DESIGN AND IMPLEMENTATION OF AN OPTIMIZED J-BAND MICRO-STRIP SYMMETRIC COUPLED LINE BAND PASS FILTEr

F.G. Awan, N.A. Sheikh
Dept. of Electrical Engineering, University of Engineering and Technology Lahore
fawan@uet.edu.pk, sheikh151@yahoo.com

ABSTRACT— *In this paper J -band Symmetric Coupled Line Band pass Filter has been designed and implemented using microstrip transmission line topology. Initially the filter is developed by using the appropriate design equations for the exact physical dimensions of the filter. The resulting structure is simulated using features of Advanced Design System (ADS). Due to manufacturing constraints, first and last resonator spacing of the above filter are adjusted to the minimum value that can be physically implemented. Accordingly other physical dimensions of the resonators, including length and width, are also optimized to get the desired response. This optimized filter is then manufactured and its insertion loss is measured using Network Analyzer. Finally the simulated results for the proposed filter and the measured results for the implemented filter generated by Network Analyzer are compared.*

Keywords: Microstrip, Symmetric Coupled Lines, Quasi-Static Analysis, Full Wave Analysis, Method of Moments

INTRODUCTION

Microwave Coupled Lines Band pass filters are basic building blocks in state of the art Radars, Microwave Radio links and Satellite Communication Systems. These filters employ coupled lines, consisting of two parallel transmission lines placed in close proximity to each other. Thus the power can be coupled between the two lines due to interaction of electromagnetic fields between them. The characteristics of these coupled lines are described by Napoli [1]. When the two conductors of the coupled lines are identical, we have a symmetrical configuration. For simple design procedures and easy realization in planar circuits, quarter-wavelength λ/4 coupled-lines sections based coupled-lines band pass filters are becoming a popular choice among filters [2]-[3]. In general, Even and Odd modes are excited simultaneously in coupled lines. However, they propagate with different phase velocities and thus experience different permittivity resulting in different effective dielectric constants as well as different characteristic impedances for the two modes of coupled microstrip lines [4].The band pass filters which are implemented from these symmetric coupled lines consist of *N+1* resonators, where *N* is the order of the filter.

The filter parameters are length (l), width (w) and spacing (s) of each resonator. Desired frequency response can be obtained by adjusting the values of these parameters. The schematic diagram of Symmetric Coupled Lines Band Pass Filter is shown in **Figure 1**.

As compared to end coupled filters, the parallel coupled line filters have the advantage of larger gaps between the coupled lines and therefore they are less critical, making them easier to manufacture.

In comparison to hairpin filters, they are easier to manufacture as they don't require bends and also offer better bandwidth [5]. And finally, when compared to line and stub filters, they can be easily implemented as they don't require short circuit.

These filters can be implemented with Microstrip fabrication technology. Microstrip belongs to a group of parallel plate transmission lines and consists of a single ground plane and an open strip conductor separated by a dielectric substrate. The parallel-coupled Microstrip arrangement is a TEM mode arrangement. The field distributions on these lines result in even mode and odd mode impedances denoted by Z_{0_e} and Z_{0_o} respectively.

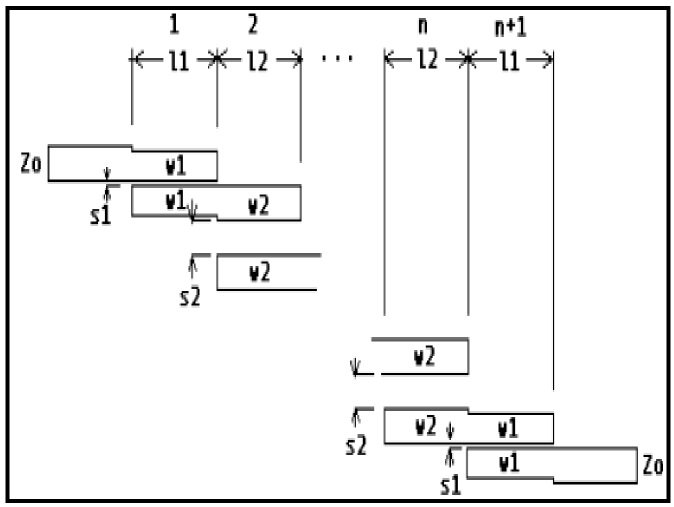


Figure 1. Symmetric coupled line band pass filter

The design of Microstrip Symmetric Coupled Lines Band Pass filters on ADS requires a step-by-step approach to meet the design specifications. The length of each coupled section is one quarter wavelength at the centre frequency f_0.The width and the spacing of each coupled section can be completely specified by Z_{0_o} and Z_{0_e} [6]-[7], its odd and even mode impedances respectively.

