ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 6, Issue 6, November 2017

# Simulation and Analysis of Coupled Microstrip Band Pass Filter for 9.3−9.7GHz

REHAB ELMOGIRA HAMZA (1), AHMED A. BABIKER (2), MOUTAMAN MIRGHANI (3)
(1) Researcher, Institute of Engineering Research and Materials Technology,
National Center for Research, Khartoum, Sudan.
(2) Assistant Professor, Electrical and Computer Department
Karary University, Omdurman, Sudan
(3) Associate Professor, Institute of Space Research and Aerospace,
National Center for Research, Khartoum, Sudan.

***Abstract*— This paper demonstrates a complete design, development, simulation and analysis of micro strip band pass filter at 9.5 GHz frequency and 400 MHz bandwidth. A Chebyshev filter of order of 10 and of 0.01 dB ripple in pass band is chosen. First, the corresponding low pass prototype filter is designed, and then impedance and frequency scaling transformations are used to convert it to the desired filter. Return loss and insertion loss have been measured. The lumped element band pass filter has been derived and converted into micro strip filter. The design shows good agreement with theoretical results. Advanced Design System software tool is used for the simulation of the lumped element filter and edge-coupled micro strip filter circuits. MATLAB code is designed to calculate the values of the filter's elements at any filter order.***

*Keywords*— **ADS, BPF, Chebyshev, Edge-Coupled Micro strip, Insertion Loss, Pass band Ripple, Return Loss.**

## I. INTRODUCTION

Microwave band pass filters play important roles in the microwave systems, especially in the transmitting and receiving systems, so as to transmit and identify the desired signals. As for the planar microwave band pass filters, there are normally four different types: the comb-line filters, the inter-digital filters, the parallel coupled filters and the hairpin-line filters [1].

Band pass Filter (BPF) is one of the essential components of almost all RF communication systems. BPF filter passes the frequency in passband and provides attenuation for frequencies which lie outside pass band that means stop band. Thus, BPF acts as frequency selective circuit [2].

Filters are generally realized using lumped or distributed circuit elements. Filters designed above 1 GHz using lumped elements produce distributed effects, as the dimensions of electronic component are comparable to the wavelength of the signal [2]. At high frequencies in the range of microwaves, lumped inductors and capacitors lack their intrinsic characteristics. For this reason, it is wise to use distributed elements, for example transmission lines that are used for design of required filter at higher frequencies [3].

Micro strip filters are more attractive in microwave applications as they possess advantage over lumped filters. Micro strip filters are small in size, economical and provide improved performance [2]. Micro strip filters are used for the reduction of the complexity of microwave circuits and passive components used in efficient communication systems.

Symmetrical coupled micro strip lines consist of two signal strips integrated on a substrate with a backside ground plane, as shown in Fig.1 [4]. Coupled-line structures are available for all forms and types of transmission lines/dielectric guides and waveguides.

Strip lines, micro strip lines, coplanar waveguides, image guides, and insular and inverted strip guides are the most popular planar forms. In Fig.1, cross sections of micro strip coupled lines are shown. In these structures, practical spacing limitations between the lines limits the tight coupling achievable to about 8 dB over λ/4 sections. These configurations are parallel (edge)-coupled structures [5].

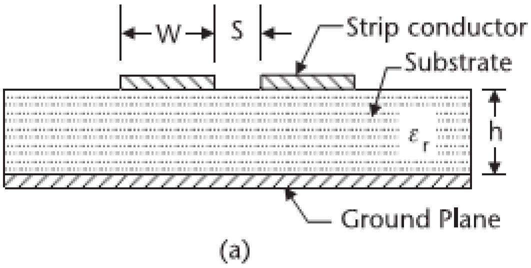

**Fig. 1: Coupled Micro strip Lines [5].**

This paper deals with the design and development of BPF filter in X-band frequency. The development of band pass filter includes calculation, simulation and analysis of the filter parameters. This paper is presented with filter structure that suits for the frequency between 9.3-9.7GHz. The prototype structures for the coupled micro strip band pass filter transformation are simulated using ADS software.

