Design of a Coupled-Line Microstrip Bandpass Filter at 3.5 GHz

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Abstract - *Bandpass filters play a important role in wireless communication systems. Transmitted and received signals have to be filtered at a certain center frequency with a specific bandwidth. In this paper A Coupled-Line Microstrip Bandpass Filter made up of Roger material having permittivity ε_r=10.2 and center frequency=3.5 GHz is proposed. It will demonstrate the fourth order of the Tschebyshev elements. The specified passband insertion loss must not exceed 3dB while the pass band return loss was to be more than 10dB. Printed circuit board (PCB) based filters are popular and relatively practical to design. The geometry is analyzed by using Computer Stimulation Techniques (CST) software.*

Key Words: Coupled-line, Bandpass filter, Microstrip, Return loss, Insertion loss.

1. INTRODUCTION

The key component in the microwave communication system is filter. There are various types of filter that used in microwave communication systems classified as low-pass filter, high-pass filter, band-pass filter, and band-stop filter. The Microwave band pass filter is a fundamental device that contributes to the overall performance of a wireless communication system, be it in receiving or transmitting devices, to filter out unwanted frequency. The wireless communication systems has increased the demand of bandpass filters with higher accuracy due to growing applications and standards introduced in the modern communication system, the demand for the précised, narrow bandwidth and low loss had led to the innovative design of a band-pass filter. While designing a bandpass filter, consideration of parameters such as center frequency, bandwidth, low pass frequency, high frequency etc. needs to be made. As communication devices are getting smaller day by day and due to rough use, robustness and compact size of the filter are another important design consideration. Coupled-line filter is a good choice to start with for the design of microstrip bandpass filter. Coupled-line microstrip bandpass filters are easy to design for narrow bands, but for relatively large band, it becomes complex, as more parameters are need to be considered. When it comes to GHz frequency range the coupled-line microstrip bandpass filter is a general choice. PCB fabricated coupled-line microstrip bandpass filter usually consists of narrow bandwidth. A disadvantage The coupled-line microstrip bandpass filter suffers the disadvantage as the presence of spurious passbands at the harmonics of the bandpass filters operational frequency. Many good literatures regarding the matter can be found.

A research done by Jia Sheng Hong and Micheal J. Lancaster proposed the cross coupled planar filter using hairpin resonator for center frequency of 965MHz with 2% bandwidth. The cross coupled planar hairpin filter can change its susceptance slope parameter independently of its resonant frequency. This feature help to change the bandwidth while keeping the center frequency at constant [1].

A research was done by Wael M.Fathelbab and Micheal B. Steer using a parallel coupled filter with enhanced stopband performance. The design was based on Minnis's Class D network prototype with center frequency of 1 GHz. However, the filter design is suitable for broader frequency application with bandwidth of 20%, combine with the application of appropriate circuit transformations. It offers flexibility of independently specifying the center frequency of the filter [3]

This paper presents the design of a new third order of Tschebyshev hairpin band-pass filter with center frequency of 5 Ghz and bandwidth less than 10%. This design is proposed due to its compactness and does not require grounding. Thus, it makes manufacturing a lot easier [4]. The hairpin band-pass filter significantly reduces the size of the lower frequency of parallel coupled. As the frequency is increased, the aspect ratio of each resonator becomes squarer and saves space [5]. The design of the filter is based on microstrip technology. It is a popular type of planar high frequency technology due to ease of fabrication and its ability to integrate with other devices. The substrate used is from type RT/Duroid, which is one of the microstrip laminates that are suitable in designing microstrip band-pass filter at high frequency.

2. Filter Design Method

Design Problem: Given a center frequency of 3.5 GHz, bandwidth of 3% and equal ripple in the pass-band of 0.5dB, design a microstrip band-pass filter with 4th order Coupled Line configuration for the given specification. Use RT/Duroid substrate of dielectric constant 10.2 with thickness of 1.27mm.