DESIGN PROBLEM

The design equations of the n^{th} order parallel-coupled filter are given [8], [9] and [10]. The equations utilize normalized inductive and capacitive elements $g_1, g_2, g_3, \ldots\ldots, g_n$ of the prototype low pass filter.

For the first coupling structure

$$Z_0 J_{0,1} = \sqrt{\frac{\pi Bw}{2 g_0 g_1}} \tag{1}$$

For intermediate structures

$$Z_0 J_{i,i+1} = \frac{\pi Bw}{2\sqrt{g_i g_{i+1}}} \tag{2}$$

For last structure

$$Z_0 J_{n,n+1} = \sqrt{\frac{\pi Bw}{2 g_n g_{n+1}}} \tag{3}$$

Where

$$Bw = \frac{f_u - f_l}{f_o} \tag{4}$$

And

$$f_o = \frac{f_u + f_l}{2} \tag{5}$$

Here *Bw* is 3dB fractional bandwidth and f_o is the centre frequency in the pass band while f_u and f_l are 3dB upper and lower cut off frequencies in the pass band respectively. The even and odd mode impedances are calculated from

$$Z_{0e}\Big|_{i,i+1} = Z_0\left[1 + Z_0 J_{i,i+1} + (Z_0 J_{i,i+1})^2\right] \tag{6}$$

$$Z_{0o}\Big|_{i,i+1} = Z_0\left[1 - Z_0 J_{i,i+1} + (Z_0 J_{i,i+1})^2\right] \tag{7}$$

Based on these values, width and spacing of each coupled structure can be calculated [8], [9], [10].

A typical example of step by step Microstrip coupled line filter design is described as follows: The filter specifications are given in **Table 1**.The order of the filter comes out to be $N = 3$. The coefficients are given as follows:

$$g_1 = 1$$

$$g_2 = 2$$

$$g_3 = 1$$

$$g_4 = 1$$

Equation (4) gives the required band width

$BW = 0.1295$

Corrosponding to Z_{0e} and Z_{0o}, the even and odd mode impedances, the width and spacing of each section are calculated. The length of each section is quarter wavelength that comes out to be 121mil. The computed results are summarized in **Table 3**.

The circuit is simulated in **Figure 2** using both the ideal transmission lines with no dielectric loss and Microstrip transmission lines which-accounts for the tangent loss of the substrate.

The ideal transmission line parameters are even mode impedance Z_{0e} and odd mode impedance Z_{0o} .Electrical length E is equal to quarter wavelength at the centre frequency of 16.4GHz. The Microstrip transmission line parameters are width (w) of each coupled line, spacing (s) between the two coupled lines and finally the physical length (l) of the line (quarter wavelength long).

The simulation results of the two schematics are shown in **Figure 3**.As seen from the figure, the 3dB bandwidths of (a) and (b) are nearly equal. The insertion loss of the **Figure 3(b)** is larger because it accounts for the dielectric loss, radiation loss and conductivity of the copper strip over the substrate.

For more accurate results, Full wave analysis of ADS is employed as shown in **Figure 4**. The Momentum feature can perform Full Wave Analysis unlike the Quasi-Static Analysis that assumes the pure TEM mode. Also the microstrip transmission line cannot support pure TM or TE waves. Longitudinal components of both the electric and magnetic field are needed to satisfy the boundary conditions. To account for this, hybrid modes are generated which may be considered as superposition of TE and TM fields. Full wave analysis carried out by Momentum takes into account these hybrid modes. The Layout is shown in **Figure 4**. The simulated results from Momentum are shown in **Figure 5**. The insertion loss is greater than 1dB and the bandwidth is less than 2GHz.

The first and last resonator spacing is nearly 3mil that are quite difficult to manufacture. The minimum spacing that can be manufactured locally is not less than 10mil. So the values need to be optimized in order to make insertion loss less than 1dB and the minimum spacing of first and last resonator equal to 10mil.

As per analysis the length is not changed, while the resonator spacing is fixed at 10mil and 20 mils due to physical constraints. The resonator widths are optimized step by step in order to achieve the desired results. After performing a few iterations, the final layout is shown in **Figure 6**.

