

# Realization of Microstrip Band-Pass Filter Design

Mr. K.S.Khandelwal<sup>1</sup> (ME VLSI & Embedded), Dr. A.K.Kureshi<sup>2</sup> (Professor)  
Department of Electronics & Telecommunication<sup>1,2</sup>  
VACOE, Ahmednagar, Maharashtra

**Abstract**— This paper represents a complete design, development and simulation of microstrip band-pass filter at 2.4 GHz frequency. The Chebyshev filter with 0.5 dB ripple in pass-band is chosen. The design of low-pass prototype filter, impedance and frequency scaling transformation are clearly explained. The paper also explains design of filter using MCLIN and MCFIL microstrip lines. The microstrip filter designed shows good agreement with theoretical results. Advance Design Simulation tool is used for simulation of microstrip filter.

**Index Terms**— BPF, Chebyshev filter response, microstrip, parallel coupled line, even and odd impedance;

## I. INTRODUCTION

Band Pass Filter (BPF) is the essential components of all RF communication systems. BPF filter passes the frequency in pass band and provides attenuation for frequencies which lie outside pass band. Thus BPF acts as frequency selective circuit. To meet consumer demand, BPF are designed in compact size, low development cost with guarantee of high quality in performance. Figure 1 shows the block diagram for generalized RF communication system.

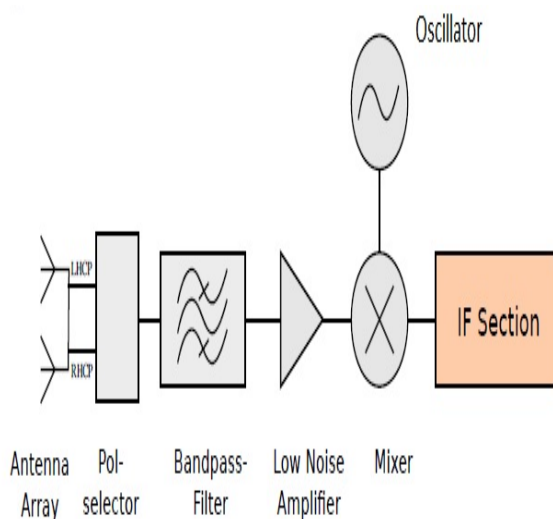


Fig. 1: Block diagram of RF communication system.

Filters are generally realized using lumped or distributed circuit elements. Filters designed above 1 GHz, using lumped elements produced distribute effects as the dimensions of

electronic component are comparable with the wavelength of the signal. The microstrip filters are very attractive for microwave applications as they possess advantage over lumped filters. Microstrip filter are small in size, economical and provides improved performance.

BPFs may be designed using following types of ladder filter as listed below.

1. Maximally Flat or Butterworth Filter
2. Equal Ripple or Chebyshev Filter
3. Elliptic Filter or Caurer Filter
4. Linear Filter

## II. FILTER DESIGN USING LUMPED COMPONENTS

Generally for microwave applications Butterworth or Chebyshev filter may be used. Other factors such as desired rejection, high or low frequency roll off, variation with phase, etc are also decides choice of filter. It is now possible to design filter with reduced harmonics. [1] The table below shows the required specification for any type of filter

The specifications for microstrip filter design are as follows:

- Equal ripple Chebyshev Filter response in pass band.
- Centre frequency  $f_c = 2.4$  GHz of
- Operating Bandwidth: 2.35-2.45 GHz
- Substrate Rogers RO4003

### A. Design of Prototype Low Pass Filter

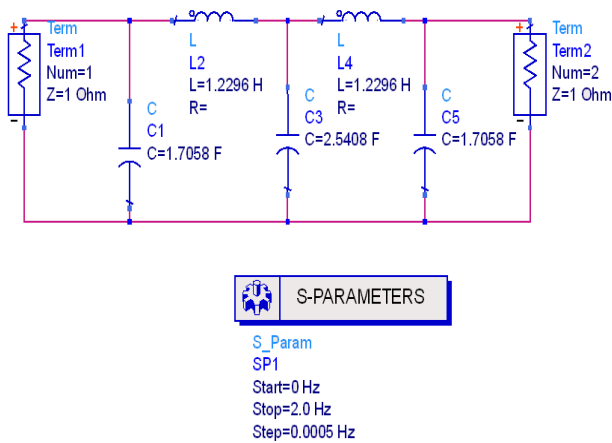
The filter prototype is normalized design structure which has source impedance of  $1\Omega$  and cut-off frequency of  $1\text{rad/sec}$ . Prototype filter acts as template to provide a modified filter design for particular application

