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Design Edge-Coupled Stripline Band Pass Filter at 39 GHz

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***Abstract*— In this paper we propose a edge-coupled stripline band pass filter for 39 GHz application using Ansoft designer/Nexxim V2.2 software and Matlab 2009a software. The filter is operated at Q band frequency range in 39 GHz for various microwave applications & the filter is design on Roger RO6006 substrate with dielectric constant of 6.45, with dimension conductor thickness 0.035 mm and substrate height 0.787 mm. The proposed filter is design at a center frequency of 39 GHz. Simulation results show that the filter operation is optimum over the frequency range 38 GHz to 40 GHz which is best in this range. In this paper, band pass filter order n=3 development with the assistance of the Richards-Kuroda Transformation method is used.**

***Keywords*— Chebyshev band pass filter, Dielectric substrates, Edge-coupled, Q band spectrum. Strip line.**

I. INTRODUCTION

The presented process includes the estimation of filter parameters using analytical formulas, the simulation of ideal and strip line transmission line models in a circuit simulator. A strip line circuit uses a flat strip of metal which is sandwiched between two parallel ground planes. The insulating material of the substrate forms a dielectric.

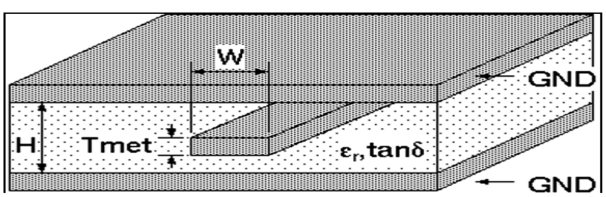

Fig. 1: Model used by designer for edge-coupled strip line band pass filter

However, waveguides systems are bulky and expensive[8]. Strip line requires three layers of conductors where the internal conductor is commonly called the "hot conductor," while the other two, always connected at signal ground, are called "cold" or "ground" conductors[1]. The hot conductor is embedded in a homogeneous and isotropic dielectric, of dielectric constant "ε_r". So, unlike the case of micro strip, the word "substrate" is not appropriate since the dielectric completely surrounds the hot conductor[4].

A band pass filter is an important component must be found in the transmitter or receiver. Band pass filter is a passive component which is able to select signals inside a specific bandwidth at a certain center frequency and reject signals in another frequency region, especially in frequency regions, which have the potential to interfere the information signals[11].Third order n=3 chebyshev edge-coupled stripline band pass filter is design in the paper.

In this paper, Ansoft Designer was used for the purpose of designing and simulating different types of filters. Ansoft Designer is a very powerful microwave simulator. Ansoft Designer is the first suite of design tools to fully integrate high-frequency, physics-based electromagnetic simulation, modeling, and automation into a seamless environment for circuit and system analysis. Ansoft Designer's unique Solver on Demand technology allows flexible and highly accurate modeling and verification of unrestricted structures used in high-frequency component, circuit, and system designs [3].

MATLAB was used for the purpose of designing and simulating different types of RF filters. The MATLAB code was a good way of understanding the intricacies of the stripline. The mathematical analysis was done for each design and verified by writing a MATLAB code [5].

II. RESEARCH METHODOLOGY

Design of chebyshev band pass filter:

The BPF circuit is simulated with Ansoft Designer/Nexxim V2.2 Software in order to predict the performance of the filter. An optimization process has been introduced along the simulation procedure focusing on the filter dimension in order to improve the response of the filter. Refer to the filter tables given in D.M Pozar and G. L. Matther [7] to find the following coefficients for a third order chebyshev filter. Normalized element values for 0.5 dB ripple low-pass chebyshev filter given in was g0 = 1, g1 = 1.5963, g2 =10967, g3 = 1.5963, g4 = 1.000 for simulated third order filter.