The insertion loss is 0.761 dB while 3dB bandwidth equals 1.93 GHz. So the filter response is quite close to the desired one.

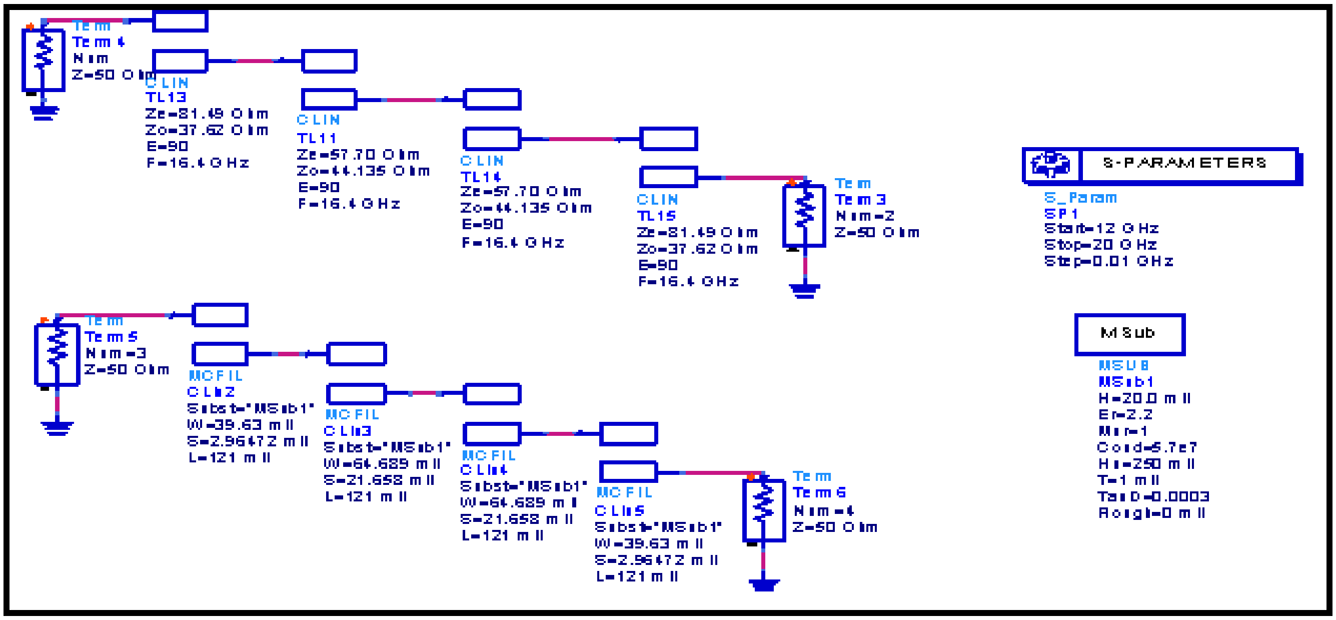


Figure 2. Ideal Transmission lines and Microstrip Transmission lines Filters on ADS

Table 1. Filter Specifications

FEATURES	VALUE OR TYPE
Centre Frequency f_o	16.4 GHz
Bandwidth	2 GHz
Filter Type	Butterworth
Attenuation in Pass band	<1 db
Fabrication Technology	Microstrip
Substrate Thickness	20 mil
Permittivity	2.2
Characteristic Impedance	50 Ω
Attenuation at 18.52 GHz	At least 18.75 db

Table 2. Parameteric Effect

Parameter Name	Effect on Response
Length of resonator	Central Frequency f_o
Width of resonator	$B\omega$
Spacing of resonator	Bω

The filter designed on Momentum is finally implemented on duroid substrate $(\varepsilon_r = 2.2)$ shown in **Figure 8**. The response is measured using Network Analyzer and is shown in **Figure 9**.

The centre frequency is still 16.4 GHz while the bandwidth has decreased to 1.622 GHz compared to the desired bandwidth of 2 GHz. Also the attenuation is 1.68dB which is greater than the required one.

