SindhUniv. Res. Jour. (Sci. Ser.) Vol. 49(2) 357-362 (2017)

SINDH UNIVERSITY RESEARCH JOURNAL (SCIENCE SERIES)

Optimal Design: Confining the Spurious Ripples of Coupled Line Microstrip Bandpass Filter for WiMax Links

R. A. SOOMRO[++], F. A. UMRANI, M. R. ANJUM*, B. S. CHOWDHRY, I. A. LASHARI**

Institute of Information and Communication Technologies, Mehran UET, Jamshoro, Sindh, Pakistan

Received 1st February 2017 and Revised 18th May 2017

Abstract: The development of advanced meta-materials and new fabrication techniques has revealed the new dimensions of Microstrip structures. Microstrip filters designed with meta-materials offer several merits of being smaller in size, low cost and good performance. However, bearing these merits, such structures also suffer in efficiency due to the ghost of spurious passbands emerged at harmonics of the centre frequency. Furthermore, heterogeneous dielectric material encircled with conductors generates undesired odd-even spurious passbands during propagation. The variation in propagation speeds between odd and even modes results in unwanted ripples in the microstrip coupled lines. These needless spurious bands are generally hurtful in microwave filters especially for wireless applications such asWiMAX.In this regard, the proposed work focuses on the investigation of new microstrip parallel coupled structure to control the insertion and return losses in the passband of bandpass filter (BPF) for WiMAX applications. The concern of adjusting the ripple levels of filter is attained by properly tuning the resonator elements and selection of Aluminum oxide (Al_2O_3) as substrate materials. The utilization of Alumina as substrate material reduces the dissimilarity in propagation velocity of the odd and even modes in microstrip coupling structures. After tuning the resonator elements significant outcomes have been observed in terms of return losses (S_{11}) reaching the extent of >10dB to persuade the requirements of WiMAX band of 5.792GHz. The proposed work presents the optimal simulation model with AWR Microwave Office platform to evade the presence of spurious modes and complementing the bandwidth and ripple levels of the filter.

Keywords: Microstrip filter, Meta materials Aluminum oxide (Al_2O_3), Return loss, WiMAX.

1. INTRODUCTION

Microwave Filters are extensively employed in communication fields such as satellite modules, base stations transceivers and military applications. However, achieving stability and optimal performance characteristics from micro RF structures under tougher operating conditions (such as, fully crowded radio spectrum) demands finer expertise to design sophisticated microwave filters. In conjunction with higher performance scenario, the industry continues to demand for the development of cost effective and miniaturized filter structures. In this regard, co-planer wave guide architecture by (Wang and Chen, 2009) applied admittance inverters to minimize the radiation losses with sharp skirt selectivity, 3-dB 110% fractional bandwidth has been achieved for UWB communication systems. The microstrip parallel coupled half-wavelength resonator filter has been one of the most commonly used filters. The parallel arrangement of resonators by (Cai, *et al.*,2010) offers strong dual-line coupling sandwiched between input/output ports with two square defected structure; configuration produces substantial stopband features S_{21}< -55dB at 2.2 GHz and S_{21}<-38.8dB at 5.75GHz for fractional bandwidths 34% to 40% with low insertion loss. With high dielectric substrate, filter segment can be shrink drastically. Furthermore, feasible substrate with low loss tangent can decline the insertion loss of the filters as well. This type of filter has many takings such as smooth design procedures, a wide bandwidth range reveals plausibly better performance in comparison to other planar circuit filters (Moradian and Tayarani, 2010), (Abbosh, 2012), (Mohra, 2009).

However, the equal-width microstrip coupled line filters undergo the phenomenon of spurious passband at harmonics of the resonant frequency (Marimuthu and Henin, 2013). Therefore, it is quite tricky to eliminate the harmonic signal generated by frequency synthesizer when typical microstripparallel coupled filter operates at the subsequent phase of frequency conversion in the Radio Frequency modules, resulting in the deprivation of system performance which needs to be resolved before optimizing the filter design.

The remains of this paper is categorized as follows. In section 2, the constitution of the microstrip coupled line band-pass filter is described. Section 3 presents the results and discussion of the PCB designed microstrip filter plus simulated model of the proposed

. [++]Corresponding AuthorEmail: riaz.soomro@faculty.muet.edu.pk ;Tel : +92-333-2713205
*Department of Electronic Engineering, The Islamia University of Bahawalpur- Bahawalpur, Pakistan
**IBA,University of Sindh, Jamshoro

microstripcoupled line band-pass filter. Finally, section 4 concludes the paper.

