C-Band Microstrip Band Pass Filter Design

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Abstract- In this article, a complete procedure is shown to develop, design and simulate a microstrip band pass filter working at a center frequency of 5.25 GHz with lower and upper cut-off frequencies as 5 GHz and 5.5 GHz respectively. The Chebyshev prototype of 0.5 dB passband ripple is chosen for the design. In this work, designing of Low Pass filter prototype is explained and then impedance and frequency scaling is performed to achieve a band pass filter. The band pass filter is then further designed using lumped components (L & C), Ideal microstrip lines, practical microstrip lines, and finally microstrip layout version is also presented at the last. The agreement between theoretical and simulated results seems good.

Index Terms- Microstrip Filter, BPF, Chebyshev Prototype, MCFIL, CLIN.

1. INTRODUCTION

Band Pass filter is a type of filters that allows a range of frequencies to go through without much attenuation and stops the frequencies lie outside the specified range. Most of the communication systems work for a certain band of frequencies and hence they incorporate a band pass filter, most of the time, just after the Low Noise Amplifier as shown in Fig. 1. [3,4,5]
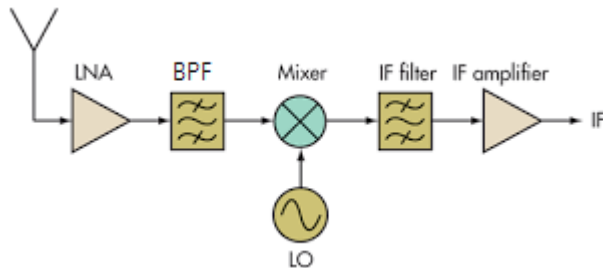

Fig. 1: Block Diagram of RF Receiver system

A practical filter demands low cost, compact size, close to unity gain in passband and high attenuation in stop band. At the RF frequencies, wavelength is almost comparable to the dimensions of the lumped components which leads to distortions in output and degrades the performance. To overcome this problem, microstrip filters are preferred. They are compact in size, have low cost and provide better performance. There are several techniques to design the RF filters as listed below: [4]

1. Butterworth Filter
2. Chebyshev Filter
3. Linear Phase Filter
4. Elliptic Filter

2. FILTER DETAILS

In this work, a Chebyshev prototype with 0.5 dB passband ripple is used for designing the filter. The specifications of the filter are chosen to be as shown in Table 1.

Table 1: Parameters of the Filter

Parameter	Value
Order of the filter	5
Source Impedance (R_0)	50 Ohms
Center Frequency	5.25 GHz
Operating Range	5 GHZ – 5.5 GHz
Substrate	Rogers RO3003
Dielectric Constant	3
Loss Tangent	0.001

2.1 Low-Pass Prototype

Firstly, a low pass prototype is designed considering source impedance to be 1 Ohm and cut off frequency to be 1 rad/sec. by using table 8.4 of [4], the element values for the 5th order filter prototype are selected as shown in Table 2.

Table 2: Element values for 5th order filter prototype

Parameter	Value	Element
g_1	1.7058	C_1
g_2	1.2296	L_2
g_3	2.5408	C_3
g_4	1.2296	L_4
g_5	1.7058	C_5
g_6	1.0000	Z_L

Once the prototype values are obtained, frequency and impedance scaling are performed to achieve the lumped model of the filter. Transformation equations for impedance and frequency scaling are given below:

$$L'_k = \frac{R_0 L_k}{\omega_c} \qquad (1)$$

$$C'_k = \frac{C_k}{R_0 \omega_c} \qquad (2)$$

where R_0 is 50 Ohms and ω_c is the angular cut off frequency. After applying Eq. (1) and (2), the element values that were obtained are summarized in table 3.

Table 3: Component values after impedance and Frequency scaling

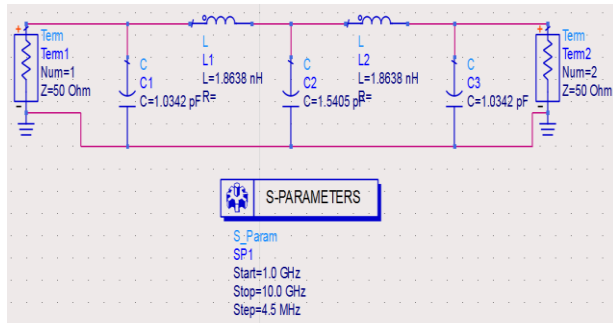| Parameter	Value (C in pF, L in nH)
C_1	1.0342
L_2	1.8638
C_3	1.5405
L_4	1.8638
C_5	1.0342
Z_L	50 Ohm

Fig. 3: Low Pass filter prototype using lumped components

Figure 3 shows the Low pass filter designed using the lumped components of values given in Table 3. The S parameter analysis is carried out for a frequency range of 1 GHz – 10 GHz in the steps of 4.5 MHz.