The element values for the low-pass circuit are given in table below:

Table I. Element Values For Equal-Ripple Low-Pass Filter Prototypes [5]

Order	$R_s$	$g_1$	$g_2$	$g_3$	$g_4$	$g_5$
5	1	1.7058	1.2296	2.5408	1.2296	1.7058

The value of capacitor and inductor for prototype LPF can be directly taken from Table 1. Therefore we have  $g_1 = 1.7058 = C_1 = C_5$ ,  $g_2 = 1.2296 = L_2 = L_4$ ,  $g_3 = 2.5408 = C_3$ . The source and load impedance  $Z_0 = Z_L = 1\Omega$ .



S-PARAMETERS  
S\_Param  
SP1  
Start=0 Hz  
Stop=2.0 Hz  
Step=0.0005 Hz

Fig. 2: Schematic for Low-pass prototype filter using lumped components

Figure 2 shows the circuit diagram for prototype low-pass filter using lumped components. As seen in Figure 2 the elements values are same as mentioned in Table I.

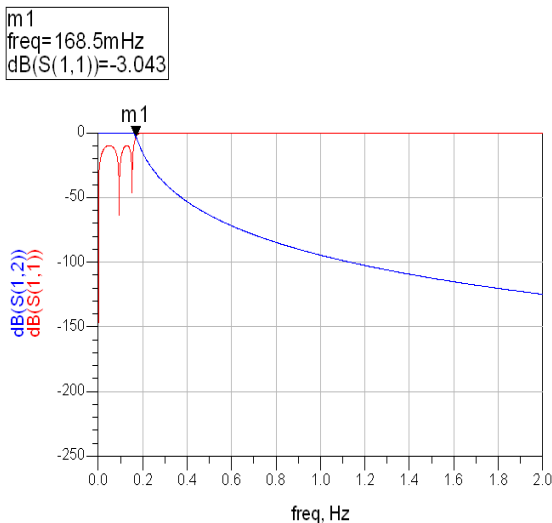


Fig. 3: Frequency spectrum for low-pass prototype filter

Figure 3 shows the frequency response. The cut-off frequency obtained from simulation is 168.5 mHz, when S(1,1) is 3.043 dB.

### B. Impedance and Frequency Transformation

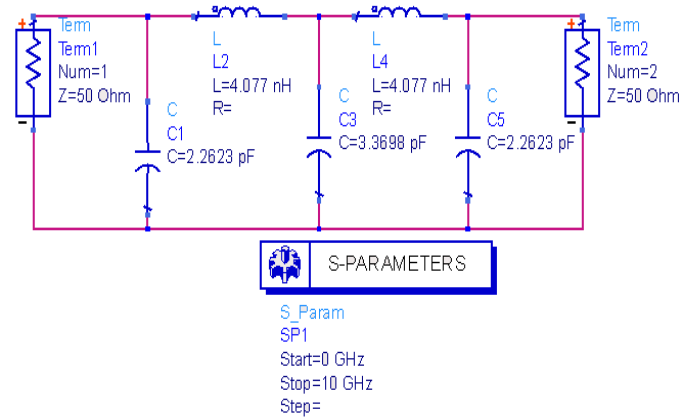
The low-pass filter prototypes are circuit designed for unity cutoff frequency and unity source and load impedance. In order to design BPF, impedance and frequency scaling is done. By using equation 1, new values of L and C are obtained.

$$L' = \frac{R_0 L}{\omega_c}, C' = \frac{C}{R_0 \omega_c} \quad (1)$$

The new element values are obtained with desired cut-off frequency and source impedance as per desired. In this paper the cut-off frequency is chosen as 2.4 GHz and  $Z_L = Z_S = 50$ . Table II contains new values of lumped components using above equation.

