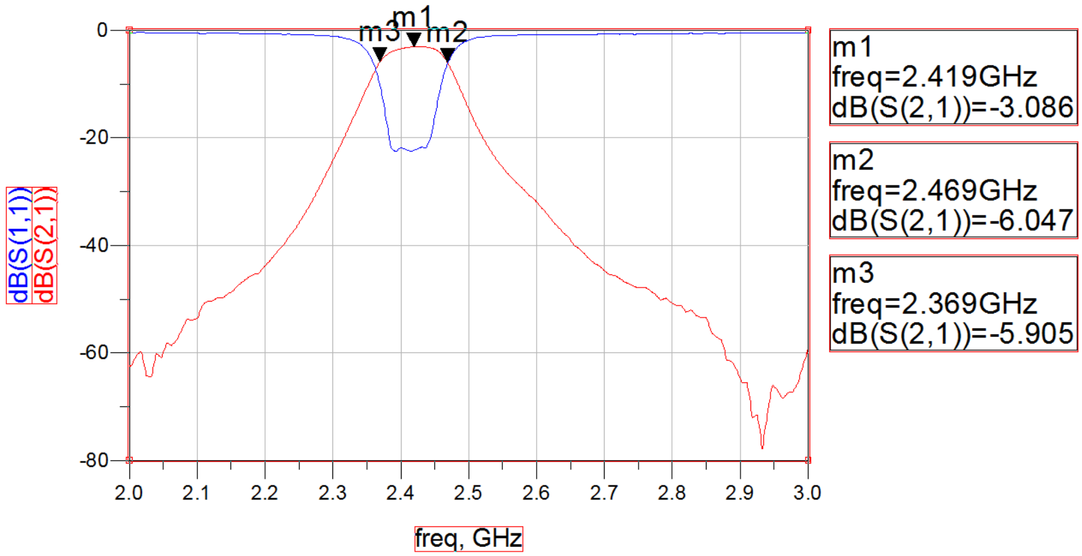

Figure 19: Transmission and reflection coefficients of the actual band pass filter

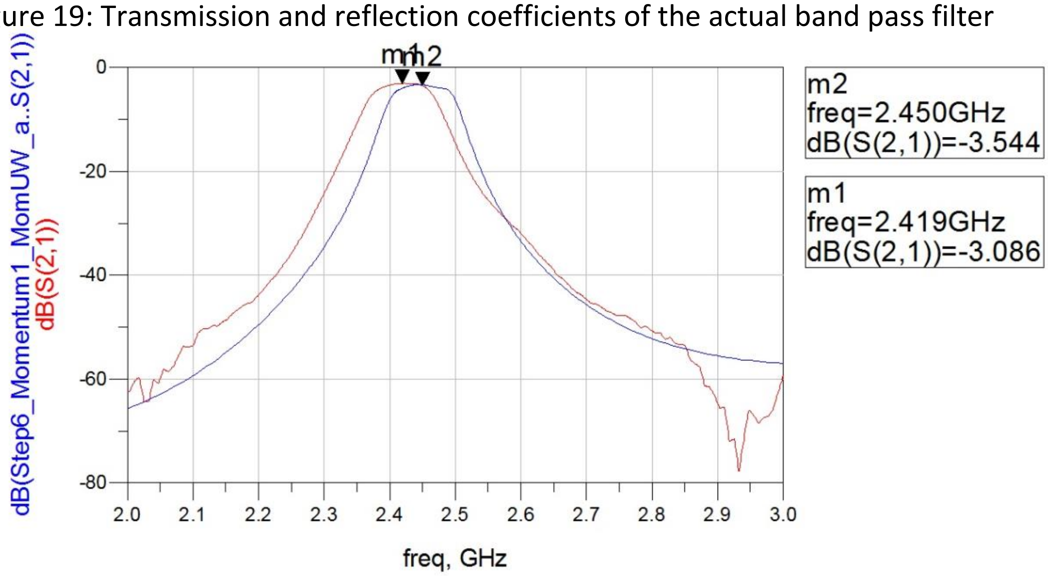

Figure 20: Transmission coefficients of the actual band pass filter

As we can see there is a shift in center frequency of the graph between the stimulation and the real result. The center frequency is shifted from the 2.45 GHz to about 2.419 GHz, the shift is about 0.031 GHz

This shift may be cause from the deviation of the machine and the process of making circuit board.

4. Conclusion:

   The measured results were close to the simulated but not matched with the desired specification. One main reason is substrate material. Second reason is the problem of making circuit board. There were some problems with the driller when circuit was made. This could be due to the deviation to make the shifted center frequency in figure 20. Although the filter did not meet the specification perfectly, but there are still rooms for further improvement such as change a better substrate.