The filter design steps are described as follows:

1. We have started the design procedure with a four-pole (n=4) ladder-type low pass prototype (i.e., with Chebyshev response) with element values of the low pass prototype are taken from normalized values g_i i.e g_1, g_2, g_3. From [1] the element values of the low pass prototype are $g_1 = g_4 = 0.7654$, $g_2 = g_3 = 1.8478$, $g_5 = 1.0000$.

2. The normalized element values of the low pass prototype filters are then transformed to the L-C elements for the desired mid band frequency f_0 and desired source impedance, which is normally 50 ohms for micro strip filters.

3. The next main step in the design of micro strip band stop filter is to find an appropriate micro strip realization that approximates the lumped element filter. The filter is fabricated on a RT/Duroid substrate having dielectric constant $\varepsilon_r = 10.2$ and of thickness h=1.27mm.

4. The design equations for parallel coupled bandpass filter given by[3]

$$\frac{J_{01}}{Y_0} = \sqrt{\frac{\pi\, FBW}{2}\, \frac{1}{g_0 g_1}} \tag{1}$$

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

$$\frac{J_{n,n+1}}{Y_0} = \sqrt{\frac{\pi FBW}{2 g_n g_{n+1}}} \tag{3}$$

Where $g_0, g_1 \ldots \ldots g_n$ are the element of a ladder-type lowpass prototype with a normalized cutoff frequency $\Omega_c = 1$, and FBW is the fractional bandwidth of bandpass filter. $J_{j,j+1}$ are the characteristic admittances of J inverters and Y_0 is the characteristic admittance of the terminating lines.

To realize the J-inverters obtained in above equations, the even and odd mode characteristic impedances of the coupled microstrip line resonators are determined by

$$(Z_{0_e})_{j,j+1} = \frac{1}{Y_0}\left[1 + \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right] \tag{4}$$

$$(Z_{0_o})_{j,j+1} = \frac{1}{Y_0}\left[1 - \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right] \tag{5}$$

5. The next step of the filter design is to find the dimensions of coupled microstrip lines that exhibit the desired even- and odd-mode impedances. Firstly, determine equivalent single microstrip shape ratios (w/h)s. Then it can relate coupled line ratios to single line ratios.

For a single microstrip line,

$$Z_{0se} = \frac{(Z_{0_e})_{j,j+1}}{2} \tag{6}$$

$$Z_{0so} = \frac{(Z_{0_o})_{j,j+1}}{2} \tag{7}$$

6. Now using single line equations to find (w/h)se and (w/h)so from Zose and Zoso [1]

For $\frac{w}{h} < 2$,

$$\frac{w}{h} = \frac{8\exp(A)}{(\exp(2A) - 2)} \tag{8}$$

Where $A = \frac{z_c}{60}\, \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right)$

For $\frac{w}{h} > 2$,

$$\frac{W}{h} = \frac{2}{\pi}\left[B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left\{\ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r}\right\}\right] \tag{9}$$

Where, $B = \frac{377\pi}{2Z_c\sqrt{\varepsilon_r}}$

(w/h)se and (w/h)so by applying Zose and Zoso (as Zc) to the single line microstrip equations.

7. Now it comes to a point where it reach the w/h and s/h for the desired coupled microstrip line using a family of approximate equations as following

$$\left(\frac{w}{h}\right) = \frac{1}{\pi}\left[\cosh^{-1}\frac{1}{2}\left(\left(\cosh\left(\frac{\pi}{2h}\right) - 1\right)\right) + \cosh\pi s2h + 1\cosh\pi 2whse^{-\pi}s2h\right] \tag{10}$$

$$\frac{s}{h} = \frac{2}{h}\cosh^{-1}\left[\frac{\cosh\left(\left(\frac{\pi}{2}\right)\left(\frac{w}{h}\right)se\right) + \cosh\left(\left(\frac{\pi}{2}\right)\left(\frac{w}{h}\right)so\right) - 2}{\cosh\left(\left(\frac{\pi}{2}\right)\left(\frac{w}{h}\right)so\right) - \cosh\left(\left(\frac{\pi}{2}\right)\left(\frac{w}{h}\right)se\right)}\right] \tag{11}$$