Table I
Dielectric material used Rogers R06006 from Rogers high frequency material specifications of edge-coupled stripline band pass filter

Specifications of edge-coupled Band Pass Filter, Specifications of Dielectric Material From ROGERS Corporation.		
1).	Input and output impedance:	Z = 50 Ohms
2).	Pass band ripple of	0.5 dB
3).	Filter order:	n= 3
4).	Pass band centre frequency: 39 GHz ((broadband PCS), cellular radio, and other commercial and private mobile radio operations)	
5).	Ripple bandwidth:	2 GHz
Board and substrate properties:		
6).	Substrate:	Rogers R06006
7).	Conductor thickness:	0.035 mm
8).	Dielectric constant:	6.45
9).	Loss tangent:	0.0027
10).	Substrate height:	.787 mm

The sections are numbered from left to right. The source is connected at the left and the load is connected to the right. The filter could be reversed without affecting the response [2]. The results of Z0o and Z0e, are shown in table III , are almost identical to that of the n=3 order approach, except an additional coupling section is used to represent the increased order.

Table II
Element values for equal ripple band-pass filter prototypes (g_0 = 1, ω_c = 1, n = 1 to 10 and 0.5 dB ripple.)[6]

0.5 dB Ripple

n	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	0.6986	1.0000									
2	1.4029	0.7071	1.9841								
3	1.5963	1.0967	1.5963	1.0000							
4	1.6703	1.1926	2.3661	0.8419	1.9841						
5	1.7058	1.2296	2.5408	1.2296	1.7058	1.0000					
6	1.7254	1.2479	2.6064	1.3137	2.4758	0.8696	1.9841				
7	1.7372	1.2583	2.6381	1.3444	2.6381	1.2583	1.7372	1.000			
8	1.7451	1.2647	2.6564	1.3590	2.6964	1.3389	2.5093	0.8796	1.9841		
9	1.7504	1.2690	2.6678	1.3673	2.7239	1.3673	2.6678	1.2690	1.7504	1.0000	
10	1.7543	1.2721	2.6754	1.3725	2.7392	1.3806	2.7231	1.3485	2.5239	0.8842	1.984

(A). Choice of 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 in trade for more ripples in the pass band section.

Higher order filters can have a narrower shape factor but will be physically larger in shape. The filter specification goals for return loss (scatter parameter S11) are >40 dB and for insertion loss (scatter parameter S21) <10dB. Simulations showed a filter order of n=3 will achieve this goal. The required order for a filter meeting the given specifications is calculated below [12].

$$n = \frac{\cosh^{-1}\sqrt{\dfrac{10^{\frac{L_T}{10}}-1}{K-1}}}{\cosh^{-1}\left(\dfrac{f}{fc}\right)} \quad \textbf{(1)}$$

Where L_T is the minimum attenuation at frequency f_t, and **K = 10^(Lar/10),** with Lar being the maximum ripple in dB allowed in the pass band. The order of the filter is a measure of the minimum number of elements to be included in the filter to realize the required amount of ripple in the pass band and attenuation at a frequency outside of the pass band. Additional elements may be included in the filter which will further improve the filter response at the cost of size and increased design time [12]. The following equations are used to calculate the order for edge coupled band pass filter values. Using figure 2 we get the value of [$\frac{f_t}{fc}$ =1.4].

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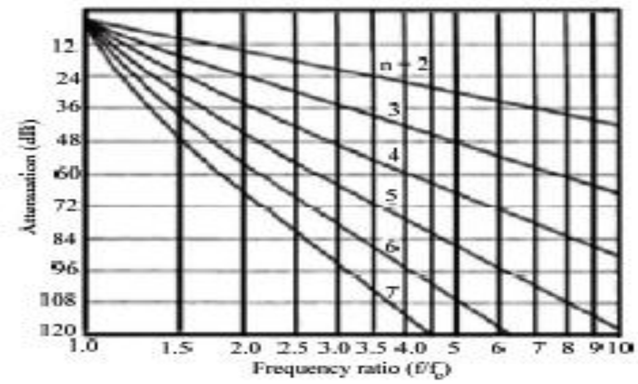

Fig. 2 : Characteristics for a chebyshev filter with 0.5dB ripple [9]

(B). Find the low pass prototype

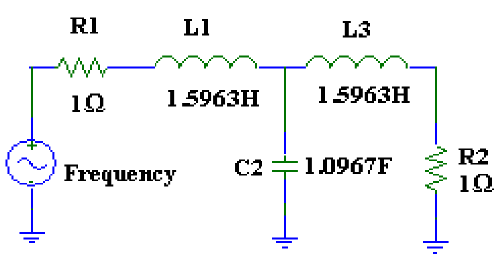

Fig. 3: Third order low pass prototype [9]

After getting the low pass filter prototype values, then it's transformed into band pass filter design. The transformation from low pass to band pass all shunt element of the low pass prototype circuit becomes parallel-resonant circuit, and all series elements become series-resonant circuit in Fig.4.