TABLE II. ELEMENT VALUES OBTAINED AFTER IMPEDANCE AND FREQUENCY TRANSFORMATION

Order	Rs	g1	g2	g3	g4	g5
5	1	1.7058	1.2296	2.5408	1.2296	1.7058
5	50	$C_1 = 2.2623$ pF	$L_2 = 4.077$ nH	$C_3 = 3.3698$ pF	$L_4 = 4.077$ pF	$C_5 = 2.2623$ pF



S-PARAMETERS  
S\_Param  
SP1  
Start=0 GHz  
Stop=10 GHz  
Step=

Fig. 4: Schematic for Low-pass filter using lumped components

Figure 4 shows the schematic for low-pass filter using lumped components. The schematic of low-pass filter is same as that of prototype low-pass filter. But now new values are used. The values are  $C_1 = C_5 = 2.2623$  pF,  $L_2 = L_4 = 4.077$  nH and  $C_3 = 3.3698$  pF. The source and load impedance are  $Z_0 = Z_L = 50\Omega$ .

Figure 5 shows the frequency spectrum for low-pass prototype filter. The cutoff frequency is obtained point where S(1,1) and S(1,2) meet each other. The marker shown in Figure 4 indicates that cutoff frequency is 2.4 GHz and S(1,1) is 2.99 dB.

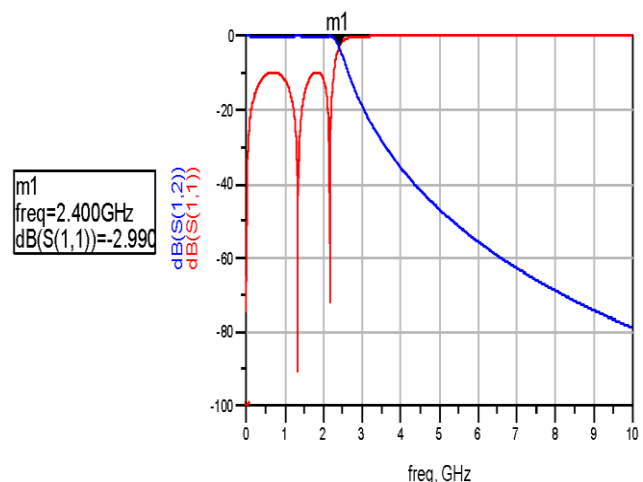


Fig. 5: Frequency spectrum for low-pass prototype filter

### C. Low Pass to Band pass transformation

Once the prototype filter is ready, it can be now used for impedance and frequency scaling. It is possible to design bandpass filter with better response for broadband

applications. Broadband filters with better response could be designed with [3]

During transformation process:

- The series inductor of low-pass prototype are converted to parallel LC circuits having element value given by[5]:

$$L' = \frac{R_0 L}{\omega_c BW} \quad C' = \frac{BW}{R_0 L \omega_c} \quad (2)$$

- The shunt capacitor of the low-pass prototype is converted to series LC circuits having element value given by [5]:

$$L' = \frac{R_0 BW}{\omega_c C}, \quad C' = \frac{C}{R_0 BW \omega_c} \quad (3)$$

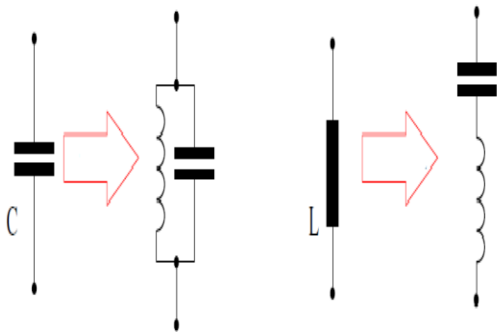


Fig. 6: Schematic illustrating transformation of LPF to BPF

- If  $\omega_1$  and  $\omega_2$  are cutoff frequencies of BPF than, fractional bandwidth  $\Delta$  and the center frequency,  $\omega_0$  (geometric mean of  $\omega_1$  and  $\omega_2$ ) are given as:

$$\Delta = \frac{\omega_2 - \omega_1}{\omega_0} \quad \text{and} \quad \omega_0 = \sqrt{\omega_1 \omega_2}. \quad (4)$$

Using equations (2), (3) and (4) new element values are calculated as represented in Table III.