## II. METHODOLOGY

To obtain a high degree of control over pass and stop bands, the insertion loss method is to be used. It allows filter performance to be improved at the expense of a higher order filter [6]. The design specification of the filter is shown in Table I. The proposed filter is designed using the following five steps: (1) determining the order and type of approximation functions to be used, (2) finding the corresponding low pass prototype, (3) transforming the low pass network into required band pass configuration, (4) scaling the band pass configuration in both impedance and frequency, and, (5) then transforming the lumped circuit element into distributed realization [7].

**Table I: Specification of Edge-Coupled Microstrip Band Pass Filter**

| Parameter | Value |
|---|---|
| Upper cutoff frequency | 9.7 GHz |
| Lower cutoff frequency | 9.3GHz |
| Pass band ripple | 0.01dB |
| Filter order | 10 |
| Pass band center frequency | 9.5GHz |
| Attenuation at rejection region | ≥30dB |
| Substrate | Duroid RTD5880 |
| Conductor thickness (T) | 0.017mm |
| Dielectric constant (Er) | 2.2 |
| Substrate height (H) | 0.787 mm |

### A. *Filter Type and Order*

A good band pass filter has minimal signal loss in its pass-band, as well as a narrow pass band with as much out of band attenuation as possible. Chebychev filters have narrower pass- band response with trade for more ripples in the passband section. Higher order filters may have narrower shape factors, but will be physically larger in shape. The required order for a filter meeting the given specifications is calculated as below [7]:

$$n = \frac{\cosh^{-1}\sqrt{\dfrac{10^{\frac{K_T}{10}}-1}{K-1}}}{\cosh^{-1}\left(\dfrac{f}{f_c}\right)} \qquad (1)$$

Where $K_T$ is the minimum attenuation in dB at some out-of-band frequency which is determined as ≥30dB, and

$K = 10^{(Lar/10)}$, with $L_{ar}$ being the maximum ripple in dB that is allowed in the passband [7]. The value of $(|f/f_c|-1)$ is equal 0.2632 when (f) is equal 12GHZ and ($f_c$) is a cutoff frequency.

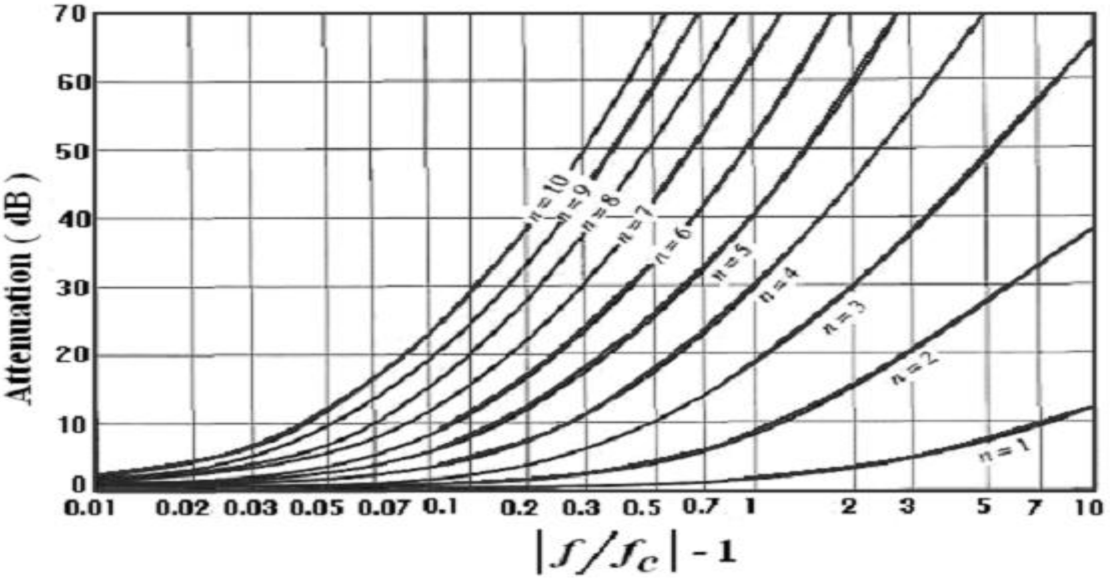

**Fig 2: Attenuation vs Normalized Frequency for an N-section Chebychev Filter, 0.01dB passband ripple [8].**

Fig.2 shows how the order of the filter can be determined with the assumed attenuation. For this design, the attenuation is assumed to be $\geq 30$dB, so the corresponding filter order is found to be equal to10.
The order of a filter determines how steep the response falls off in the stopband. The higher the order, the steeper the slope of the amplitude (or phase) response versus frequency is going to be [9].

