Design and Implementation of Coupled Line Bandpass Filter at C-Band

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ABSTRACT

A Radio frequency filters having applications that demand high performance and intends to contribute in system's size and cost must be achieved by a different approach. That might be in using an advanced material, planar technology or dielectric resonators, as filter involves in many fields like wireless receivers, transmitters and in multiple locations inside an RF system to shed noise. This paper primarily demonstrates how bandpass filter exhibits itself differently when realized using lumped elements or microstrip transmission line to acquire minimum losses when transmitting high frequency signals over long or short distances in planar technology. And explains in detail to design and simulate microstrip coupled line bandpass filter.

Keywords: BPF, coupled line, Even and Odd Method

I. INTRODUCTION

A filter is a two-port device used to allow wanted frequency components from the signals and in removing unwanted signals. Filters are categorized into four types- Lowpass, High pass, Bandpass, Band stop. Bandpass filter circuit is designed to have properties and features of high pass filter (HPF) and low pass filter (LPF) when both are cascaded into one [2]. The main objective contained in this filter is in a transmitter to limit the bandwidth of the output signal to the minimum required level and to convey data at the preferred speed and form. And in a receiver to decode signals of certain frequency range, it also optimizes the signal to noise ratio (S/N) of a receiver. Each filter is classified into four types- Butterworth filter, Bessel, Chebyshev and Elliptic. To meet our design requirements, we have used Chebyshev response or Equal ripple filter response as it gives sharper cut off in

passband and feature like Steep roll-off, where a steep transition between pass-band and stop-band required to remove unwanted products such as intermodulation of harmonics or ripple in passband advantages are provided as needed [1]. So, describing the design and simulation of a parallel coupled line microstrip band pass filter with Chebyshev response. Quarter wavelength resonators and admittance inverters are used to design this filter in the frequency range 3.95 to 4.45 GHz.

How to Cite:

Band pass filter can either be implemented using discrete elements like resistors, inductors, capacitor or distributed elements, where coupled transmission line sections is used for better frequency sensitive coupling. Planar strip technology is used as this approach is easy in fabrication and very reliable. A RT-Duroid substrate which has low electrical loss, low density and light weight material filled PTFE is used as a substrate for the design [6].

II. DESIGN MODELLING AND PROCEDURE OF LUMPED COMPONENTS

A fifth order Chebyshev low pass prototype with pass band ripple of 0.5 dB is designed. The detailed specifications are given in Table 1.

Table 1. BPF Design Specifications

Higher cut off frequency(F_2)	4.45 GHz
Lower cut off frequency(F_1)	3.95 GHz
Mid frequency(F_0)	4.2 GHz
Band Width	500 MHz
Source Impedance	50 ohms

1) Fractional Bandwidth (FBW):

$$\text{FBW} = \triangle = \frac{\omega_2 - \omega_1}{\omega_0} \qquad (1) \qquad [1]$$

$$\triangle = 0.1190 \qquad (2)$$

Where $\omega_1, \omega_2, \omega_0$ are the angular frequency for F_1, F_2, F_0

2)   Calculation of L&C:

The values of Lumped elements are decided by normalized element values given in Table 2. In the Transformation from low-pass prototype to bandpass filter, the component L will be converted to serial combinations of Ls and Cs, whereas the component C becomes parallel combination of Lp and Cp.
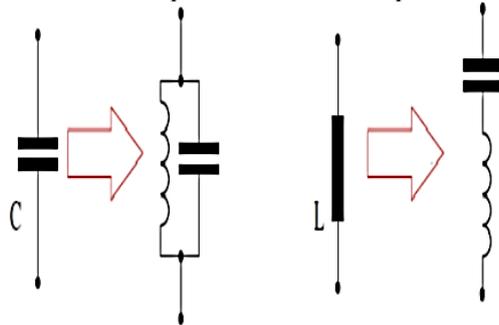
Figure 1. Schematic Illustrating Transformation of LPF to BPF [8]

For series:
$$L_K{'} = \frac{R_O L_K}{\omega_0 \triangle} \qquad (3) \qquad [1]$$

$$C_K{'} = \frac{\triangle}{Z_O L_K \omega_o} \qquad (4) \qquad [1]$$

For shunt:
$$L_K{'} = \frac{Z_O \triangle}{\omega_0 C_K} \qquad (5) \qquad [1]$$

$$C_K' = \frac{C_K}{Z_O \triangle \omega_0} \qquad (6) \qquad [1]$$

Table 2. Element values for Equal-Ripple Low-Pass Filter Prototype [1]