TABLE III. ELEMENT VALUES FOR BAND-PASS FILTER

Parameter	Specifications	
	LPF	BPF
Order	5	5
$Z_0 = Z_L$	1	50
$g_1$	$C_1 = 1.7508$	$C_1' = 27.15 \text{ pF}$ $L_1' = 0.1619 \text{ nH}$
$g_2$	$L_2 = 1.2296$	$L_2' = 48.94 \text{ nH}$ $C_2' = 0.0898 \text{ pF}$
$g_3$	$C_3 = 2.5408$	$C_3' = 40.45 \text{ pF}$ $L_3' = 0.1087 \text{ pF}$
$g_4$	$L_4 = 1.2296$	$L_4' = 48.94 \text{ nH}$ $C_4' = 0.0898 \text{ pF}$
$g_5$	$C_5 = 1.7058$	$C_5' = 27.15 \text{ pF}$ $L_5' = 0.1619 \text{ nH}$

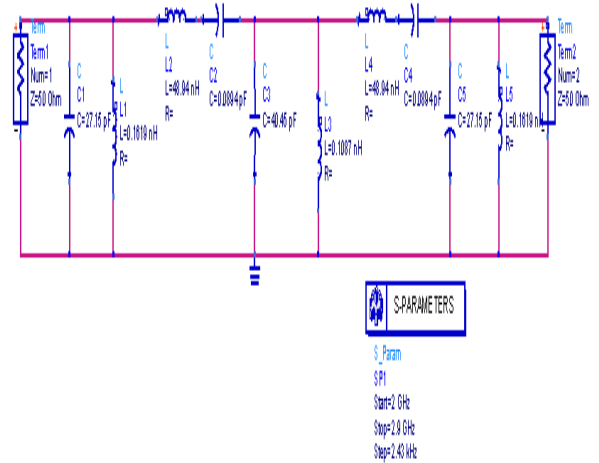


Fig. 7: Chebyshev Band-pass filter of 5<sup>th</sup> order

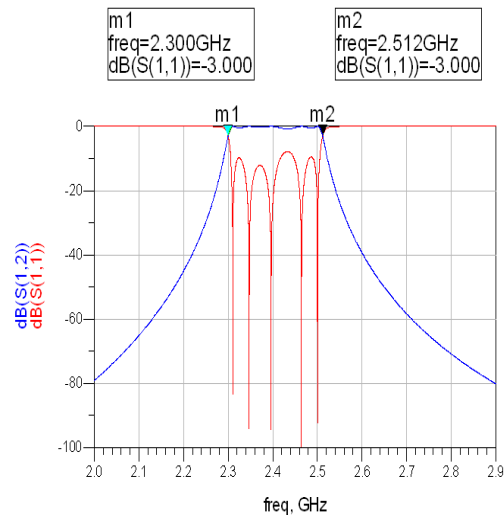


Fig. 8: Frequency spectrum of Band-pass filter

Figure 7 represents structure for Chebyshev Band-pass filter of 5<sup>th</sup> order. Figure 8 shows the frequency spectrum of Band-pass filter. As shown in figure 8, markers indicate the cutoff frequencies as 2.30 GHz and 2.512 GHz where  $S(1,1)$  is -3.0 dB.

### III. FILTER DESIGN USING MICROSTRIP LINES

There are various topologies to implement microstrip BPFs filters [6], [2], [7]. In this paper the interest is focused on parallel coupled. Figure 9 represents the generalized structure for microstrip coupled line filter.