2. MICROSTRIP COUPLED LINE BAND-PASS FILTER

Among the category of microwave filters, microstrip parallel coupled bandpass filters has been given some priorities on account of simple design geometry, good repetition and wide fractional bandwidth with significant Q-factor. Furthermore, diverse filter topologies are proposed by (Xiao nd Huang, 2010) to control spurious response and insertion loss by changing the structure of the split ring Stepped Impedance Resonators (SIR). It is very easy to configure cascaded bandpass coupled line filters or band rejection coupled line filters with narrow band (20% or less), using microstrip or coplanar striplines (CPS) (Yang, *et al.,*2007).

For the microstrip parallel coupled band pass filter, the coupling sections of adjoining resonators are arranged in parallel fashion with half wavelength dimensions as shown in**(Fig.1).**However, as filters with large band require tightly coupled lines in general, it is very difficult to fabricate them.Generally narrowband band pass filters can be designed with coupling sections arranged in cascaded symmetry as shown in **(Fig.2).**

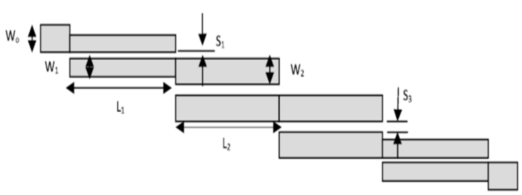

Fig.1: Parallel-coupled, half-wavelength resonator filters

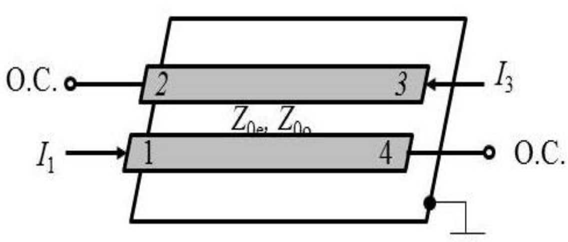

Fig. 2.Coupling sections of dual port filter with propagating channels of current and impedance (odd,even).

The equivalent circuit for the single section of coupled line is indicated in **(Fig 3),** to derive the design equations for the desired filter. Such equivalent modeling can be made possible by evaluating the propagation constant and calculating image impedance to adjust the filter terminations of cascading sections of the equivalent circuit.

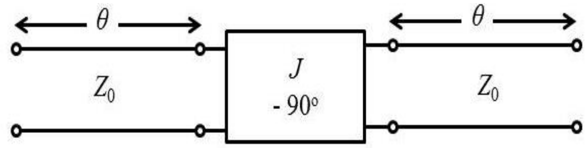

Fig. 3: Coupled line Section amid J-inverters to evaluate the odd and modes

With transformation process,the bandpass or bandstop response can be attained after conversion from Low pass prototype filters. The edges of the passband (ω_1, ω_2) can be obtained by following frequency substitution.

$$\omega \leftarrow \frac{\omega_o}{\omega_2-\omega_1}\left(\frac{\omega}{\omega_0}-\frac{\omega_o}{\omega}\right) = \frac{1}{\Delta}\left(\frac{\omega}{\omega_0}-\frac{\omega_o}{\omega}\right) \text{(I)}$$

Here, ω_1,$\omega_2$and $\omega_o$defines the upper,lower and centerfrequencies respectively. The fractional bandwidth Δ for the coupled line band-pass filter with *N* order chebyshev response can be calculated as follows:

$$\Delta = \frac{\omega_2-\omega_1}{\omega_o} \text{(II)}$$

For simplifying the equations, the center frequency $\omega_o$is selected as the geometric mean of ω_1 and ω_2:

$$\omega_o = \sqrt{\omega^1 \omega^2} \qquad \text{(III)}$$

Next the coefficient values of equal-ripple low pass filters g_1, g_2, …, g_{N+1} are calculated as shown in Table 1 (Pozar, 2009),(Kwang-Wook, 2012) .

According to the proposed filter design ripple ε of 0.5 dB and order N=3has been given.