N	g1	g2	g3	g4	g5	g6	g7	g8	g9	g10	g11
					0.5 dB Ripple						
1	0.6986	1.0000									
2	1.4029	0.7071	1.9841								
3	1.5963	1.0967	1.5963	1.0000							
4	1.6703	1.1926	2.3661	0.8419	1.9841						
5	1.7058	1.2296	2.5408	1.2296	1.7058	1.0000					
6	1.7254	1.2479	2.6064	1.3137	2.4758	0.8696	1.9841				
7	1.7372	1.2583	2.6381	1.3444	2.6381	1.2583	1.7372	1.0000			
8	1.7451	1.2647	2.6564	1.3590	2.6964	1.3389	2.5093	0.8796	1.9841		
9	1.7504	1.2690	2.6678	1.3673	2.7239	1.3673	2.6678	1.2690	1.7504	1.0000	
10	1.7543	1.2721	2.6754	1.3725	2.7392	1.3806	2.7231	1.3485	2.5239	0.8842	1.9841

III. ADS SIMULATION OF LC COMPONENT AND RESULTS

Estimated values of capacitor and inductor generated according to the series and shunt formulas are given in Table 3:

TABLE 3. Calculated Values of Lumped Component in Serial and Parallel Combination

Serial Combination	Parallel Combination
L_1=27.17nH, C_1=0.052pF	L_2=0.183nH, C_2=7.8349pF
L3=40.4747nH, C3=0.0355pF	L4=0.183nH, C4=7.8349pF
L_1=27.17nH, C_1=0.052pF	-

The schematic for the lumped elements is as shown in Figure 2. Band Pass Filter design in lumped Elements is as shown after substituting values of Series and Shunt elements in ADS
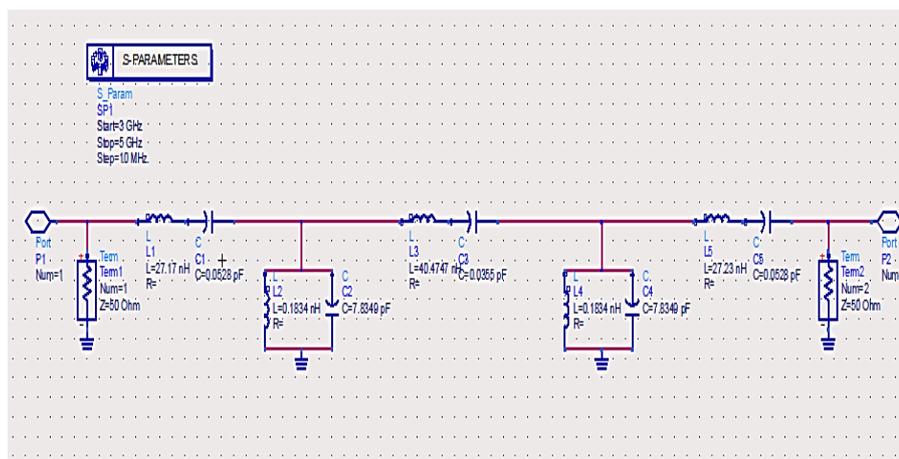
Figure 2. Schematic Diagram of Lumped Elements

The Output waveform S_{12} that is plotted with respect to frequency is shown in Figure 3. This graph tells us that signal attenuation at 3.95 GHz is about -1.391 dB and at 4.45 GHz about -0.130 dB. And at center frequency return loss is said to be about -55.113dB
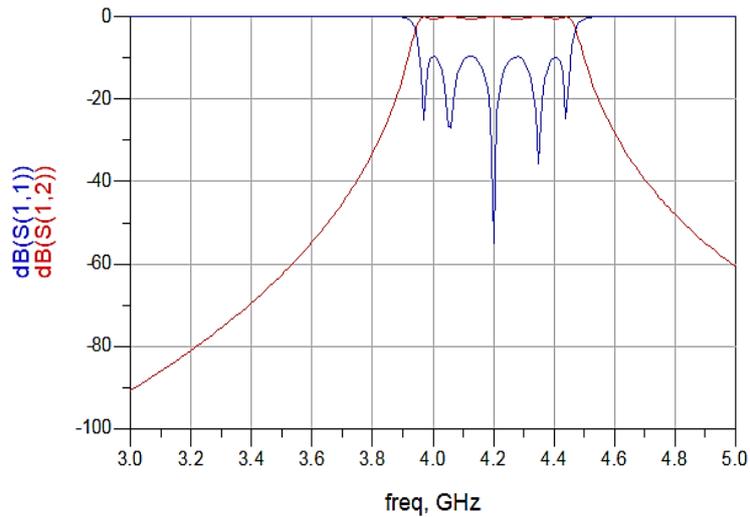
Figure 3. Output Simulation of Frequency Vs S-parameter

Practically, it is not possible to design this bandpass filter at high frequency in such LC components for that we can use microstrip line as a transmission line.