8. The effective dielectric constant is given by [2]

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\, \frac{1}{\sqrt{1 + 12\frac{h}{w}}} \tag{12}$$

9. Once the effective dielectric constant of a microstrip is determined, the guided wavelength of the quasi-TEM mode of micro strip is given by

$$\lambda_g = \frac{\lambda}{\sqrt{\varepsilon_{reff}}} = \frac{c}{f\sqrt{\varepsilon_{reff}}} \tag{13}$$

Thus the length of the required resonator is

$$l = \frac{\lambda_g}{4} \qquad (14)$$

Table1: Circuit design parameters of the four pole, parallel-coupled quarter wavelength resonator filter

J	$J_{j,j+1}/Y_0$	$(Z_{oe})_{j,j+1}$ (Ω)	$(Z_{oo})_{j,j+1}$ (Ω)
0	0.24812	65.4802	40.6722
1	0.15969	59.2595	43.2905
2	0.15969	59.2595	43.2905
3	0.24812	65.4802	40.6722
4	0.21708	63.2101	41.5022

3. Design And Simulation

A simulation study was performed to verify the validity of the above dimensions in millimeter wave regime. For the simulation purpose we have used Method of Moment based Full-wave EM solver IE3D [7]. Simulated structure of the desired band stop filter is shown in figure2 and figure 5 indicates the response of the filter using EM solver IE3D.
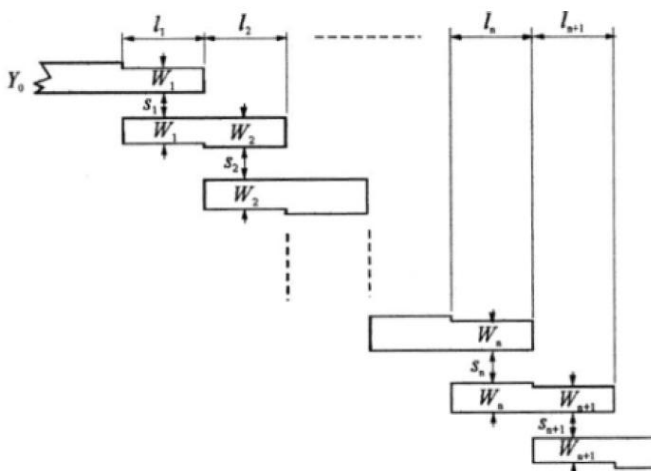
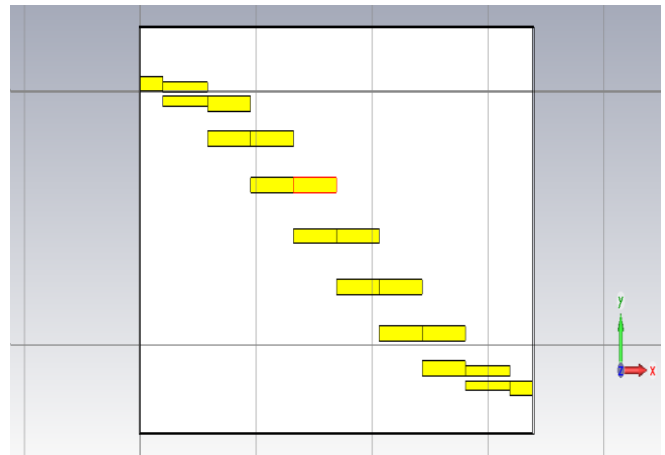**Fig -1:** General structure of parallel (edge)-coupled microstrip bandpass filter.