Figure 4 displays the analysis result of this filter. Input return loss (S_{11}) and forward transmission coefficient (S_{12}) are plotted against frequency. As shown in the figure, the cut-off frequency obtained is 5.244 GHz where both S_{11} and S_{21} are intersecting with each other.
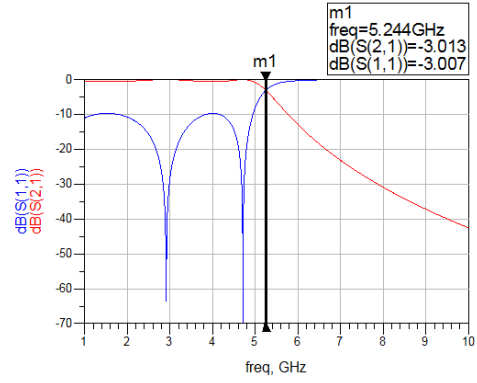

Fig. 4: Response of Low Pass Filter prototype

2.2 Band Pass Filter Using Low Pass Filter

By using transformation techniques as mentioned in [3], a band pass filter can be designed using low pass filter prototype. The low pass filter can easily be transformed into band pass filter by replacing an inductor with series LC circuit of values obtained by using Eq. (3) and replacing a capacitor with parallel LC circuit of values obtained by using Eq. (4). This is shown in Figure 5. [1] (pp.414, 4th ed.)
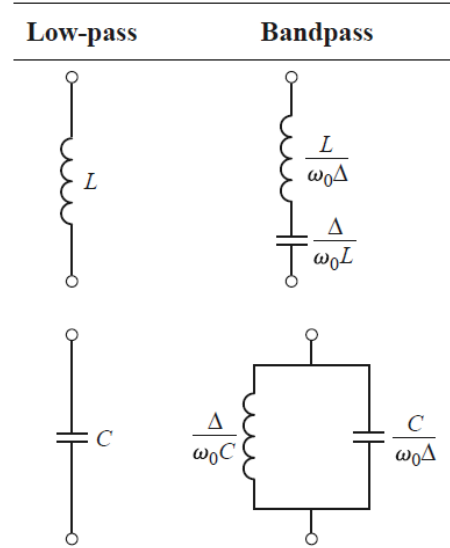

Fig. 5: LPF to BPF element transformation

For ready reference, Eq. (3) and (4) are reproduced below:

$$L'_k = \frac{R_0 L_k}{\omega_0 \Delta}, \quad C'_k = \frac{\Delta}{R_0 L \omega_0} \qquad (3)$$

$$L'_k = \frac{R_0 \Delta}{\omega_0 C_k}, \quad C'_k = \frac{C_k}{R_0 \Delta \omega_0} \qquad (4)$$

Where Δ is fractional bandwidth and ω_0 is the center frequency obtained by geometric mean of lower cut-off frequency and upper cut-off frequency. Formulas for fractional bandwidth and center frequency are given by Eq. (5) and (6) respectively.

$$\Delta = \frac{\omega_2 - \omega_1}{\omega_0} \qquad (5)$$

$$\omega_0 = \sqrt{\omega_2 \omega_1} \qquad (6)$$

After using Eq. (3) – (6) we get the following results.

Table 4: BPF lumped component values

Parameter	Value	LPF Element	BPF Element	
			L	C (pF)
g_1	1.7058	C_1	88.86 pH	10.342
g_2	1.2296	L_2	18.63 nH	0.0493
g_3	2.5408	C_3	59.66 pH	15.405
g_4	1.2296	L_4	18.63 nH	0.0493
g_5	1.7058	C_5	88.86 pH	10.342

Using these values, a lumped model of Band pass filter is designed as shown in Figure 6 below:
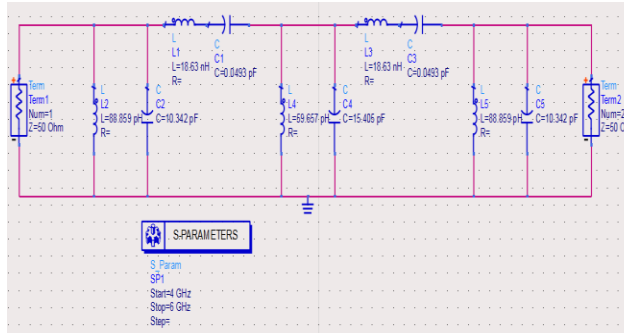

Fig. 6: Band Pass Filter Schematic model

As shown in Figure 6, all the series inductors of lumped LPF have been replaced by series LC circuit and all the shunt capacitors have been replaced by shunt LC circuit with values mentioned in Table 4. Since this is a 5th order filter having 5 LC circuits (series + shunt) are seen.