In order to optimize the filter design, *J*-parameters are used to express filter coefficients, bandwidth, midband frequency and characteristic line impedance. Calculate$J_n$using Eq.(IV),where characteristic impedance Z_0 of filter is:

$$Z_0 J_1 = \sqrt{\frac{\pi\Delta}{2g1}} \qquad \text{(IV)}$$

$$Z_o J_n = \frac{\pi\Delta}{2\sqrt{g_{n-1}\, g_n}} (n=2,3,\ldots,N) \qquad \text{(V)}$$

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

The fractional bandwidth Δ and filter coefficients g_n are already calculated in Eq. (II) and **(Table 1).** Impedances for even mode Z_{0e} and odd mode Z_{0o} can be estimated by Eq. (VII) and Eq. (VIII) respectively. For the *N* order, *N* + 1 characteristic impedance can be calculated as:

$$Z_{0e,n}=Z_0[1+J_nZ_0+(J_nZ_0)^2] \qquad \text{(VII)}$$

$$Z_{0o,n}=Z_0[1-J_nZ_0+(J_nZ_0)^2] \qquad \text{(VIII)}$$

The estimation of characteristic impedance Z_{0e}, Z_{0o}evaluate the physical dimensions of the filter e.g. separation between two strips along with length and width of coupled lines.

Although through mathematical breakdown, a quantitative value of optimizing features for microstrip coupled lines are realized, however; ultimate final design demands renovation of the model with amended physical dimensions on the basis of analysis. Therefore in the next section analysis of S-parameters and evolution in the simulation model has been discussed.

Table 1: Equal-ripple low-pass filter prototype element values (go= l, ωc= 1, N=1 to 3, ripple ε = 0.5 dB)

N	g_1	g_2	g_3	g_4
1	0.6986	1.0000		
2	1.4029	0.7071	1.9841	
3	1.5963	1.0967	1.5963	1.0000

3.

4. RESULTS AND DISCUSSION

For enriching the design of Microstrip coupled line Bandpass filter, an essential requirement is to interpret the design considerations and make appropriate tradeoffs to meet the design issues. According to bandpass filter specifications relating to S-parameters, expanding the bandwidth will minimize the loss in the passband at the cost of selectivity. On the other hand, enhancing the selectivity will boost the magnitude of ripple; although return loss S_{11} will trim down (Yang, *et al.*,2007). Consequently, a tradeoff is required for bandwidth expansion and selectivity.

The focus of this paper is to control the ripple levels of coupled line bandpass filter. The approach adopted in this paper is first to analyze the S-parameters of Man & Tel's microstrip coupled line bandpass filter under R&S®ZVA24 Vector Network Analyzer. Next, the proposed filter model with optimized performance is designed in the AWR Microwave Office. Finally, a comparison is made between the two.

Before pursuing the simulation with improved performance; initially existing Man & Tel's microstrip coupled line filter was tested by perceiving the transmission and reflectionco efficients under R&S®ZVA24 Vector Network Analyzer with following design specifications.

The physical dimensions for resonator elements of filter are as follows:

L_1 = 26 mm, W_1= 2 mm, S_1=0.2 mm
L_2 = 25 mm, W_2= 2 mm, S_2=1 mm,
L_3 = 25 mm, W_3=2 mm, S_3=1 mm,
L_4= 26 mm, W_4= 2 mm, S_4=0.2mm.

Where L, W andS are coupling length, width and separation of the parallel coupled micro strip band pass filter.

The photograph of the Man & Tel's microstrip coupled line Bandpass filter and its measuring configuration with Vector Network Analyzer are represented in **(Fig.4 and Fig.5)** respectively. For microstripbandpass filter design a pass band insertion loss of greater than 5dB and return loss of less than 10 dB is favored especially for the wireless communication applications such asWiMax, which specify a narrower passband with less than 1dB passband insertion loss (Karthikeyan and Kshetrimayum, 2009).

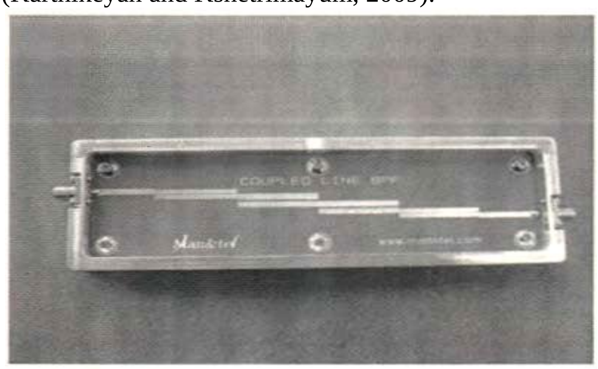

Fig. 4:Man and Tel's Microstrip coupled line filter

The filter with Teflon-based substrate having the dielectric constant of 2.5 generates the insertion loss (S_{21}) of -2.0038 dB at 2 GHz center frequency. The return loss (S_{11}) is reported to be -15.416 dB. The measured responses of scattering parameters through Vector Network Analyzer are exhibited in Fig.6 and Fig.7 suggesting the refined outcomes of insertion loss and return loss meeting specified ranges at cutoff frequency of 2 GHz. However the main challenge needs to betackled that filter should be able to sustain the efficiency and handle unwanted spurious harmonics dilemma at higher frequencies of 5.8 GHz for WiMax application.