#### A. Lumped to Coupled-Line Transformation

The equations for designing microstrip BPF with  $N + 1$  coupled line sections are as follows:

- For 1<sup>st</sup> coupling

$$Z_0 J_1 = \sqrt{\frac{\pi \Delta}{2g_1}} \quad (5)$$

2. For intermediate coupling

$$Z_0 J_n = \frac{\pi \Delta}{2 \sqrt{g_{n-1} g_n}} \quad (6)$$

3. For final coupling

$$Z_0 J_{N+1} = \sqrt{\frac{\pi \Delta}{2 g_N g_{N+1}}} \quad (7)$$

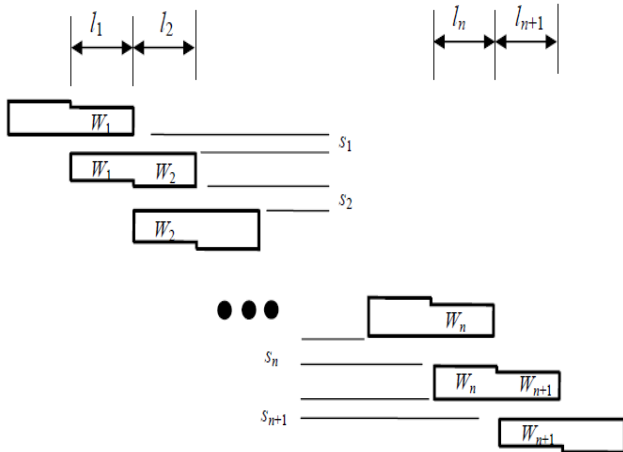


Fig. 9: Generalized structure for microstrip coupled line filter

From above equations we can obtain even and odd mode characteristic impedances.

$$Z_{0e} = Z_0 [1 + JZ_0 + (JZ_0)^2] \quad (8)$$

$$Z_{0o} = Z_0 [1 - JZ_0 + (JZ_0)^2] \quad (9)$$

where,  $Z_0$  = characteristic impedance,  $J$  = admittance inverter constant,  $\Delta$  = relative bandwidth,  $g$  = filter prototype and  $n = 2, 3, 4, \dots, N$ . Equations (5), (6), (7), (8) and (9) are used to calculate the odd and even impedances for microstrip lines [2]. The values calculated are shown in Table IV.

Table IV. Determination of Even and Odd Characteristics Impedances

n	$g_n$	$Z_0 J_n$	$Z_{0e}$ (ohms)	$Z_{0o}$ (ohms)
1	1.7508	0.27696	67.6833	39.9873
2	1.2296	0.09034	54.9250	45.8910
3	2.5408	0.07402	53.9749	46.5729
4	1.2296	0.07402	53.9749	46.5729
5	1.7058	0.09304	54.9250	45.8910
6	1	0.27696	67.6833	39.9873

In ADS tool selection of TLines-Microstrip palette gives wide range of microstrip line that may be used. In this paper

MCLIN microstrip line is selected. Figure 10 shows design of BPF using MCLIN component.

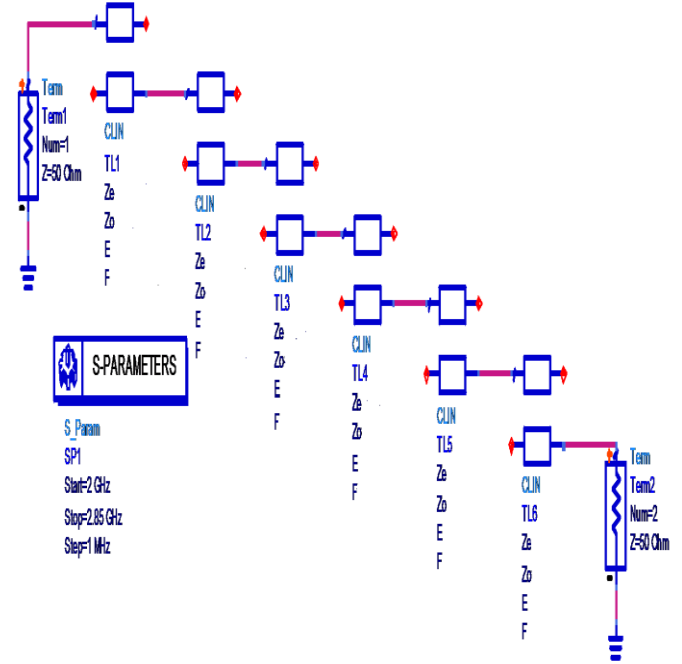


Fig.10: Realization of BPF using Ideal Transmission Lines

By double clicking MCLIN component, entries for even and odd characteristics impedances can be done. The even and odd characteristics impedances are already done as shown in Table IV.