IV. PARALLEL COUPLED LINE

Power coupled from one line to the other due to the interaction of the electromagnetic fields, such lines are called coupled transmission lines. These can support two distinct propagating modes, and this feature can be used to implement in a variety of filters. The coupled lines are symmetric, meaning that two conducting strips have the same width and position relative to ground, this simplifies the analysis of their application and is shown in Figure 4 [1].
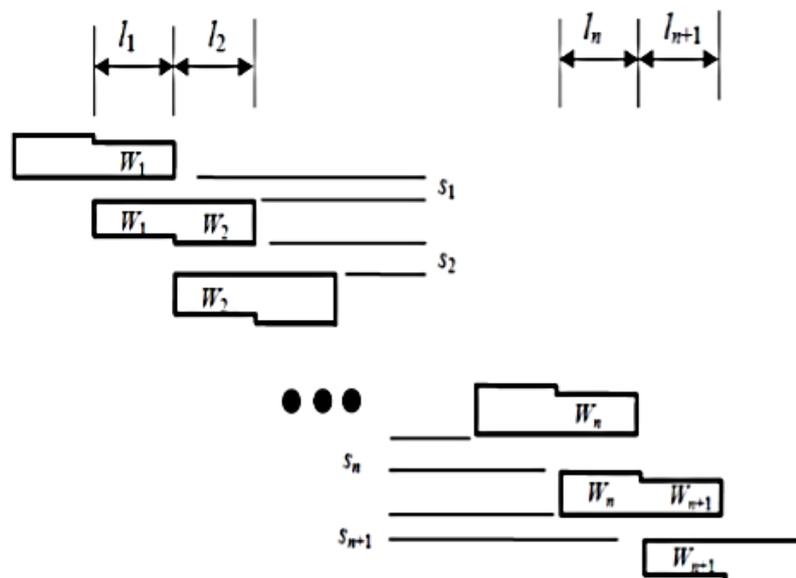
Figure 4. Generalized Structure for Microstrip Coupled Line Filter [1]

1) DESIGN FLOW

We use the following equations for designing the parallel-coupled line filter [1, 4]

Equations of Admittances:

First coupling structure-

$$Z_0 J_1 = \sqrt{\frac{\Delta\pi}{2g1}} \qquad\qquad (7) \quad [1,4]$$

Intermediate structure-

$$Z_0 J_n = \frac{\Delta\pi}{2\sqrt{gn-1*gn}} \qquad n= 2,3.... \qquad (8) \quad [1,4]$$

Final Structure-

$$Z_0 J_{n+1} = \sqrt{\frac{\Delta\pi}{2*gn*gn+1}} \qquad\qquad (9) \quad [1,4]$$

g_0, g_1,....g_n can be taken be taken from above, Δ is the fractional bandwidth, J_n, J_{n+1} is the characteristic admittance of J inverter and Z_0 is the characteristic impedance of the connecting transmission line. The calculated values of the admittance intervals is given in Table 4.

*Table 4: Calculated values of admittance interval***s**

Element Values	Admittances-Ω^{-1}
1.7058(g_1, g_6)	0.330947
1.2296(g_2, g_5)	0.129003
2.5408(g_3, g_4)	0.105701

Equations of Even and Odd characteristics:

Even and Odd modes are the two main modes of propagation of the signal through a coupled transmission line pair. Odd mode impedance is defined as impedance of a single transmission line when the two lines in a pair are driven differentially. Even mode impedance is defined as impedance of a single transmission line when the two lines in the pair are driven with a common mode signal [7]. The odd and even impedances are calculated by using the equations (10) and (11). The calculated values are given in Table 5.

$$Z_{0e} = Z_0 (1 + Z_0J + (Z_0J)^2) \quad (10) \quad [1]$$

$$Z_{0o} = Z_0(1 - Z_0J + (Z_0J)^2) \quad (11) \quad [1]$$

Table 5: Calculated values of even and odd characteristics

Stage	Z0e-Ω	Z0o-Ω
1&6	72.024995	38.928945
2&5	57.282238	44.381938
3&4	55.843685	45.273585

Linecalc is used to create the microstrip filter schematic. The dimension of the microstrip line like length (L), width (W) and gap(S) between each other are calculated for the given odd and even impedances. The parameters of the substrate are as follows:

H : Substrate Thickness: 1.27mm
ε_r : Substrate dielectric constant: 10.2
T : Thickness of metal layer: 35um
Tan D : dielectric loss tangent: 0.0012

The calculated dimensions of the transmission line is given in Table 6.