S-parameter analysis was carried out and similar to lumped LPF, input return loss S_{11} and forward transmission coefficient S_{12} graphs are plotted in Figure 7. As shown, the 3 dB points are obtained at 4.980 GHz and 5.536 GHz (correspond to marker m1 and m2 respectively). This is in good agreement with required values.
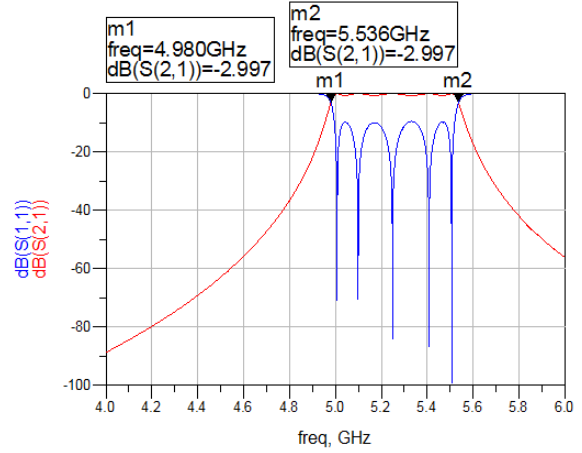

Fig. 7: Lumped BPF S-parameter response

2.3 Band Pass Filter Using Ideal Microstrip Lines

Microstrip BPF is a type of microwave filter which is under research on a wide scale. As per the hypothesis of transmission, each microstrip can be thought of as a short portion of series inductance and parallel capacitance. Coupling capacitors and inductances additionally should be considered in parallel coupled line. Assume each microstrip's characteristics impedance is Z_0, the length of mutual coupling part is L, the width of microstrip is W, the separation between each two microstrips is S, even mode trademark impedance is Z_E and odd mode trademark impedance is Z_O then the prototype of the design looks similar to shown in figure 8.
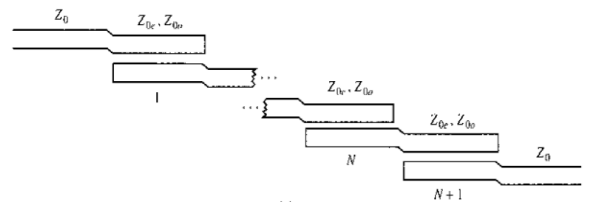

Fig. 8: Microstrip coupled line filter general prototype

As it can be observed from above figure, this is a cascade connection of segments. The relations to compute the values of these segments are given below [1] {pp. 435, 4th ed.}

$$Z_0 J_1 = \sqrt{\frac{\Delta \pi}{2 g_1}} \qquad (7)$$

$$Z_0 J_n = \frac{\Delta \pi}{2\sqrt{g_{n-1} \cdot g_n}} \qquad (8)$$

$$Z_0 J_{N+1} = \sqrt{\frac{\Delta \pi}{2 g_N g_{N+1}}} \qquad (9)$$

Eq. (7) is used for the first segment, Eq. (8) is used for the intermediate segments for n = 2,3,4…N and Eq. (9) is used for the last segment. By using these equations, even mode and odd mode impedances can be calculated as follows:

$$Z_e = Z_0[1 + JZ_0 + (JZ_0)^2] \qquad (10)$$

$$Z_o = Z_0[1 - JZ_0 + (JZ_0)^2] \qquad (11)$$

Where Z_0 is the characteristics impedance and J is admittance inverter. By using Eq. (7) – (11) the following values are obtained:

Table 5: Even Mode and Odd mode impedances

n	g_n	$Z_0 J_n$	Z_E (ohms)	Z_O (ohms)
1	1.7058	0.3034	69.77	39.43
2	1.2296	0.1085	56.01	45.16
3	2.5408	0.0889	54.84	45.95
4	1.2296	0.0889	54.84	45.95
5	1.7058	0.1085	56.01	45.16
6	1.0000	0.3034	69.77	39.43