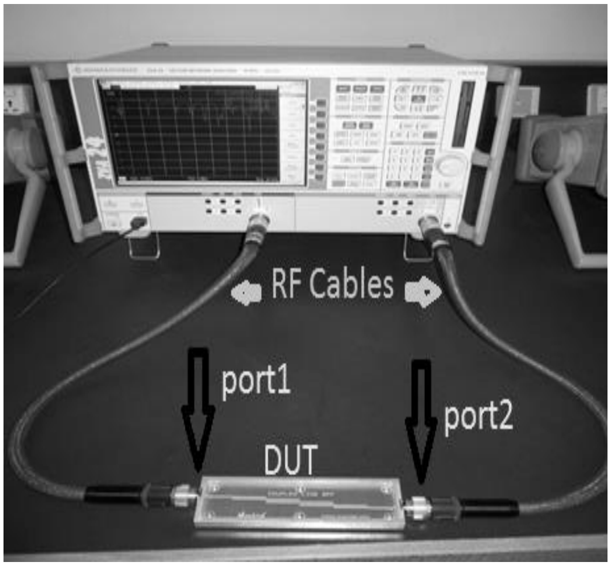

Fig5 : Measuring high frequency parameters of Microstrip filter via R&S®ZVA24 Vector Network Analyzer at ADC TL-102 Lab. Mehran UET, Jamshoro.

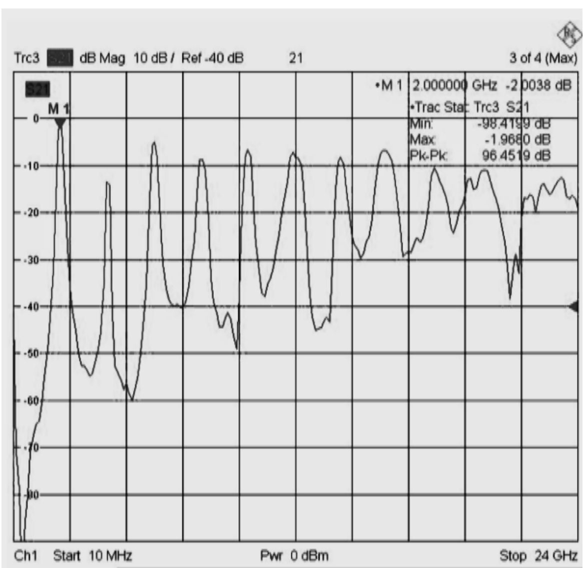

Fig. 6:Insertion loss (S_{21}) of Microstrip coupled filter at 2 GHz

The proposed work by (Alaydrus, 2010) yields microstripbandpass filter with material tangent loss and coaxial feed contacts results reflected power lesser than -10 dB and the insertion loss of about -2dB. The filter design in (Othman, 2013) for wireless local area network at 5.8 GHz with higher insertion losses and expanded transition region; (Abbosh, 2012) introduced design scheme for Ultra-Wideband Parallel-Coupled Microstrip Lines with stopband expansion and handling thepassband harmonics registered as the main concern. On the basis of preceding survey, mathematical analysis is initiated when frequency rangeis changed from 2GHz to higher frequencies 5.8 GHz. Through mathematical analysis, comprehensive electrical and physical dimensions of the design can be calculated for the enhancedperformance of the microwave band-pass filter.