Fig -2: Structure of a four-pole coupled line micro strip band-pass filter designed using CST (Front View).
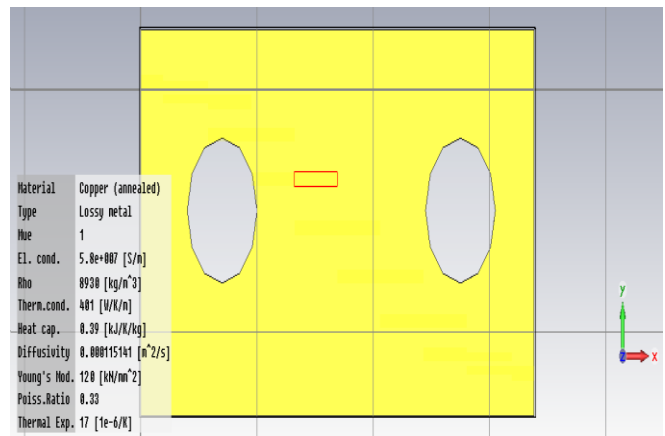

Fig -3: Structure of a four-pole coupled line micro strip band-pass filter designed using CST (Back View).
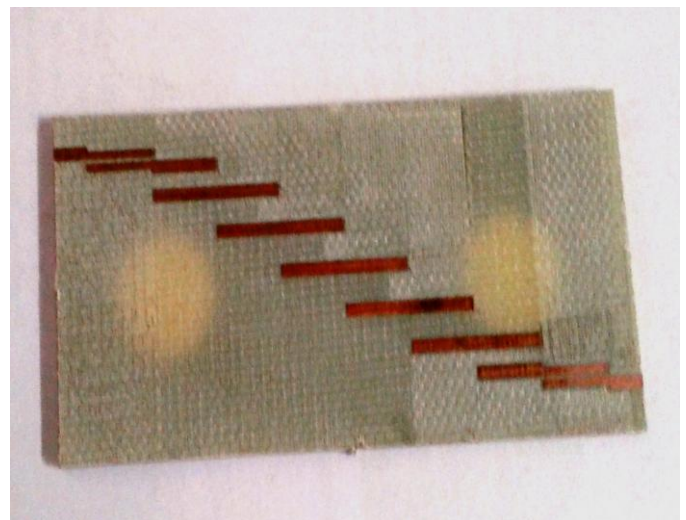

Fig -4: Fabricated structure of the four-pole coupled line microstrip band-pass filter at 3.5GHz (Front View)
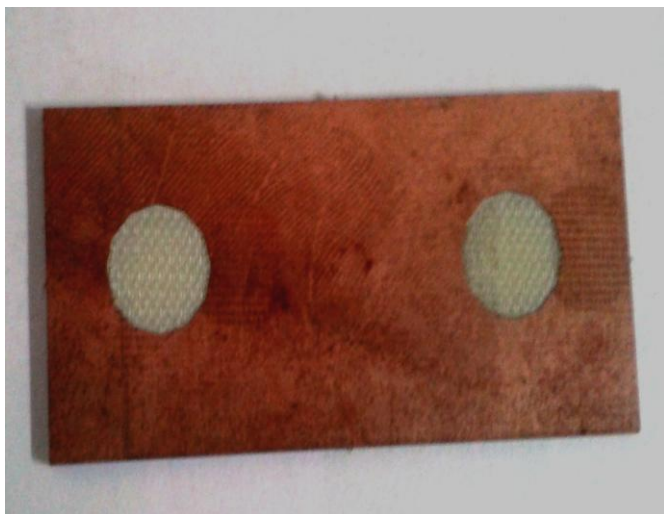
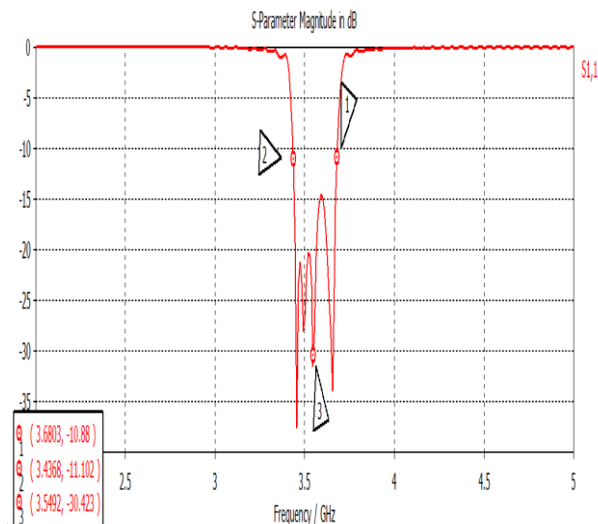**Fig -5**: Fabricated structure of the four-pole coupled line microstrip band-pass filter at 3.5GHz (Back View)
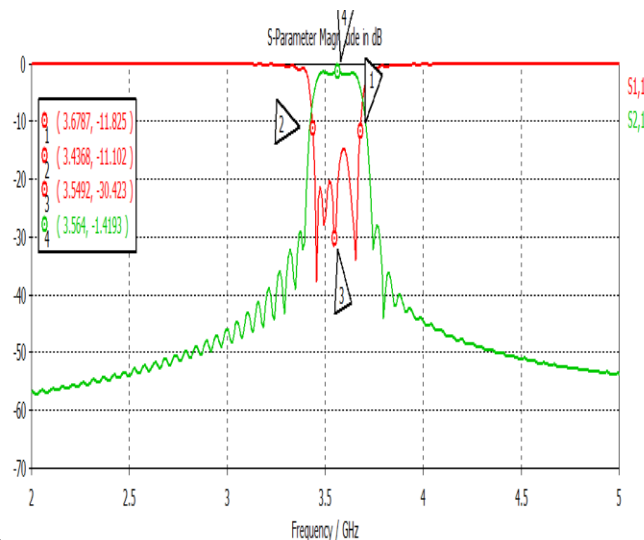