To design this filter, we have used CLIN type of lines as shown in figure 9. Values for even and odd mode impedances used are same as those in table 5 and electrical length is 90 degrees whereas the center frequency used is 5.25 GHz.
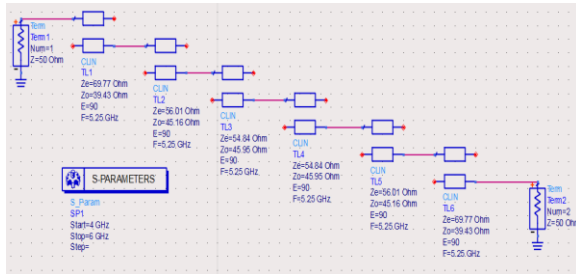

Fig. 9: BPF using CLIN

It may be noted that only two out of four pins are used in connection in CLIN. Figure 10 shows the S-parameter response of the circuit. As shown in figure 10, cutoff frequencies are obtained at 4.974 GHz and 5.526 GHz respectively.
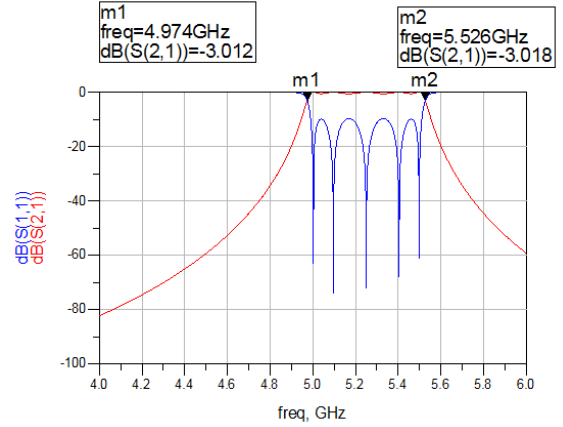

Fig. 10: S-parameter response of BPF Model designed using CLIN

2.4 *Band Pass Filter Using Practical Microstrip Lines*

In this article, we have designed a band pass filter for same frequency range using MCFIL type lines present in TLines-Microstrip pallet of ADS tool. In this type of lines, along with the even and odd mode impedances, we also need to specify the width, length, and spacing between the segments. To compute these values, we have used LineCalc tool present in ADS and one screenshot is attached as a reference in figure 11.
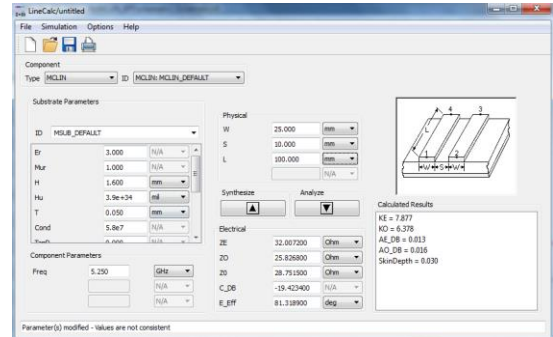

Fig. 11: A screenshot of the LinCalc tool of ADS

As shown in figure 11, we need to enter certain information in order to calculate the desired parameters. In this work, we have used dielectric constant = 3, height of substrate (H) = 1.6 mm, Height of metal (T) = 0.05 mm, conductivity of copper = 5.8e7 Ohm⁻¹ and frequency = 5.25 GHz. After entering these values along with even and odd mode impedances, we can synthesize these parameters to get the desired values of width, length and spacing between the segments. The

calculated values are summarized in table 6 below.

Table 6: Microstrip line parameters

Z_E (ohms)	Z_O (ohms)	W (mm)	S (mm)	L (mm)
69.77	39.43	3.23	0.47	8.42
56.01	45.16	3.89	2.14	8.23
54.84	45.95	3.92	2.62	8.22
54.84	45.95	3.92	2.62	8.22
56.01	45.16	3.89	2.14	8.23
69.77	39.43	3.23	0.47	8.42

The schematic model of the band pass filter is shown below:
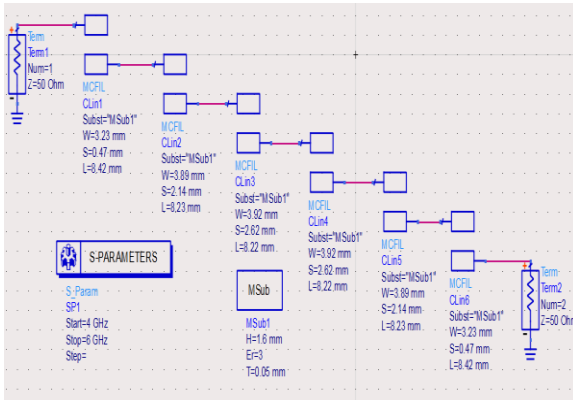
Fig. 12: Band Pass filter using MCFIL Lines
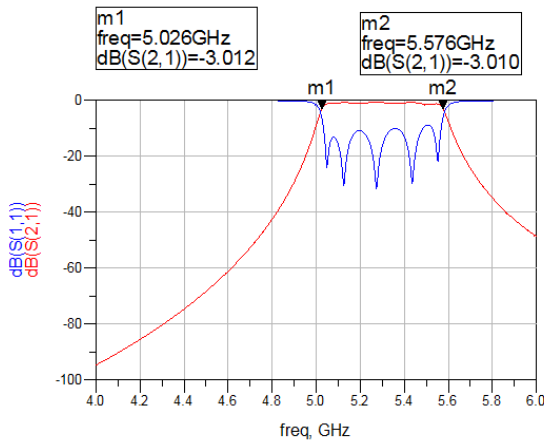
Fig. 13: S-parameter response of BPF of Fig. 12