(C). Transforming the low pass into band pass configuration

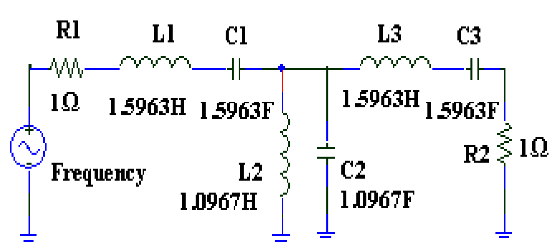

Fig. 4: Transformation third order low pass prototype to band pass prototype [9]

The transformed the filter is then frequency-scaled and impedance-scaled using the following formulas [11].

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

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

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

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

(D). Scaling the band pass configuration in both impedance and frequency

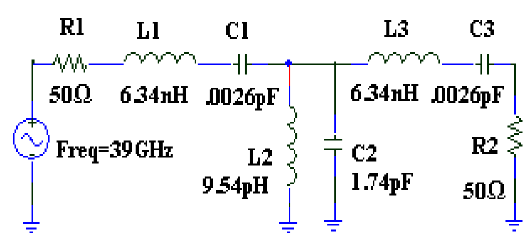

Fig. 5: Band pass prototype for designed at center frequency

(E). Even and Odd Modes in a Coupled Transmission Line

Calculation of Odd and Even Resistances to design the strip line filter, an approximate calculation is made based on the design equations. The no of stages n = 3. The characteristic impedance Z0 is typically 50 Ohms [10]. The unitary bandwidth FBW is given by

Where $FBW = \frac{(\omega_2 - \omega_1)}{\omega_0}$ is the fractional

$$FBW = \frac{(40\times10^9 - 38\times10^9)}{39\times10^9} \approx .051308 \tag{6}$$

$$\frac{J_{01}}{Y_0} = \sqrt{\frac{\pi}{2}\frac{FBW}{g_0 g_1}} \tag{7}$$

$$\frac{J_{j,j+1}}{Y_0} = \frac{\pi FBW}{2}\frac{1}{\sqrt{g_j g_{j+1}}} \quad \text{for j=1 to n-1} \tag{8}$$

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$$\frac{J_{n,n+1}}{Y_0} = \sqrt{\frac{\pi}{2}\frac{FBW}{g_n g_{n+1}}} \quad \textbf{(9)}$$

Where g_0, $g_{1\ldots}$ g_n are the element of a ladder-type low-pass prototype with a normalized cutoff $\Omega_c = 1$, and FBW is the fractional bandwidth of band-pass filter. $J_{j,j+1}$ are the characteristic admittances of J-inverters and Y_0 is the characteristic admittance of the terminating lines [11]. The equation above will be use in edge-coupled line filter because the both types of filter can have the same low-pass network representation. However, the implementation will be different [6].

To realize the *J*-inverters obtained above, the even- and odd-mode characteristic impedances of the coupled strip line band pass filter are determined by

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

for j=0 to n **(10)**

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

for j=0 to n **(11)**

Table III
Circuit design parameters (Impedance value from FDW and calculated impedance value) of 3rd order strip line edge-coupled band pass filter

j	$J_{j,j+1}/ Y_0$	$(Z_{oe})_{j,j+1}$ (Ω) (Calculated Results)	$(Z_{oo})_{j,j+1}$ (Ω) (Calculated Results)	$(Z_{oe})_{j,j+1}$ (Ω) (Simulated results)	$(Z_{oo})_{j,j+1}$ (Ω) (Simulated results)
0	**.2246**	**63.75**	**40.69**	**63.86**	**41.25**
1	**.0609**	**53.23**	**47.14**	**53.27**	**47.11**
2	**.0609**	**53.23**	**47.14**	**53.27**	**47.11**
3	**.2246**	**63.75**	**40.69**	**63.86**	**41.25**

III. SIMULATED RESULT & DISCUSSION

The frequency sweep for the linear simulation of the advanced numerical models were performed from 30 to 50 GHz in 0.1 GHz steps.

