ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijareeie.com

Vol. 7, Issue 3, March 2018

Design of Compact 5th Order Parallel Coupled Microstrip Band pass filter

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ABSTRACT: This paper presents the design of multipole chebyhev microstrip bandpass filter. The proposed 5th order filter operates at the centre frequency of 2.45GHz with FBW of ~20% and possesses characteristics of chebyshev response with a passband ripple of 0.1dB. The five resonators are provided by the half wavelength coupled lines. Simulation is carried out and the proposed structure possesses S11 of lesser than -20 dB for 5 resonant modes without occupying more area. The bandwidth ranges from 2.195 GHz to 2.61 GHz and the insertion loss in the selected frequency band is found to be very less.

KEYWORDS: Microstrip Filter, Chebyshev Response, Band pass filter, Pass band ripple

I.INTRODUCTION

A Microwave Band Pass filter (BPF) is the key component in wireless communication systems. It is a two port reciprocal, passive device which attenuates undesirable signal frequency, thereby facilitating the transmission of desired signal frequencies. The practical band pass filters have small non – zero attenuation in pass band and a small signal output in stop band due to the presence of resistive losses in reactive elements and propagating medium [1]. Such filters find extensive applications in wireless communication systems as they eliminates spurious signals, reduces harmonics and facilitates better reception . In designing filter, microtrip transmission line structures are preferred over lumped components as the latter shows performance degradation due to parasitic effect. [2]. The design of filter using microstrip structure uses various methods such as Richard’s transformation, Kuroda’s identities, immitance inverters etc. [3]. However parallel coupled microstrip line configuration is mostly preferred over its contemporaries for its compact structure and compliance [4,5].In addition, it has several advantages such as flexible design, Bandwidth stability over other filters [6].

This paper describes the design procedure of compact microstrip multipole band pass filter with wide bandwidth. Various parameters such as passband width, stopband attenuation, Input and Output Impedances, Return loss, Insertion loss and group delay are considered while designing the filter. These filter parameters play an integral role in the assessment of frequency dispersion over the given frequency band.

II.RELATED WORK

In “A cost effective dual band chebyshev parallel-coupled microstrip line bandpass filter for ISM band applications”, M.Bhagarathi priya, K.Ramprakash, P.Pavitra , D.Allin Joe proposed a dual band chebyshev parallel-coupled filter of order five for ISM band applications. The frequency ranges from 2.4GHz to 5GHz.This filter is designed and simulated on advance Design system platform. It is implemented on FR4 substrate with dielectric constant of 4.6.This design has high return loss and low insertion loss which is suitable for ISM frequency band applications.
In “Design of parallel coupled filter”, Chih-Jung Chen designed a procedure for the parallel coupled dual mode resonators by analysing a circuit model. The design of parallel coupled dual mode resonators is similar to the design of

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parallel coupled line filters. The major advantage of this proposal is that this design uses half wavelength line resonators. This has resulted in a smaller size and a better performance which leads to a simple design and easy fabrication process. This filter is used for many practical application that accept the chebyshev or butterworth response. Filters are designed for FBW of 10% and bandbass ripple of 0.1dB. The four pole filter is implemented in microstrip on a 20-mil thick R04003C substrate which has a dielectric constant of 3.365 and loss tangent of 0.003.This centre frequency is 1GHz.The filter is designed and analysed**.**

III. STRUCTURE OF MICROSTRIP BPF

In general, an Nth order parallel coupled filter consists of N+1 coupling sections. The resonators of the coupled line filters are equivalent to LC resonant circuits [7] as shown in Fig 1. The resonators are half wavelength long. The coupling between the resonators occurs by means of gap capacitors between coupling sections.