Fig. 12 shows the band pass filter realized using MCFIL lines in ADS tool. The substrate used here has the same specifications that were entered into the LineCalc tool.

Figure 13 shows the S-parameter analysis frequency response of the model in the frequency range 4 GHz – 6 GHz. As clear from the figure, cut-off frequencies obtained from this model are 5.026 GHz and 5.576 GHz, respectively.

2.5 Band Pass Filter Layout

Although schematic designs provide good agreement of output, the result of the simulated circuit may be different from the practical circuit results that we use in practice. The reasons behind this includes dielectric loss, edge capacitance and others. Therefore, to reach near close to the reality, we perform layout simulation as well. In this work, the layout design of this band pass filter is also presented designed in ADS tool.
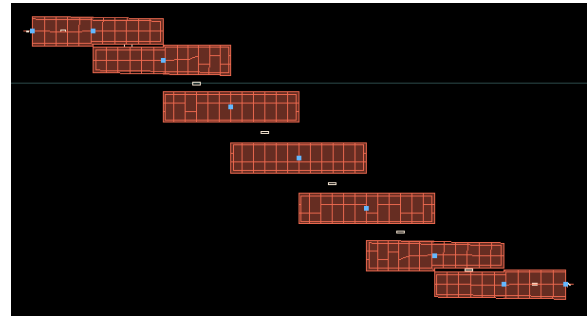

Fig. 14: Layout design of Band pass filter

For the layout simulation, we need to define all the parameters in EM setup e.g. Substrate properties, conductor, simulation type and frequencies. After the EM simulation setup with the same parameters used in schematic designing, simulation results obtained are shown below:
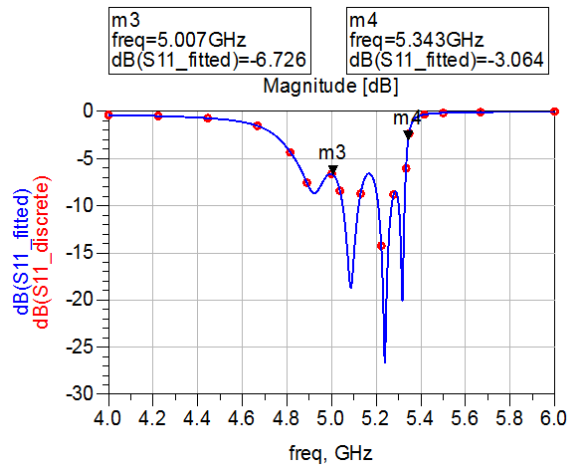

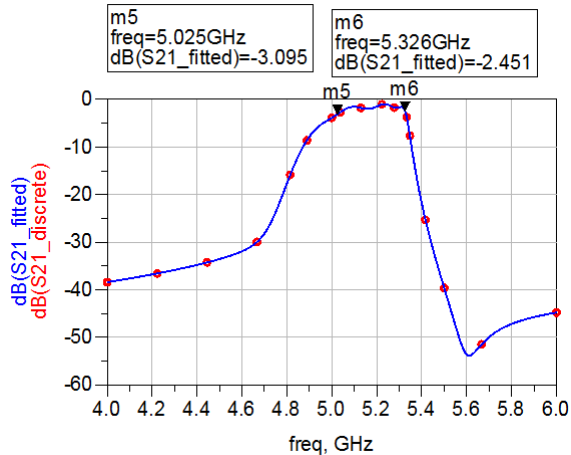Fig. 15: S_{11} Response of layout design

Fig. 16: S_{21} response of layout BPF

As shown in figure 15 and 16, the layout design meets the design requirement.

3. CONCLUSION

A complete procedure to design a band pass filter using various techniques is reported. All the designs are providing results that are in good agreement with theoretical results. However, the layout version can further be optimized and bandwidth can be increased using different techniques.

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