### *B. Design of Low Pass Filter Prototype Using Lumped Components*

The main step that should be considered is the design of microstrip low pass filters into appropriate micro strip realization of the lumped elements filter. In this design, the targeted specification of the filter for low pass prototype is a ripple factor of Lar = 0.01 dB. After finalizing the order selection process, the prototype of the low pass filter is developed using the lumped elements, which are the components values that are explained in Table II. The values $g_i$ shown in Table II are the inductances for series inductors and capacitances for shunt capacitors. Normalized lumped elements values of the low pass filter prototype are found using a MATLAB code. The low pass filter prototype is shown in the circuit of Fig.3 below.

**Table II: Low Pass Prototype Circuit Element Values (0.01dB Chebychev Passband Ripple)**

| Prototype Elements/ Order | $g_1$ | $g_2$ | $g_3$ | $g_4$ | $g_5$ | $g_6$ | $g_7$ | $g_8$ | $g_9$ | $g_{10}$ | $g_{11}$ | $g_{12}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.0960 | 1.0000 | | | | | | | | | | |
| 2 | 0.4489 | 0.4078 | 1.100 | | | | | | | | | |
| 3 | 0.6292 | 0.9703 | 0.629 | 1.000 | | | | | | | | |
| 4 | 0.7129 | 1.2004 | 1.321 | 0.647 | 1.100 | | | | | | | |
| 5 | 0.7563 | 1.3049 | 1.577 | 1.304 | 0.756 | 1.0000 | | | | | | |
| 6 | 0.7814 | 0.3600 | 1.689 | 1.535 | 1.497 | 0.7098 | 1.1007 | | | | | |
| 7 | 0.7969 | 1.3924 | 1.748 | 1.633 | 1.748 | 1.3924 | 0.7969 | 1.0000 | | | | |
| 8 | 0.8073 | 1.4131 | 1.782 | 1.683 | 1.852 | 1.6193 | 1.5554 | 0.7334 | 1.1007 | | | |
| 9 | 0.8145 | 1.4271 | 1.804 | 1.712 | 1.905 | 1.7125 | 1.8044 | 1.4271 | 0.8145 | 1.0000 | | |
| 10 | 0.8196 | 1.4370 | 1.819 | 1.731 | 1.936 | 1.7590 | 1.9055 | 1.6528 | 1.5817 | 0.7446 | 1.1007 | |
| 11 | 0.8235 | 1.4442 | 1.829 | 1.743 | 1.955 | 1.7855 | 1.9555 | 1.7437 | 1.8299 | 1.4442 | 0.8235 | 1.000 |

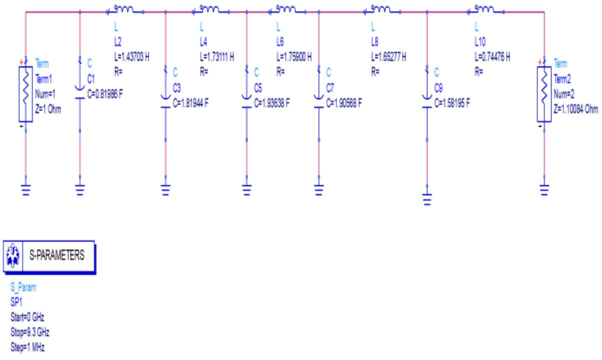

Fig 3: The Low Pass Filter Prototype

### C. *Transforming Low Pass Filter into Band Pass Filter*

After obtaining the low pass filter prototype values, it is transformed into band pass filter. Series inductors of the low pass prototype are transformed into a series combination of inductors and capacitors, while the shunt capacitors are transformed into a parallel combination of an inductor and a capacitor. The designed circuit is as shown in Fig.4. The values of the components are calculated using a MATLAB code that follows the design equations.