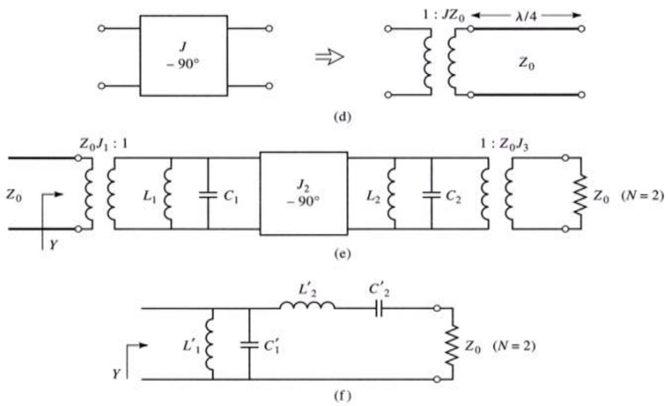

Fig 1. Equivalent circuit of microstrip line bandpass filter

In order to obtain wide band response, the resonators are tightly coupled in such a way that spacing between the resonators must be smaller than the height of the substrate. The values of admittance inverters are calculated using the element values of lowpass prototype filters i.e.g0,g1,g2,……..gn Also g0,g1,g2….gn are elements with a normalized cut-off $_C$ =1 and FBW is the Fractional Bandwidth of Bandpass Filter. The lumped elements such as inductors and capacitors in LC resonant circuit of the filter are used to determine values of admittance inverters as shown in Fig 2.

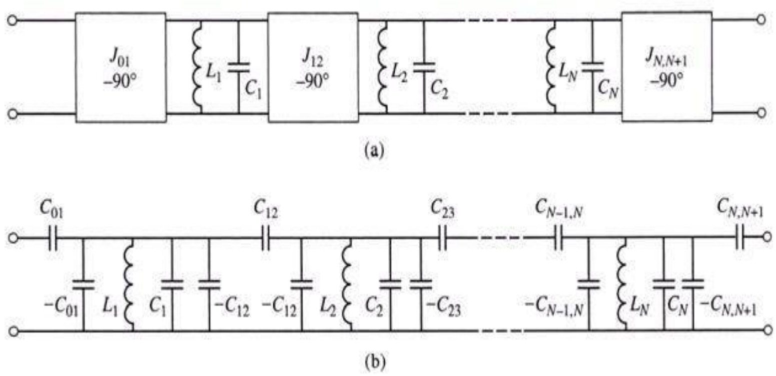

Fig 2. Admittance inverters with equivalent circuit implementation for bandpass filter

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Physical dimensions such as length, width and line spacing between the resonators are calculated using design equations. These calculations provide length of parallel coupled microstrip l1, l2, l3……lN, lN+1 of first, second and Nth resonator respectively [4]. Similarly width w_1 , w_2 ,.....w_N , $w_{N\ 1}$ and line spacing between two resonators s_1 , s_2 ....s_N , $s_{N\ 1}$ are also calculated [8,9].

IV. DESIGN PROCEDURE

This section describes the design procedure for the realization of Parallel coupled microstrip bandpass filter with the following filter specifications:

Centre Frequency: 2.45GHz

Order of the Filter (N): 5

Fractional BW: 20%

Passband Ripple: 0.1dB

Prototype: Chebyshev

Dielectric constant: 4.4

Height of the Substrate: 1.6mm.

The filter coefficients for 0.1dB ripple and 5th order filter are obtained from the filter table 1.The odd mode and even mode coupled line impedances, are determined from the admittance of the inverter where odd mode and even mode are the main modes of propagation of signal through coupled transmission line [10-12].

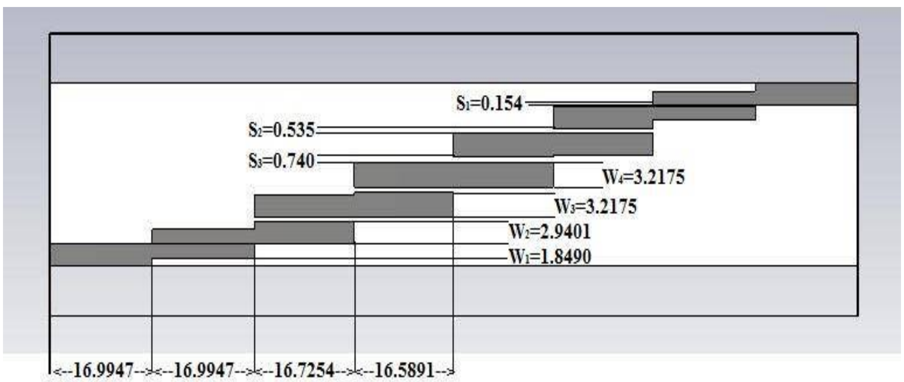

Fig 3. Layout of 5th order parallel coupled microstrip line Bandpass Filter

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Step 1: Calculation of admittance inverter:

Admittance of the inverter is given by,

$$Z_0 J_{K+1.K} = \frac{\pi.\Delta}{2\sqrt{g_{K+1} g_K}} \quad ; \qquad (1)$$

K = 1, 2, 3……..N-1.
(For intermediate coupling section)
where $g_0 . g_1, \ldots \ldots g_N, g_{N+1}$ are prototype element values for chebyshev filter.

For first and final coupling section,

$$Z_0 J_{N+1,N} = \sqrt{\frac{\pi.\Delta}{2 g_i g_{i+1}}} \qquad (2)$$

The values of admittance inverters are calculated using the equations (1) and (2)

Step 2: Calculation of even and odd mode characteristic impedances

The even mode and odd mode characteristics impedances [9] are as follows,

$$[Z_{oe}]_{K+1,K} = Z_0 \left[1 + J_{K+1,K} Z_0 + \left(J_{K+1,K} Z_0\right)^2\right] \qquad (3)$$

$$[Z_{oo}]_{K+1,K} = Z_0 \left[1 - J_{K+1,K} Z_0 + \left(J_{K+1,K} Z_0\right)^2\right] \qquad (4)$$

where Z_0 is the characteristic impedance of input and output lines of filter.

Step 3: Calculation of W/h ratio

The width to height ratio is calculated according to specifications using the equations (5) and (6)

For $\frac{W}{h} < 2$ $\qquad \frac{W}{h} = \frac{8.e^A}{e^{2A} - 2} \qquad (5)$

Where $A = \frac{Z_{os}}{2}\sqrt{\frac{\varepsilon_r}{2}} + \sqrt{\frac{\varepsilon_r - 1}{\varepsilon_r + 1}}\left[0.11 + \frac{0.23}{\varepsilon_r}\right]$

For $\frac{W}{h} > 2$ $\qquad \frac{W}{h} = \frac{2}{\pi}\left\{B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(\ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r}\right)\right\} \qquad (6)$

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

Step 4: Calculation of S/h ratio

To find $\frac{S}{h}$ ratio equation (7) is used

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$$\frac{S}{h} = \frac{2}{\pi}\cosh^{-1}\left[\frac{\cosh\left\{\frac{\pi}{2}\left(\frac{W}{h}\right)_{se}\right\}+\cosh\left\{\frac{\pi}{2}\left(\frac{W}{h}\right)_{so}\right\}-2}{\cosh\left\{\frac{\pi}{2}\left(\frac{W}{h}\right)_{so}\right\}-\cosh\left\{\frac{\pi}{2}\left(\frac{W}{h}\right)_{se}\right\}}\right] \quad (7)$$

Step 5: Calculation of line spacing, width and length

The line spacing, width and length of the resonators are determined from equations (8)-(10)

$$\left(\frac{W}{h}\right)_{se} = \frac{2}{\pi}\cosh^{-1}\left[\frac{2d-g+1}{g+1}\right] \quad (8)$$

Where $d = \cosh\left(\pi\frac{W}{h} + \frac{\pi}{2}\frac{S}{h}\right)$

To calculate length $\varepsilon_{eff} = \frac{\varepsilon_r-1}{2}\left(\frac{\varepsilon_r-1}{2}.\frac{1}{\left[1+\frac{12h}{W}\right]^{\frac{1}{2}}}\right)$ **(9)**

$$\lambda_g = \frac{\lambda}{\sqrt{\varepsilon_{eff}}} = \frac{c}{f\sqrt{\varepsilon_{eff}}} \quad (10)$$