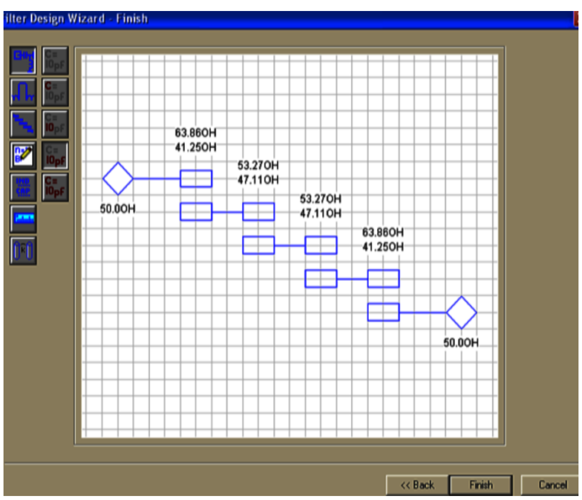

Fig. 6: Software result of odd and even impedances response of 3rd order edge-coupled strip line band pass filter

In Fig.6 shows the graph for stripline in separation is small the even mode impedance is high, and the odd mode impedance is small.

In order to achieve the impedance pair (Zoe) = 63.86Ω , and (Z0o) = 41. 25 The same data will be also used for the fourth resonator.

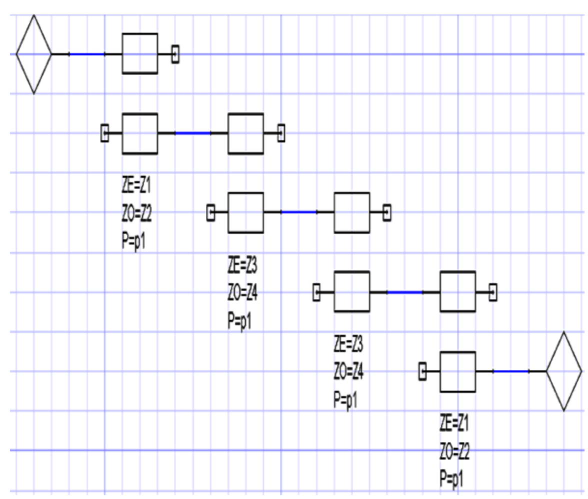

Fig. 7: Electrical model configuration of 3rd order strip line edge-coupled band pass filter

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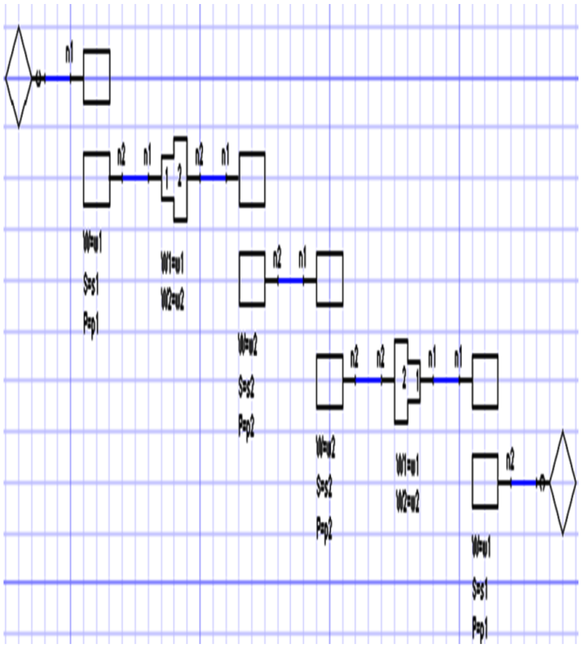