### D. *Scaling the Configuration in Both Impedance and Frequency*

Here in this step, the impedance and frequency scaling is carried out. The transformed filter is scaled both in frequency and impedance, using the following formulas [7]:

1. For the series resonant branches: -

$$L_S = \left(\frac{1}{FBW \times \omega_0}\right) Z_0 \times g \qquad (2)$$

$$C_S = \left(\frac{FBW}{\omega_0}\right) \frac{1}{Z_0 \times g} \qquad (3)$$

2. For the parallel resonant branches: -

$$C_P = \left(\frac{1}{FBW \times \omega_0}\right) \frac{g}{Z_0} \qquad (4)$$

$$L_P = \left(\frac{FBW}{\omega_0}\right) \frac{Z_0}{g} \qquad (5)$$

Where $Z_0$ is the input impedance equals 50Ω, FBW is the fractional bandwidth equal $\left(\frac{BW}{f_c}\right)$, and $\omega_0 = 2\pi f_c$ .

A MATLAB code is used to obtain the components values after frequency and impedance transformation. These calculated values are shown listed in Table III.

**Table III: Element Values Obtained after Frequency and Impedance Transformation**

| Parameter | Specifications | |
|---|---|---|
| | LPF | BPF |
| **Order** | 10 | 10 |
| | Z0=Zl=1Ω | Z0=50Ω , Zl=55.037Ω |
| g1 | C1=0.8196 F | C1=6.5226 pF , L1=43.049 pH |
| g2 | L2=1.4370 H | C2= 0.0098223 pF , L2=28.587 nH |

| | | |
|---|---|---|
| g3 | C3=1.8193 F | C3=14.477 pF , L3=19.395 pH |
| g4 | L4=1.7311 H | C4=0.0081532 pF , L4=34.439 nH |
| g5 | C5=1.9362 F | C5=15.408 pF , L5=18.224 pH |
| g6 | L6=1.7590 H | C6=0.0080239pF, L6=34.995nH |
| g7 | C7=1.9055 F | C7=15.164 pF , L7=18.517 pH |
| g8 | L8=1.6528 H | C8=0.0085398 pF , L8=32.88 nH |
| g9 | C9=1.5817 F | C9=12.587 pF , L9=22.308 pH |
| g10 | L10=0.7446 H | C10=0.018955 pF, L10=14.814 nH |

Fig.4 shows the lumped elements schematic diagram of designed circuit using ADS software. After applying Richard's transformation and Kuroda's identity.

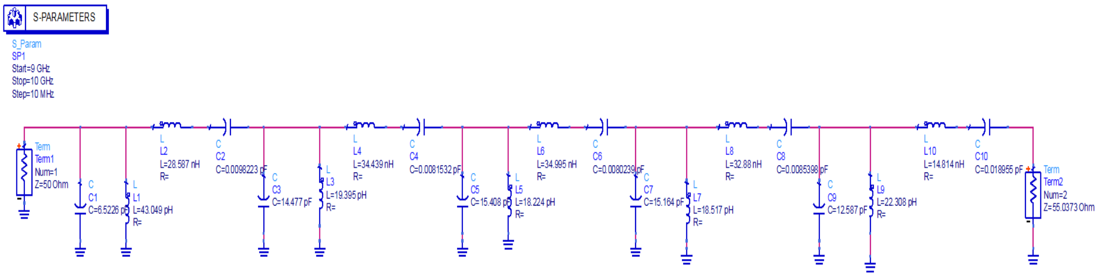

**Fig 4: Schematic diagram of Chebyshev BPF Prototype**

### *E. Transforming the Lumped Circuit Element into Distributed Realization*

Lumped element filters, i.e., filters constructed with discrete components such as capacitors and inductors, are not suitable for filter construction above 500 MHz. That is due to the wavelength becoming comparable to the physical filter element dimensions, resulting in various losses, severely degrading the circuit performance. Thus to arrive at practical filters, the lumped element filters must be converted into distributed element realizations. The conversion to micro strip filters exhibit sharp rejection attenuation and superior harmonic suppression in stopband, when compared to a conventional one [10]. To implement the filter with micro strip, the Kuroda's identities should be used to define impedance or admittance inverters [6]. The equations (6, 7 and 8) of admittance inverters for designing microstrip BPF with N+1 coupled line sections are as follow [2]:

$$Z_0 J_1 = \sqrt{\frac{\pi\Delta}{2g_1}} \tag{6}$$

$$Z_0 J_n = \frac{\pi\Delta}{2\sqrt{g_{n-1} g_n}} \tag{7}$$

$$Z_0 J_{N+1} = \sqrt{\frac{\pi\Delta}{2g_N g_{N+1}}} \tag{8}$$

Where Δ is the FBW.