Step 6: Calculation the width of end resonators (50 ohm microstrip line):

For $\frac{W}{h} > 1$, we have $Z_0 = \frac{376.7}{\sqrt{\varepsilon_{eff}}\left[\frac{W_0}{h}+1.4+0.667\ln\left(\frac{W_0}{h}+1.444\right)\right]}$ **(11)**

For calculating the width of end resonator, the above expression is used with normalized impedance value equal to Z0=50 ohms.
Thus, the physical dimensions such as Line spacing, Width and Length are calculated using the equations (7)-(11). The design values are used to realize the Parallel coupled microstrip bandpass filter with operating frequency.

Table 1: Width and line spacing of the coupled sections

K	**Width[W_g] (mm)**	**Line Spacing[S_g] (mm)**
1 and 6	1.8470	0.154
2 and 5	2.9401	0.535
3 and 4	3.2175	0.740

The filter physical parameters are optimized to obtain wide band response, good skirt selectivity and good impedance matching at the input and output lines [13]. The width and line spacing of the coupled sections are shown in Table 1 and the optimized dimensions of the filter [14] are shown in Table 2.

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Table 2: Dimensions of the proposed filter

Coupling Section	Physical Dimensions		
	Length (mm)	Width (mm)	Line Spacing (mm)
1	16.9947	1.8470	0.154
2	16.7254	2.9401	0.535
3	16.5891	3.2175	0.740
4	16.5891	3.2175	0.740
5	16.7254	2.9401	0.535
6	16.9947	1.8470	0.154

V. SIMULATION AND RESULT ANALYSIS

The filter structure is realized using 1.6mm thick FR4 substrate with dielectric constant 4.4 and upon a ground plane of 0.035mm thick PEC.(Fig 4).Simulation is carried out using CST software and all the necessary parameters of the proposed filter is determined.

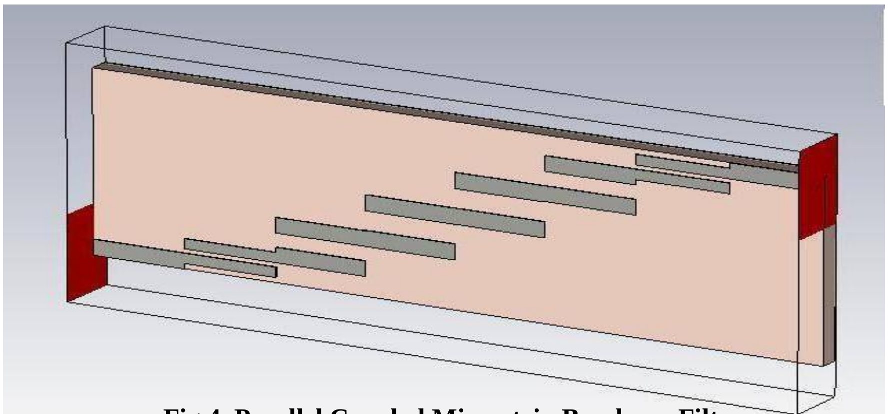

Fig 4. Parallel Coupled Microstrip Bandpass Filter

The designed filter exhibit good return loss S11, low insertion loss S12 and also wide bandwidth (as shown in Fig 5 and 6).The calculated FBW from simulation is 17.36% and is in accord with the theoretical FBW. Five resonant modes at frequencies 2.195, 2.295, 2.39, 2.48 and 2.61 (in GHz) are obtained with return loss (S11) of -39.37 dB, -43.25 dB, -38.63 dB, -33.69 dB and -21.93 dB respectively.