Figure 11 illustrates frequency spectrum for BPF using MCLIN. Simulation result show two marker positions indicating cutoff frequencies as 2.3 GHz and 2.5 GHz when  $S(1,1) = -2.9$  dB and  $-2.4$  dB respectively. Also, it may be noticed that improved performance is obtained as compared to design using lumped components.

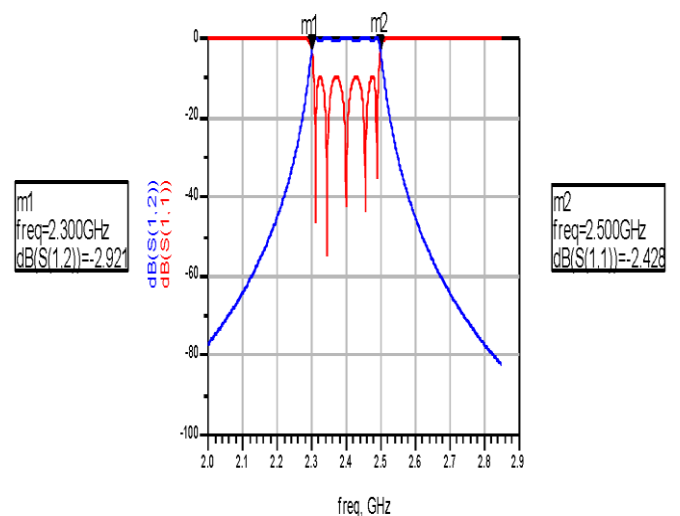


Fig. 11: Frequency response for BPF using MCLIN

### B. Transformation form Ideal line to Microstrip line

In this section another microstrip line component is chosen for the design of BPF. The values for odd and even impedances are obtained directly from Table IV. We use

LineCalc feature of ADS tool to calculate physical parameters of microstrip component. In-order to find physical parameters Lin-Calc provides three different sections. In substrate parameter section, properties of substrate could be entered as per design.

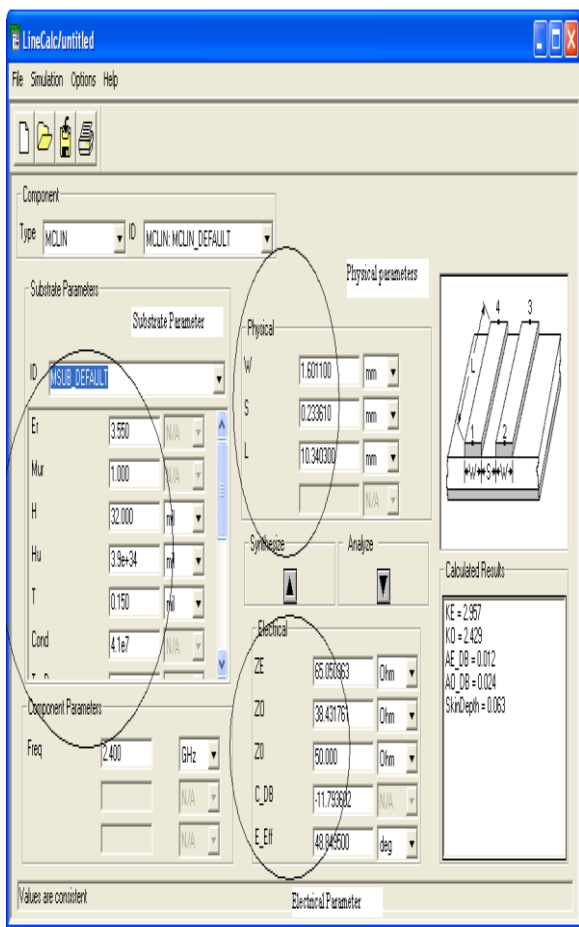


Fig. 12: Determination of physical parameter using Line-Calc

Under electrical parameter, the odd and even characteristic impedance are entered. These impedances are obtained from equations (5), (6), (7), (8) and (9). Once the impedances are entered, synthesize icon should be clicked to get W, S and L. As shown in Figure 12, when  $Z_{0e} = 67.6833$  ohm and  $Z_{0o} = 39.9873$  ohm are entered,  $W = 1.6011$  mm,  $S = 0.233610$  mm and  $L = 10.3403$ mm. Similar procedure is repeated and physical parameters are obtained.