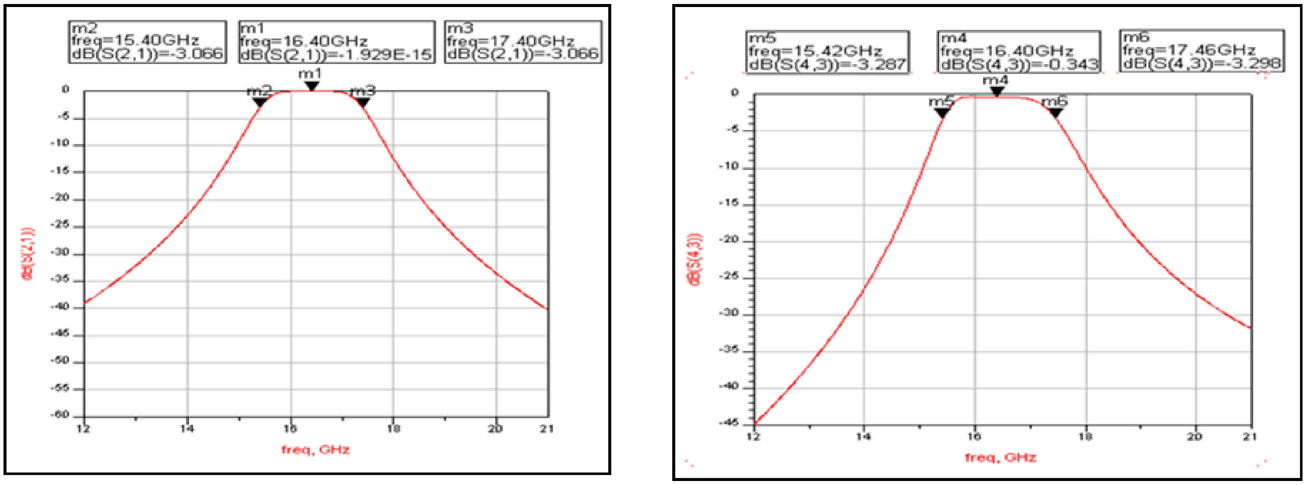
Table 3. Computed Results

i	$Z_0 J_{i,i+1}$	Z_{0_o} Ω	Z_{0_e} Ω	W (mil)	S (mil)
0	0.4510	37.69	81.49	39.32	2.96472
1	0.1438	44.135	57.70	64.689	21.658
2	0.1438	44.135	57.70	64.689	21.658
3	0.4510	37.69	81.49	39.32	2.96472

CONCLUSION

A step-by-step procedure to design a symmetric Microstrip coupled lines resonator band pass filter on ADS is presented. The designed filter when simulated on ADS schematic doesn't give the desired results. So the filter needs to be optimized. Power full tool of ADS Momentum is employed that carries out an EM analysis using Method of Moments. The results generated by Momentum are very close to the actual measured results. Hence whenever we have to work on the Microstrip Band Pass Filters at microwaves frequencies, we can simply follow the design equations to calculate length, width, and spacing of each resonator. The resulting structures can be simulated using ADS schematic. That schematic can then be translated to Momentum to carry out the EM analysis. Optimization feature of the momentum can be used to carry out optimization. In this way we can get a result very close to the desired result. The effectiveness of the optimization procedure has been proven by the experimental results of the sample filter.

ISSN 1013-5316; CODEN: SINTE 8 Sci.Int.(Lahore),27(5),4501-4505,2015



(a) for ideal transmission line

(b) Microstrip transmission lines with dielectric losses with no substrate losses

Figure 3. Circuit responses on ADS:

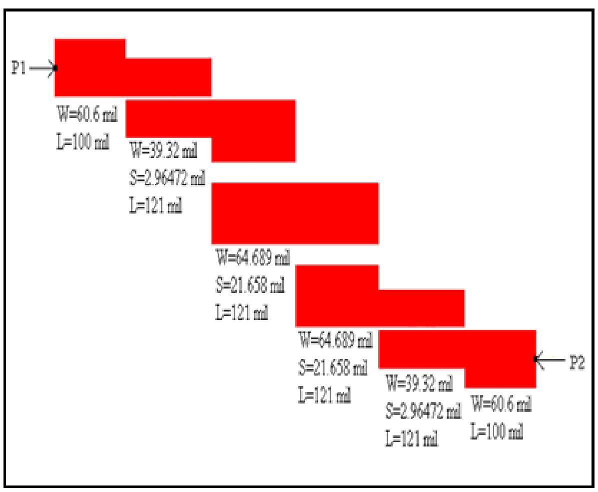


Figure 4. Momentum Layout on ADS for the optimized filter

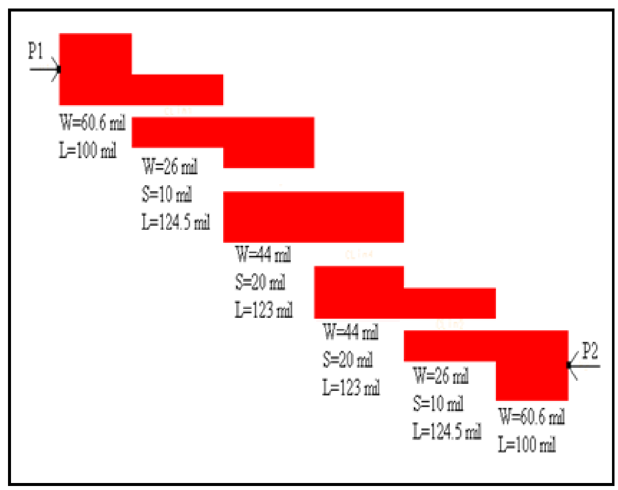


Figure 6. Momentum Layout on ADS for physically implemented filter

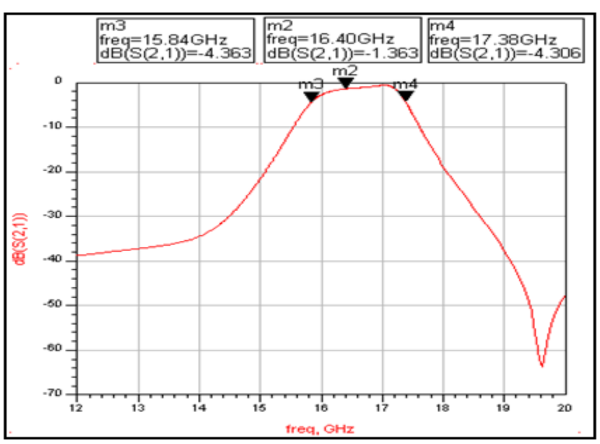


Figure 5.Full wave analysis result of optimum filter

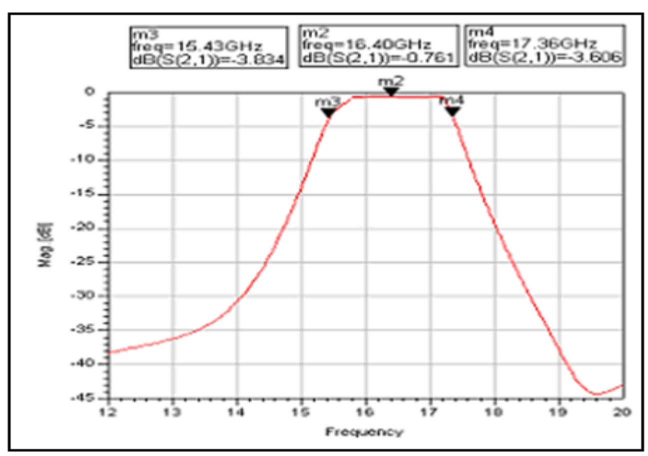


Figure 7.Full Wave Analysis of physicallyImplemented filter

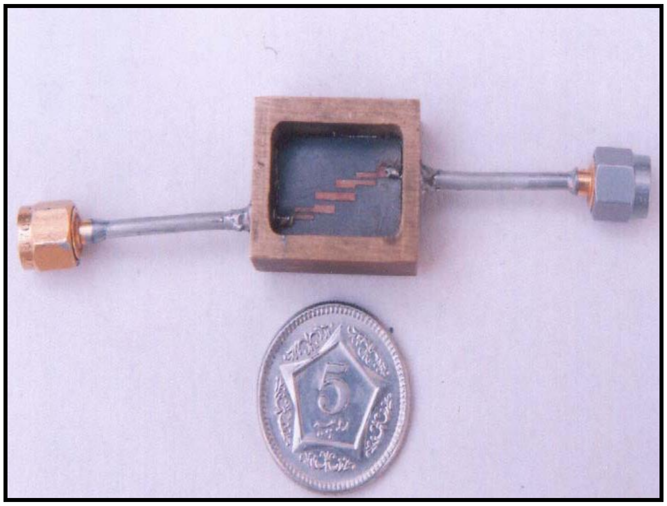


Figure 8. Photograph of implemented Symmetric Coupled Line Band Pass Filter

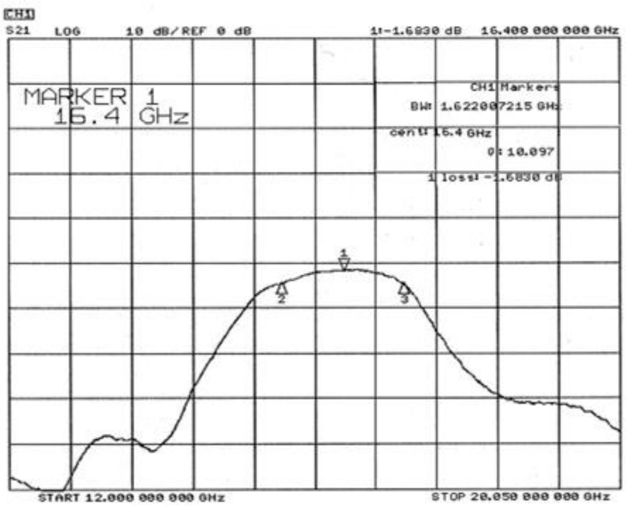


Figure 9. **Response of physically implemented Symmetric Coupled Line Band Pass Filter**

The obtainable loss in the implemented filter is greater than the one obtained by simulation in Momentum. This is due to the fact that substrate roughness, metal thickness and radiation losses are not incorporated in the software simulation. Also the measured bandwidth is less than the designed one. According to Young [9] such discrepancy can be due to the nature of the design equations. The loss can be reduced by placing the filter inside a metallic housing which will reduce the radiation loss. In the enclosed case the coupling coefficients are tighter than those in the open geometry. Coupled Microstrip with metallic housing lines have been modeled by Bedair [10]. However the placement of the filter inside a metallic housing will cause it to act as a cavity with unwanted modes of excitation having different resonant frequencies. These generated modes will cause sharp dips in the filter response at the resonant frequencies of the hybrid modes which are generated inside the cavity. In order to avoid these unwanted modes within the required spectrum, cavity perturbation techniques can be applied which will cause the resonant frequencies of the metallic housing to be shifted out of required spectrum. Additionally spurious pass band suppression in microstrip coupled line band pass filters can also be achieved by means of split ring resonators (SRRs) [11].