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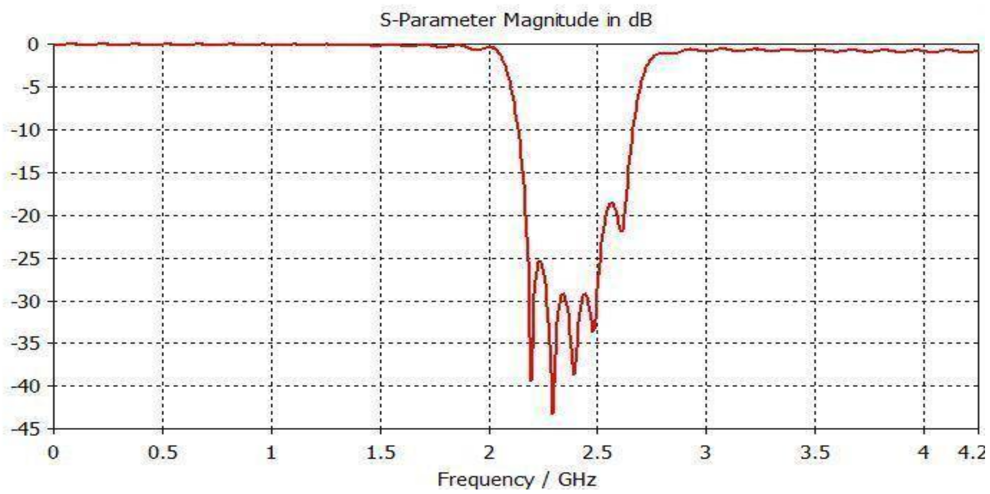

Fig 5. Simulated S_{11} of 5^{th} order chebyshev band pa

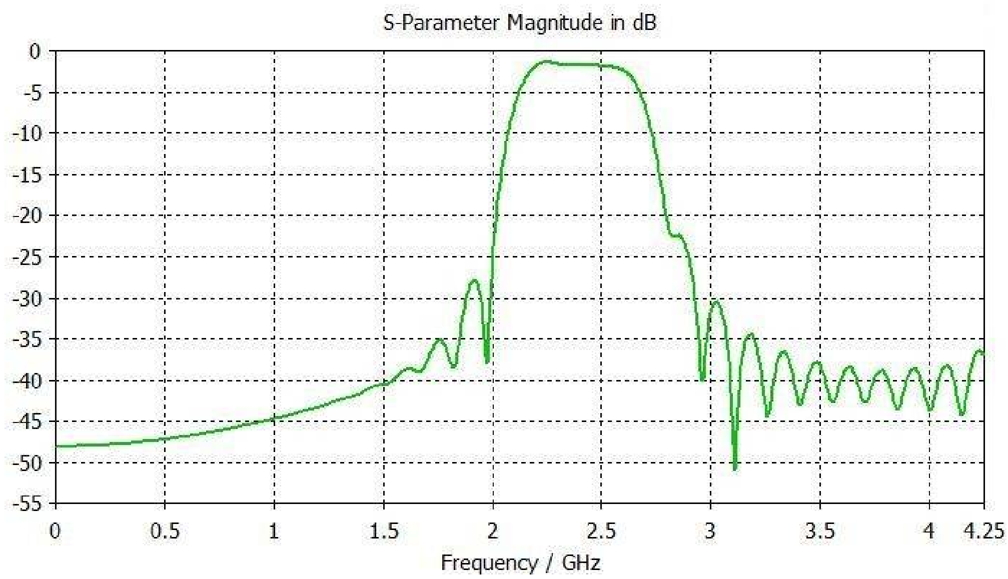

Fig 6. Insertion Loss (S12) for the simulated parallel coupled microstrip line Bandpass filter

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Table 3: Resonant Frequencies and Return loss obtained at corresponding frequencies

Modes	Frequencies (GHz)	Return loss (db)
1	2.195	-39.37
2	2.295	-43.25
3	2.39	-38.63
4	2.48	-33.69
5	2.61	-21.93

VI. CONCLUSION

The parallel coupled microstrip line Bandpass filter which is designed using FR4 Substrate provides efficient filter response and is found out to be more suitable for operating frequency of 2.45GHz.Thus the filter is employable in several applications [15]. The filter has five resonant modes with return loss of < -20 dB. Insertion loss is very less in the selected band and FBW obtained is 17.36% approximately. Moreover the structure is of smaller size because of employing quarter wavelength resonators.

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