Table 6: Calculated Dimensions of transmission line sections

Stage	W(mm)	S(mm)	L(mm)
1&6	0.85	0.59	6.99
2&5	1.19	1.53	6.83
3&4	1.32	1.83	6.81

The schematic diagram of the coupled line is shown in Figure   5. Different sections of parallel coupled line are set up by the W, S, L values generated in the software. Output waveform of S parameter versus frequency has observed which tells that there is minimum attenuation of at least 15dB, to reach our optimal request we acquire the tuning method. The tuned output waveform is shown in Figure 6.
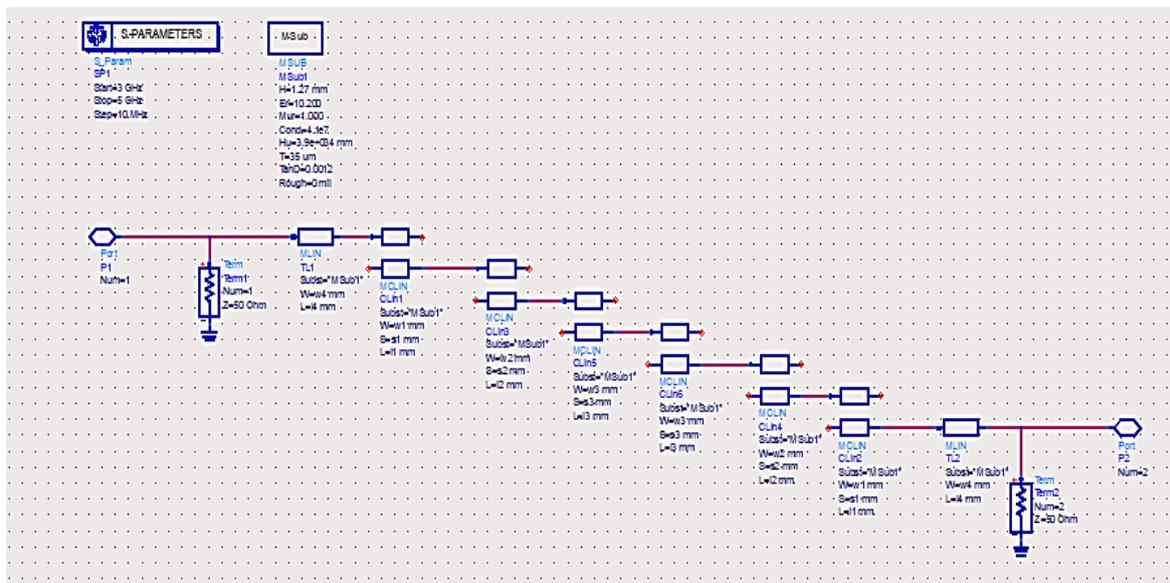
Figure 5. Schematic Diagram of Coupled Line Filter
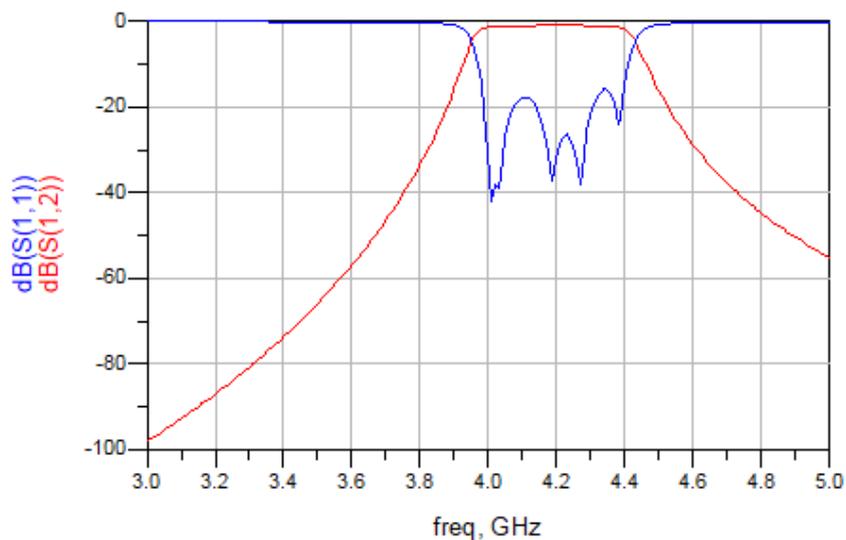
Figure 6. Output Waveform