ACKNOWLEDGMENT

The authors would like to thank personnel in Wireless and DSP Lab UET Lahore for their constructive suggestions.

REFERENCES

[1] L S Napoli and J J Hughes. “Characteristics of Coupled Microstrip Lines” *RCA Review*, vol. **31**, pp. 479-498, 1970.

[2] C.-Y. Chang and T. Itoh, “A modified parallel-coupled filter structure that improves the upper stop band rejection and response symmetry*,” IEEE Trans.* MTT- **39**, pp. 310-314, Feb. 1991.

[3] J.-T. Kuo and Eric Shih, "Wideband bandpass filter design with three-line microstrip structure*,” in IEEE* Int. Microwave Symp. Dig., pp. 1593-1595, 2001.

[4] Jia-Sheng Hong and M. J. Lancaster. *“*Microstrip Filters for RF/Microwave Applications*”. New York: John Wiley & Sons, Inc*., 2001.

[5] Naves, Martins R, Abdalla H. *“*Techniques Yield Tiny Hair-Hairpin-Line Resonator Filters”. *Microwaves and RF*, pp.1-11, November 1999.

[6] Shamasundara S D and N Singh “Design of Coupled Microstrip Lines*” IEEE Trans*, vol.MTT-**25**, pp.232-233, 1977

[7] Bryant T G and J A Weiss “Parameters of Microstrip Transmission Lines and Coupled Pairs of Microstrip Line*” IEEE Trans*, vol. MTT-**16**, pp.1021-1027, 1968.

[8] T C Edward, *Foundations for Microstrip Circuit Design* .John Wilrey & Sons Ltd, 1981.

[9] L Young, *Microwaves Filters Using Parallel Coupled Line*s. Artech House, Inc., 1972.

[10] S S Bedair and M I Sobhy “Accurate Formulas for the Computer-Aided Design of Shielded Microstrip Circuit,” *Proc.IEE, Part H*, vol. **127**, pp.305-308, 1980.

[11] Garcia-Garcia, J. Martin, F “Spurious passband suppression in microstrip coupled line band pass filters by means of split ring resonators*” IEEE Microwave and Wireless Components Letters*, vol.**14**, pp. 416 – 418, Sept. 2004.