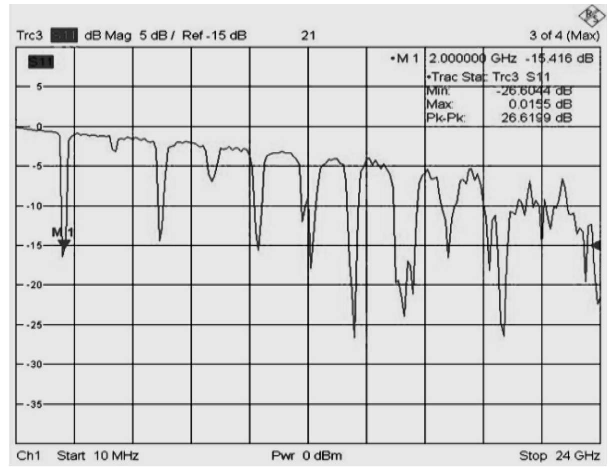

Fig. 7: Return loss (S_{11}) of Microstrip coupled filter at 2 GHz

The filter needs to be designed with 0.5dB equal-ripple response and N=3 for characteristic impedance of $Z_0 = 50\Omega$. The center frequency using Eq. (III) is calculated to be ω_0= 5.792 GHz, where ω_1 = 5.5 GHz and ω_2= 6.1GHz are edges of the passband. Using Eq.(II), the fractional bandwidth Δ is approximately 10%. Using Table 1, in case of ripple 0.5 and N=3 element values for filter coefficients are given by :

g_1= 1.596
g_2=1.096
g_3= 1.596
g_4= 1.000

For extracting electrical dimensions of filter, Eq. (V), (VI) and (VII) will yield following J-parameters.

$$Z_o J_1 = \sqrt{\frac{\pi\Delta}{2g1}} = 0.3136$$

$$Z_0 J_2 = \frac{\pi\Delta}{2\sqrt{g1g2}} = 0.1186$$

$$Z_o J_3 = \frac{\pi\Delta}{2\sqrt{g2g3}} = 0.1186$$

$$Z_0 J_4 = \sqrt{\frac{\pi\Delta}{2g3g4}} = 0.3136$$

Eq.(VII) and Eq.(VIII) will yield line impedances for even mode Z_{0e} and odd mode Z_{0o} by utilizing characteristic impedance Z_o=50Ω and J-parameters. Table 2 summarizes resulting even and odd impedances for each stage of filter with specified parameters.

Utilizing AWR Microwave Office,final optimized designis accomplished by transforming the interval, length and width of the microstrip coupled line along with choice of feasible substrate material.

Table 2: Design Specifications of Man & Tel's Microstrip Coupled line Filter

#	Parameters	Values
1.	Center frequency [ωo]	2.0 GHz
2.	Pass band width	10%
3.	Filter characteristic impedance	50 Ω
4.	Ripple	0.5 dB equal [Chebyshev]
5.	Order of the filter, N	3
6.	Substrate material	Teflon
7.	Dielectric constant	εr = 2.5
8.	Thickness of PCB	h=0.787mm

The RF simulation tool demands computation of prime design parameters to endorse the requisite filter model. The elementary parameters e.g filter type, filter order, dielectric constant (ϵ_r), loss tangent, bulk resistivity of conductor metal, substrate and conductor thickness generates physical layout dimensions which canbe translated to a PCB layout ultimately.

In the proposed filter design, Aluminum Oxide (Al_2O_3) substrate has been chosenwith low loss tangent of 0.0003 up to 10GHz band. Pragmaticdielectric strength (Breakdown Potential) of 210 V/ mil and prominent temperature absorption of 1750°C at higher frequencies are coreattributes of the selection.

While simulating filter design, initially identical physical dimensions for resonator elements were employed as measured through Man & Tel's Microstrip coupled line filter. Due to the discrepancy of return loss (S_{11}) and insertion loss(S_{21}) in meeting the desired roads, tuning tools in AWR Microwave Office adjusted the preceding parameters to find out the new dimensions of the filter as specified below:

L_1 = 29.3 mm, W_1= 2.8 mm, S_1=0.2 mm

L_2 = 26.2 mm, W_2= 1.2 mm , S_2=1 mm

L_3 = 25 mm,W_3=1.46 mm , S_3=1 mm

L_4= 30.5 mm ,W_4= 2.22 mm, S_4=0.2mm

The simulation model of Microstrip Coupled line Bandpass Filter and its 3D layout with amended dimensions are represented in **(Fig. 8 and Fig. 9)** respectively**. (Fig.10)** demonstrates simulated insertion loss (S_{21}) and return loss (S_{11}) for the proposed filter structure embeddedon 0.787mm substrate with relative permittivity level of 9.6 amid loss tangent of 0.0003 at resonant frequency of 5.792GHz. The optimal design demands pass band insertion loss of <5dB and return loss of >10dB for selectivity of refined ripple response.