The coupled line structure supports two quasi-TEM modes, even mode and odd mode. The two field distributions result in even-mode and odd-mode characteristic impedances denoted by $Z_{0e}$ and $Z_{0o}$ as shown in Fig. 5.These characteristic impedances are major parameters in design procedures [11].

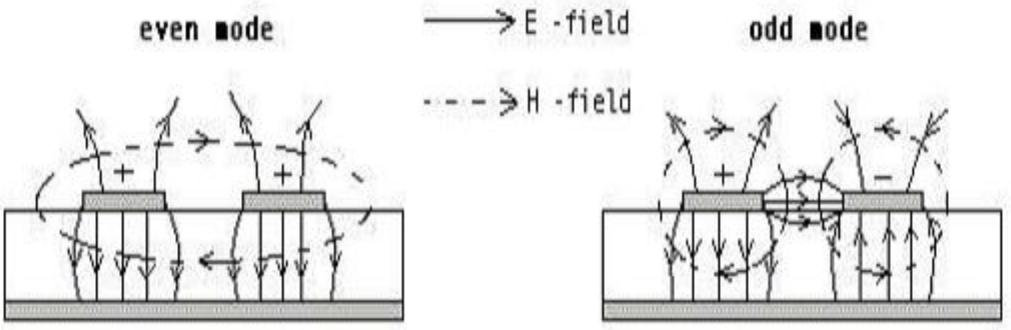

**Fig. 5: Field Distribution for Coupled Line [11].**

From equations (9) and (10), it can be obtained even and odd mode characteristics impedances [6].

$$Z_{Oe} = Z_o\left[1 + JZ_o + (JZ_o)^2\right] \qquad (9)$$

$$Z_{Oe} = Z_o\left[1 - JZ_o + (JZ_o)^2\right] \qquad (10)$$

MATLAB code is used for calculating the filter parameters for any number of orders. The code’s outputs are:

1. Normalized Lumped elements values of the low pass filter prototype.
2. Lumped elements values of the band pass filter that are impedance and frequency scaled.
3. The value of load resistance.
4. For the step of transforming lumped elements to distributed elements, the code has to calculate the following:
   i. Admittance inverters.
   ii. Even and odd impedances.

Richard’s Transformation is used to convert lumped elements into micro strip. Kuroda’s identities are used to physically separate filter elements. The width *W*, length of each micro strip *L*, and the space between them *S*, are calculated using a MATLAB code as shown in Table IV.

**Table IV: Determination of Even, Odd Characteristics Impedance and Physical parameters**

| No | ZoJn (Siemens) | Zoe (ohm) | Zoo (ohm) | W (mm) | S (mm) | L (mm) |
|---|---|---|---|---|---|---|
| 1 | 0.2841 | 68.2402 | 39.8308 | 2.11659 | 0.19524 | 5.82130 |
| 2 | 0.0610 | 53.2336 | 47.1380 | 2.40031 | 1.76873 | 5.74107 |
| 3 | 0.0409 | 52.1295 | 48.0379 | 2.41343 | 2.54620 | 5.75016 |
| 4 | 0.0373 | 51.9333 | 48.2056 | 2.41667 | 2.78641 | 5.75359 |
| 5 | 0.0361 | 51.8720 | 48.2586 | 2.41776 | 2.87474 | 5.75488 |
| 6 | 0.0358 | 51.8565 | 48.2720 | 2.41805 | 2.89826 | 5.75522 |
| 7 | 0.0361 | 51.8720 | 48.2586 | 2.41776 | 2.87474 | 5.75488 |
| 8 | 0.0373 | 51.9333 | 48.2056 | 2.41667 | 2.78641 | 5.75359 |
| 9 | 0.0409 | 52.1295 | 48.0379 | 2.41343 | 2.54620 | 5.75016 |
| 10 | 0.0610 | 53.2336 | 47.1380 | 2.40031 | 1.76873 | 5.74107 |
| 11 | 0.2841 | 68.2402 | 39.8308 | 2.11659 | 0.19524 | 5.82130 |

## III. RESULTS AND DISCUSSION

An X-Band microstrip band pass filter is designed to pass signals within the frequency range 9.3-9.7GHz. The filter material is Duroid RTD5880, whose dielectric constant is 2.2, thickness is 0.017 mm and substrate height 0.787mm. The simulated filter showed an excellent return loss of −26.262 dB and insertion loss of −1.270 dB in the passband.