Fig. 8: Tuned chebyshev band pass filter made from physical model configuration of 3rd order edge-coupled strip line band pass filter

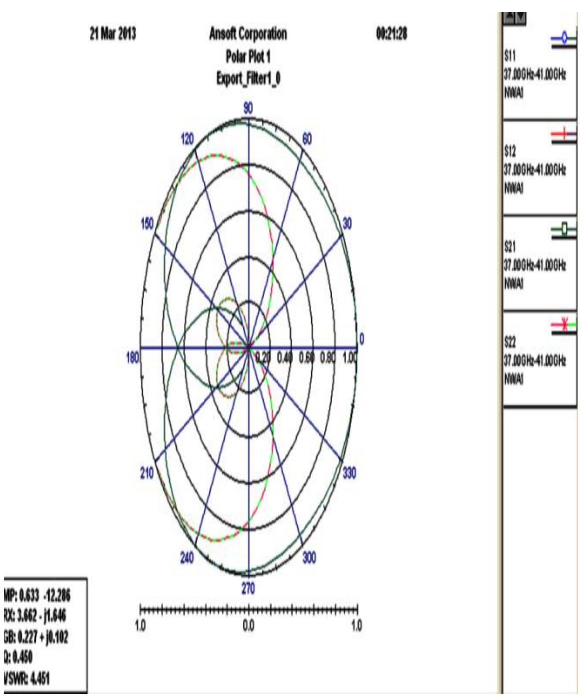

Fig.9: Simulated result for polar plot of 3rd order edge-coupled strip line band pass filter

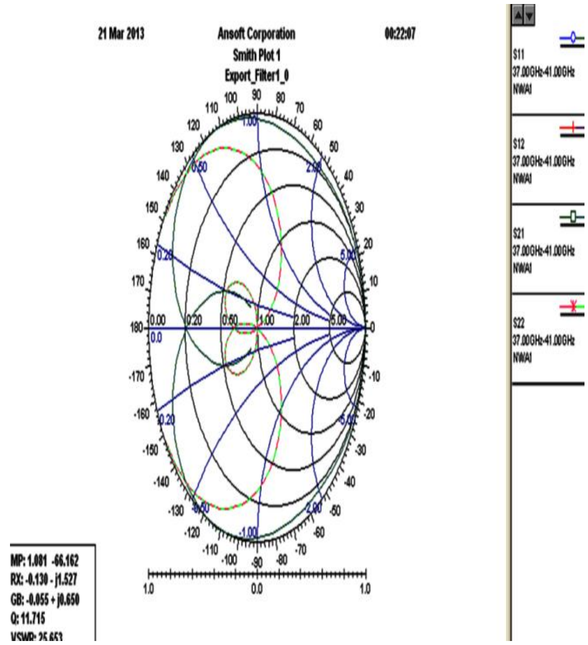

Fig. 10: Simulated smith chart result of 3rd order edge-coupled strip line band pass filter

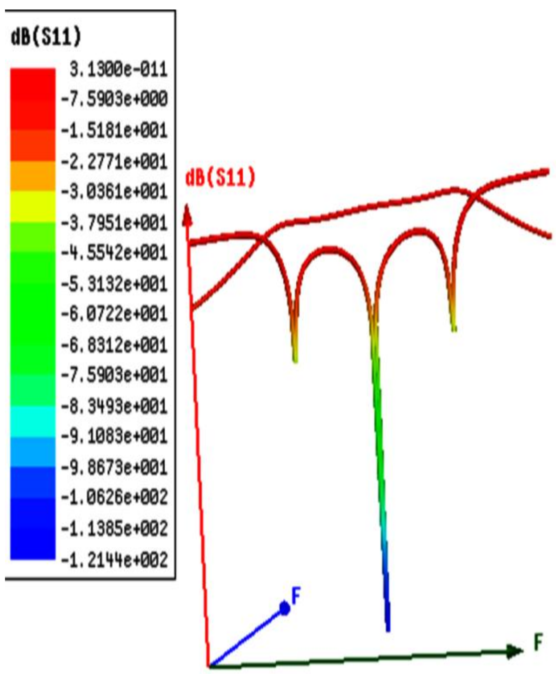

Fig. 11: Simulated 3D rectangular plot result of 3rd order edge-coupled strip line band pass filter