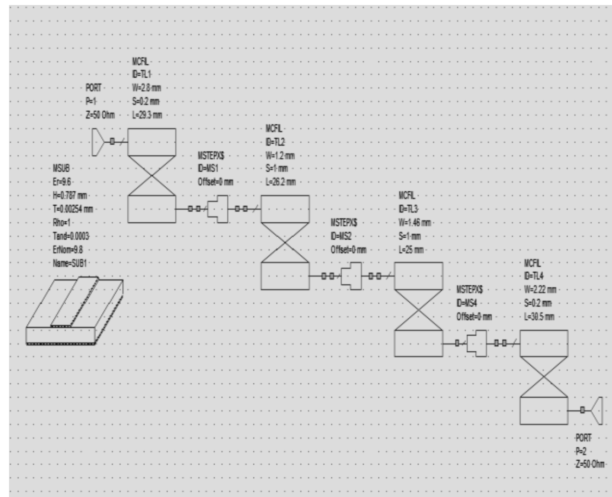

Fig. 8 :Simulation Model of the proposed microstrip coupled line filter

Fig. 9: 3D presentation of the coupled line microstrip filter with new physical dimensions

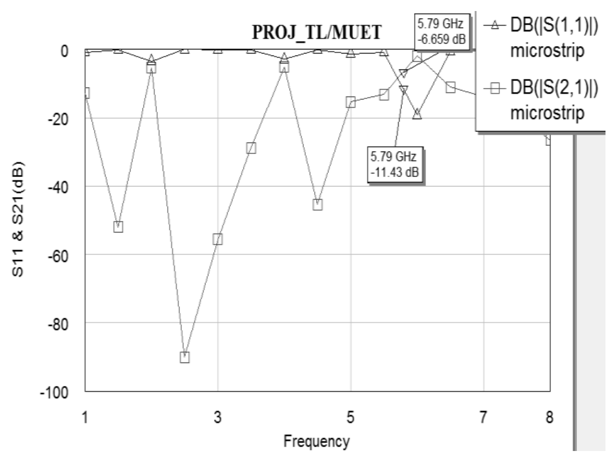

Fig.10: Microstrip Coupled Line BPFscattering parameters after tuning - Insertion loss (S_{21}) and Return loss(S_{11})

The passband of proposed bandpass filter is designed from 5.5 GHz to 6.1 GHz with frequency transformation.The return loss (S_{11}) and insertion loss (S_{21}) centered at 5.792 GHz with customizeddimensions are monitored as -11.43 dB and -6.659 dB respectively. Hence the simulated return loss (S_{11}) lies in the range of 10dB to 15dB to show good agreement with the outcomes. Although insertion loss (S_{21}) slightly deviates as compare to ideal range which is obviously understandable with respect to tolerance levels of filter but return losses (S_{11}) illustrate fine results for controlling the ripple levels of filter in pass band region as former suggest inverse relation with ripple intensity.

5. CONCLUSION

A Coupled line Microstrip bandpass filter is successfully designed by mathematical analysis and optimal model with CAD design tool. Initially PCB designed Microstrip filter with Teflon-based substrate was tested under R&S®ZVA 24 Vector Network Analyzer at center frequency of 2 GHz. Consequently, reasonable amount of return loss (S_{11}) and insertion loss (S_{21}) have been measured with pass band insertion loss measured less than the 5dB goal. Although shifting at higher frequencies suitable transformation is exercised to convert lumped elements to distributed transmission lines especially for microstrip coupled sections where equilibrium of odd and even modes become fundamental stuff of the design. Therefore, in order to optimize the filter design at higher band of 5.8GHz, filter coefficients, fractional bandwidth, midband frequency, admittance inverters and impedance for odd and even modes have been derived through precise mathematical equations. Utilizing these electrical quantities, simulation model of Microstrip coupled line bandpass filter was generated with AWR Microwave Office to achieve the aims and objectives of the proposed work. With parallel arranged coupling resonators the goal was not satisfied in first iteration but after tuning these resonator elements significant outcomes have been observed in terms of return losses (S_{11}) reaching the extent of >10dB to persuade the requirements of WiMAX band of 5.792 GHz.

ACKNOWLEDGMENTS

This proposed work is supported by M/S Birds Chemotec, Karachi.We highly acknowledge the assistance and funding provided by M/S Birds Chemotec, Karachito support the research activities at Telecommunication Engineering department, Mehran UET, Jamshoro.

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