The Insertion Loss results showed 1.270 dB at center frequency and the expected rejections at 9.18GHz and 9.83GHz are more than 30dB, whereas results showed around 59 dB. Fig. 6 shows the frequency response in passband region for lumped element BPF. Fig.7 shows the attenuation of the designed filter designated by the scattering parameter S(2,1) in the stop-band region. It is observed that the insertion loss at 9.18 GHz is about −59.978 dB and at 9.83 GHz it is about −60.988dB. Table IV shows the attenuation over entire band and stop-band.

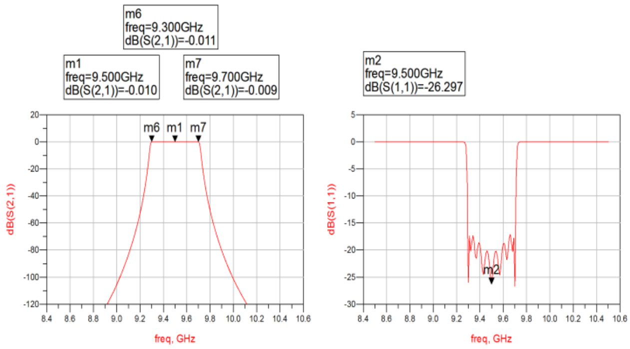

**Fig. 6: Lumped Element BPF Output Waveform S(21), S(11) vs. Frequency in Passband Region.**

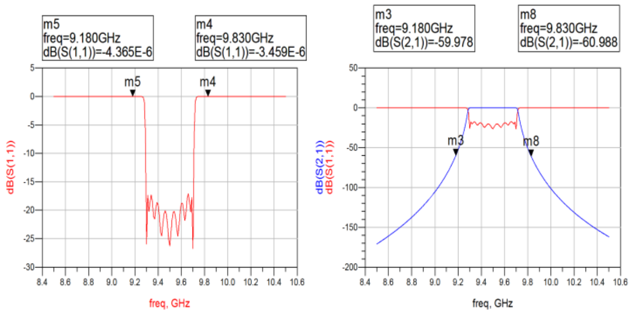

**Fig. 7: Lumped Element BPF Output Waveform S(21), S(11) vs. Frequency in Stopband Region.**

In Table V, it is observed that an insertion loss between-0.011 dB to -0.009 dB in the desired passband and greater than -59dB at out of band frequencies. The simulated return loss is -26.297 dB at the center frequency 9.5GHz.

**Table V: Attenuations In and Out of band for Lumped elements BPF**

| Frequency GHZ | Passband Attenuations | | Frequency GHZ | Stopband Attenuations | |
|---|---|---|---|---|---|
| | S(21) dB IL | S(11) dB RL | | S(21)dB IL | S(11)dB RL |
| 9.3 | -0.011 | -26.022 | 9.18 | -59.978 | -4.365e-6 |
| 9.7 | -0.009 | -26.755 | 9.83 | -60.988 | −3.459e-6 |
| 9.5 (center frequency) | -0.01 | -26.297 | | | |

Fig.8 shows the schematic circuit of microstrip BPF designed by ADS after inputting the even and odd characteristic impedances, which are listed in Table IV. Microstrip Line (MLIN) components are added to the source and load sides of the filter to match input and output impedances. The length is 5.72015 mm and the width is 2.41957 mm, which are calculated using Line Calc tool in ADS software.

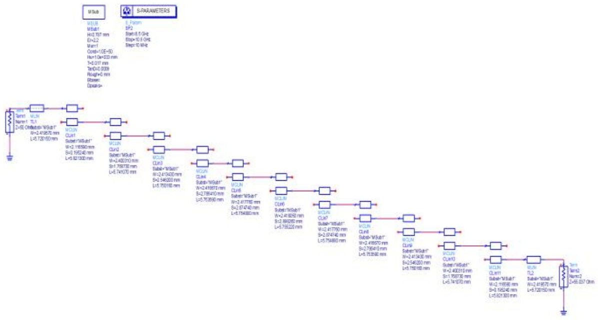

**Fig. 8: Parallel Coupled Micro strip Transmission Line BPF Model in ADS**

Fig.9 shows the layout of micro strip BPF using ADS software.