Fig -5: Simulated Performance of four-pole coupled line micro band-pass filter

Fig -7: Measured Insertion loss (S21) of four-pole coupled line microstrip band-pass filter using Network Analyzer
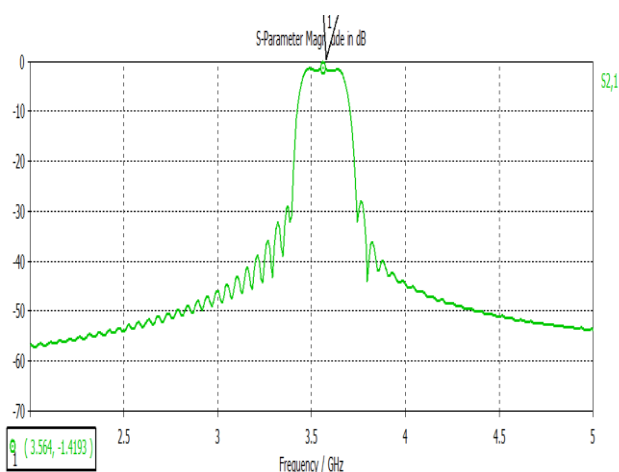

Fig -8: Measured Insertion loss (S21) of four-pole coupled line microstrip band-pass filter using Network Analyzer

4. Results And Discussion

The simulated filter structure and response is shown in figure 5.In the response graph gain (dB) is plotted on the y axis and frequency (GHz) on the X axis. It is clear that the simulated midband frequency is found to be 3.564GHz.The band edge frequencies are 3.6787GHz and 3.4368GHz.The value of insertion loss (S21) and return loss(S11) at 3.564GHz are -1.4193 dB and -30.423 dB respectively. The Fabricated filter was measured using vector network analyzer and the measured band edge frequencies are found to be 3.6787GHz and 3.4368GHz respectively with center frequency of value 3.564GHz.

7. Conclusion

The filters are one of the primary and essential parts of the microwave system and any communication system. Any communication system cannot be designed without filters. Our designed Coupled line microstrip bandpass filter operates with a Bandwidth of 0.03GHz and at a center frequency of 3.564GHz, which falls in the Microwave WiMAX -band applications.

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