Layout is generated from the updated schematic design. The layout is shown in Figure 7.
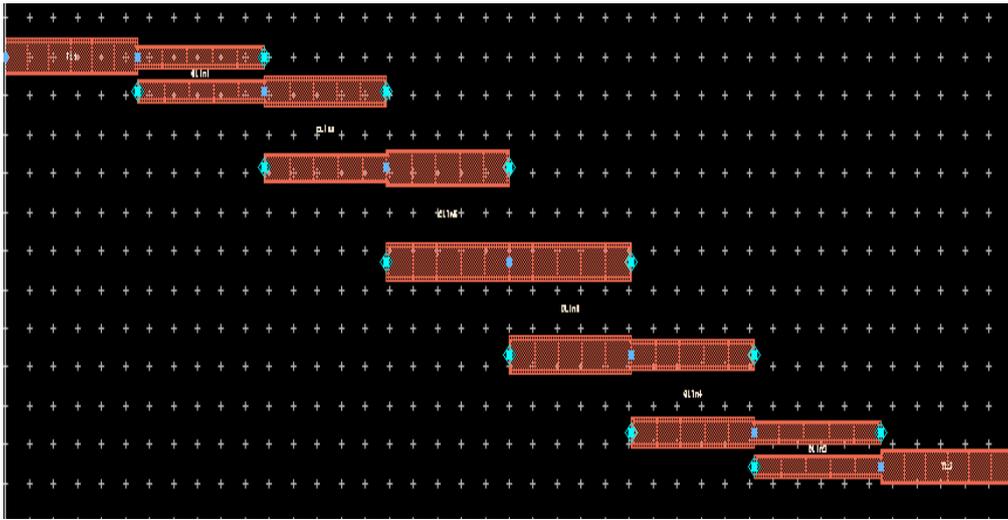
Figure 7. Layout of Parallel-Coupled Line Filter

Layout generated is simulated in momentum which gives us the better idea of the filter. The EM simulated values of return loss(S_{11}) is -27.815dB and insertion loss(S_{12}) is about -0.965dB at the Centre frequency. When Figure 8 is compared to Figure 3, there is much improvement in losses.
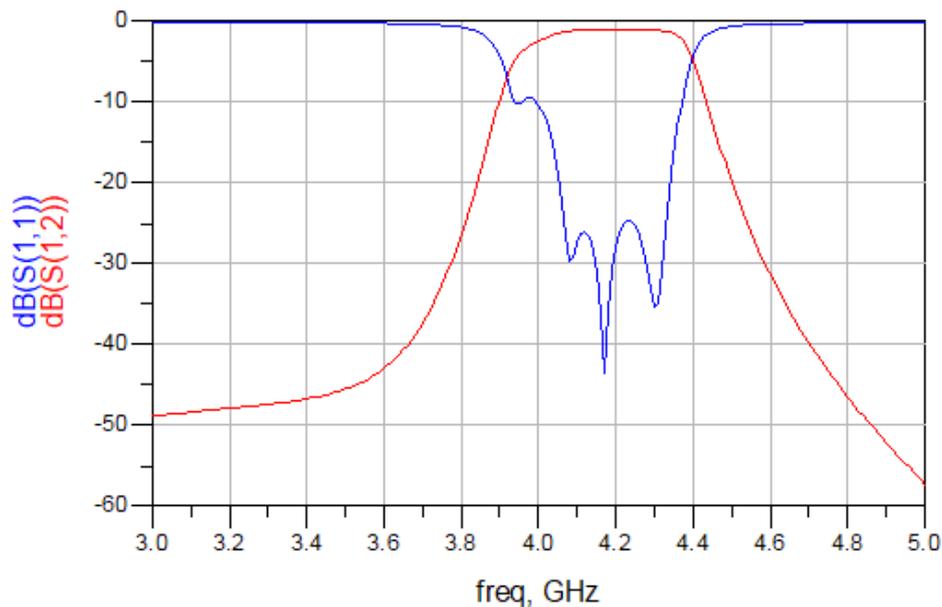
Figure 8. EM Simulated Result

V. CONCLUSION

The fifth order Chebyshev, coupled line band pass filter provides sharper selectivity and gradual decrease in losses and improvement in performance is noticed when microstrip transmission line result is compared with lumped component. Agilent ADS simulation tool provides support in reaching the required specifications.

VI. COMPETING INTERESTS

There was no particular conflict of interest.

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