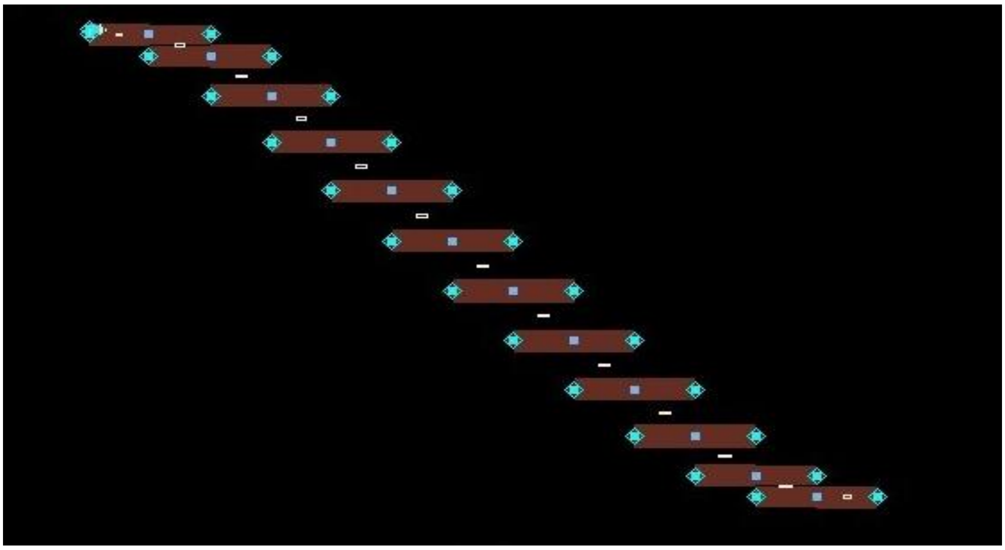

**Fig. 9: Layout of Parallel-Coupled Micro strip BPF**

Figs. 10 and 11 show the response of the parallel coupled micro strip BPF in the passband and in the stopband regions. It is observed that the insertion loss is between −3.306 dB and −2.987 dB in the desired pass band and is greater than −59 dB at out of band frequencies. At the center frequency 9.5GHz, the simulated return loss and insertion loss are −26.262dB and −1.270dB, respectively.

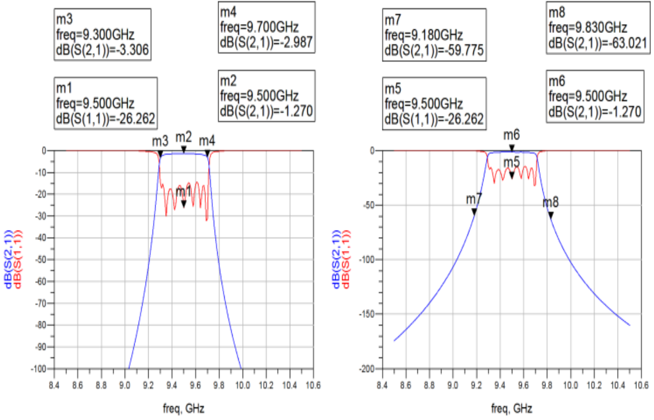

**Fig. 10: Microstrip BPF Output Waveform S(21), S(11) vs. Frequency in pass and region.**

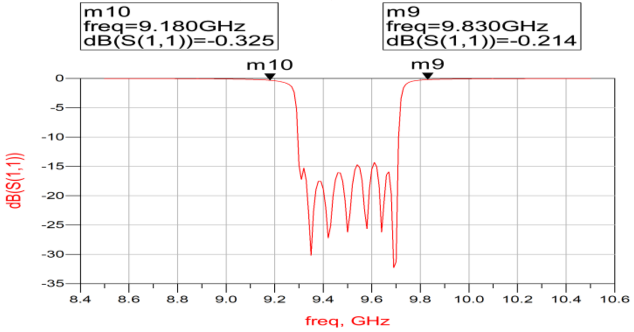

**Fig. 11: Microstrip BPF Output Waveform, S(11) in Stopband Region.**

In Table VI, it is observed that the expected rejection at out of band frequencies is ≥30dB whereas simulated results showed the insertion loss between -3.306 dB to -2.987 dB in the desired passband and greater than -59dB at out of band frequencies. The simulated return loss is -26.297 dB at the center frequency 9.5GHz.