The calculated physical parameters are shown in Table V.

Table V. Values For Microstrip lines Obtained Using Line-Calc Tool

$Z_{0e}$ (ohms)	$Z_{0o}$ (ohms)	W (mm)	S (mm)	L (mm)
67.6833	39.9873	1.601100	0.233610	10.340300
54.9250	45.8910	1.786540	1.144830	10.186000
53.9749	46.5729	1.786530	1.383910	10.179900
53.9749	46.5729	1.786530	1.383910	10.179900
54.9250	45.8910	1.786540	1.144830	10.186000
67.6833	39.9873	1.601100	0.233610	10.340300

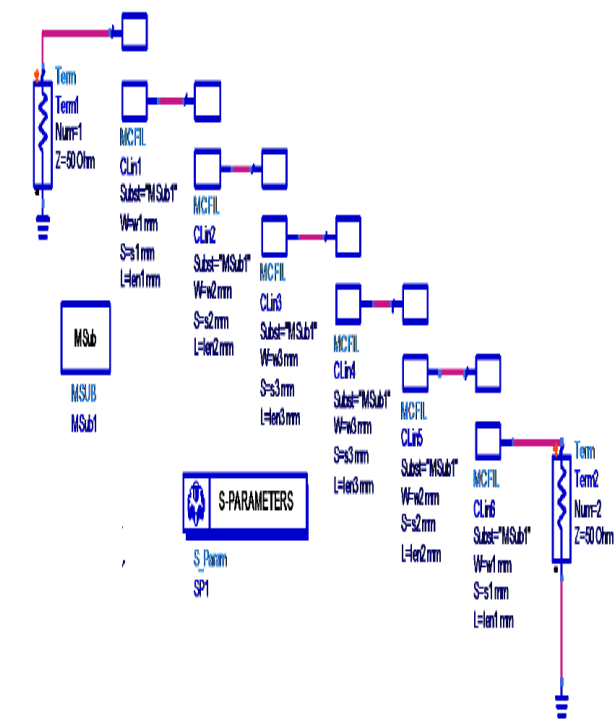


Fig. 13: Realization of BPF using Transmission Lines

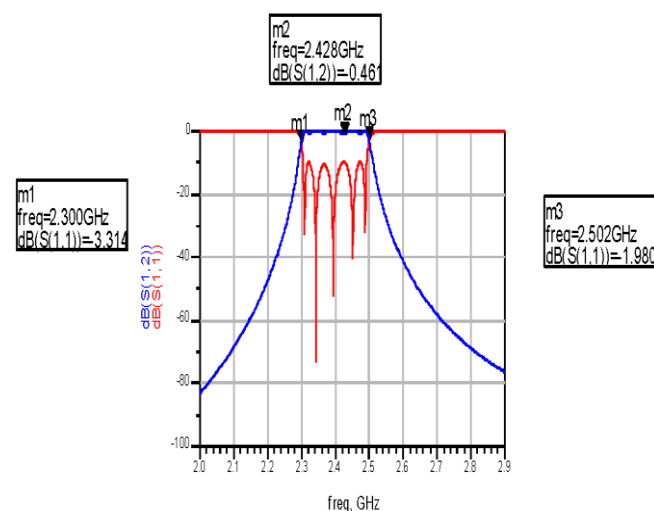


Fig. 14: Realization of BPF using Transmission Lines

Figure 13 shows the realization of BPF using microstrip lines. Figure 14 shows the frequency response of microstrip BPF. It is observed that the cutoff frequencies are 2.3GHz and 2.5 GHz.

#### IV. CONCLUSION

The paper clearly reveals design of microstrip BPF. The theoretical calculation done is in close agreement with the simulation results. It is noticed that microstrip BPF showed improved performance as compared to filter designed using lumped components. This paper only explains design and simulation using ADS tool. It is also possible to generate layout using ADS tool and fabricate the same.

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