**Table VI: Attenuations In and Out of Band for Micro strip BPF**

| Frequency GHZ | Passband Attenuations | | Frequency GHZ | Stopband Attenuations | |
|---|---|---|---|---|---|
| | S(21) dB IL | S(11) dB RL | | S(21)dB IL | S(11)dB RL |
| 9.3 | -3.306 | -14.036 | 9.18 | -59.777 | -0.325 |
| 9.7 | -2.987 | | 9.83 | -63.021 | -0.214 |
| 9.5 (center frequency) | -1.270 | -26.262 | | | |

## IV. CONCLUSION

This paper described procedures for designing a band pass filter using lumped elements and converted it to edge-coupled microstrip line band pass filter by using Richard’s transformation and Kuroda’s identities. The filter passes signals at the frequency range between 9.3GHz to 9.7GHz. High–order-edge-coupled micro strip line filter is used to obtain an insertion loss between -3.306dB to −2.987dB in the desired pass band and greater than −59dB at out of band frequencies. The simulated return loss is greater than −26dB at the center frequency 9.5GHz. The filter is simulated with Advanced Design System (ADS) 2011.10 software. MATLAB code is used to calculate the values of the filter’s elements at any filter’s order.

## ACKNOWLEDGMENT

Authors would like to thank the researchers and staff in the National Center for Research for their help and support.

## REFERENCES

[1] A.K. Tiwary, N. Gupta . “Design of Compact Coupled Microstrip Line Band Pass Filter with Improved Stopband Characteristics”. Progress In Electromagnetics Research C, Vol. 24, pp.97-109, 2011.

[2] Mr. K.S.Khandelwal, Dr. A.K.Kureshi. “Realization of Microstrip Band-Pass Filter Design”. International Journal of Advanced Research in Computer Engineering & Technology (IJARCET), Vol. 3 Issue 12, pp.4242-4247, December 2014.

[3] Md Rasheduzzaman Al-Amin, Sourav Sundar Chowdhury, Khondoker Ziaul Islam.” Design and simulation of an Edge-coupled Band Pass Filter at X Band”.International Conference on Materials, Electronics & Information Engineering ( ICMEIE), 05-06 June, 2015.

[4] Jose Lugo Alvarez.“Slow-wave coupled lines integrated over silicon in mm-wave band Applications to couplers, filters and baluns”. PHD thesis, Grenoble Alps University, France, 2015.

[5] Satish R.Gunjal, R.S.Pawase, Dr.R.P.Labade.” Design And Implementation Of Microstrip Bandpass Filter Using Parallel Coupled Line For ISM Band”, IJARIIE, Vol. 2-Issue 3, pp.3059-3036, 2016.

[6] David M.Pozar. “Microwave Engineering”. Fourth Edition. USA: John Wiley & Sons, Inc, (2012).Ch.8, pp.380- 450.

[7] Muhammad Mostafa Amir Faisal, Md. Mushfiqur Rahaman, Abdullah Al Israfil. ”Simulation and Analysis of Edge-Coupled Band Pass Filter for Ku Band Application”. Asian Journal of Engineering and Technology, Vol. 04- Issue 05, pp.109-117, October 2016.

[8] Ahmed Hameed Reja, Syed Naseem Ahmad, and Mushtaq A. Alqaisy ,” Study the Effect of SRRs on Broadband Microwave Parallel-Coupled Band-Pass Filters”. International Journal of Computer and Electrical Engineering, Vol. 6, No. 2,pp 132-136, April 2014.

[9] Kenneth A. Kuhn ,”Frequency Filters”, rev. Dec. 27, 2000, rev. March 5, 2013.

[10] Liew Hui Fang, Syed Idris Syed Hassan, Mohd Fareq AbdMalek, Yufridin Wahab and Lee YengSeng.”A Review Of Technique To Convert Low Pass Filter Into Microstrip Line Circuit ”. ARPN Journal of Engineering and Applied Sciences,Vol.10, NO.16, pp.7164-7174, September 2015.

[11] Abdul Rani Othman, Chairulsyah Wasli.” 2.4 GHz Microstrip Band Pass Filter”, The 1st International Conference on Engineering and ICT, Melaka, Malaysia, 2007.