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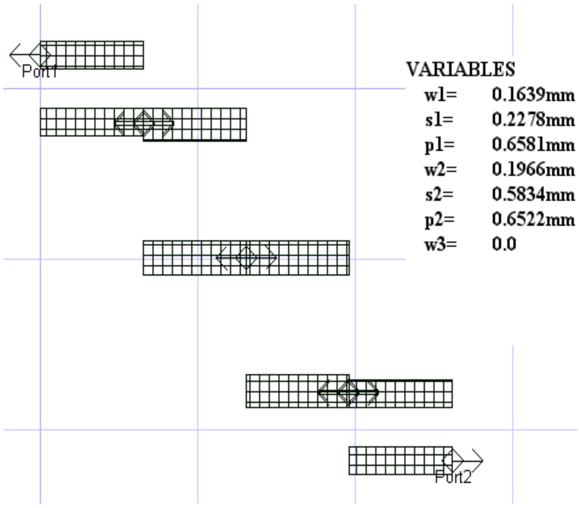

Fig.12: Detail dimensions of the simulated layout model result of 3rd order strip line edge-coupled band pass filter

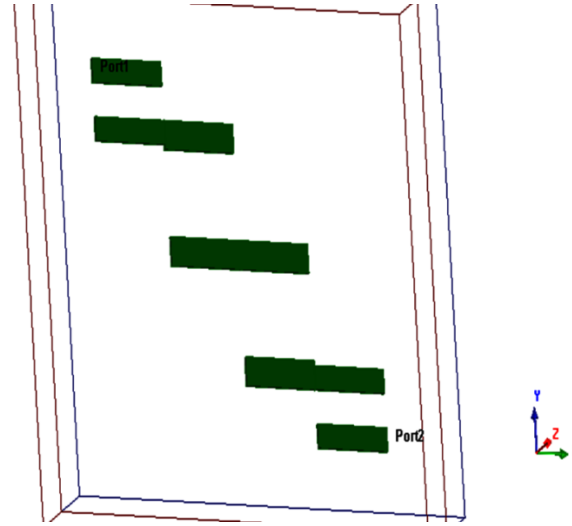

Fig. 13: Simulated 3-D layout model of 3rd order edge-coupled strip line band pass filter

A pair of parallel-coupled striplines with certain width and separation distance will deliver a pair of characteristic impedances, the even mode and the odd mode ones. We can determine the width of parallel-coupled strip line band pass filter **w** and the distance between them **s**. The process is visualized in layout Fig.12. According to layout we get w1=0.1639mm and s1=0.2278 mm. The same data will be also used for the fourth resonator.

(i). Effective dielectric constant and length measurement. For W=.1973mm/7.7677mil **(Calculate value by simulation)**

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + \frac{12h}{W}}} \quad \textbf{(11)}$$

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + \frac{12 \times .787}{.1973}}} = 4.1148 \quad \textbf{(12)}$$

$$\ell = \frac{\lambda_g}{4} = \frac{c}{4f\sqrt{\varepsilon_{re}}} = \frac{3\times10^8}{4\times39\times10^9\times\sqrt{4.1148}} = .948mm \quad \textbf{(13)}$$

The length of the resonator requires for third order coupled line filter will have four, quarter wavelength segments. So final filter length is= **(n+1)** × ***l= (3+1) ×.948=3.792mm***

(ii). Effective dielectric constant and length measurement. For W=.2459mm/9.6811mil **(Standard value)**

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + \frac{12h}{W}}} \quad \textbf{(14)}$$

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + \frac{12 \times .787}{.2459}}} = 4.1867 \quad \textbf{(15)}$$

Thus the required length,

$$\ell = \frac{\lambda_g}{4} = \frac{c}{4f\sqrt{\varepsilon_{re}}} = \frac{3\times10^8}{4\times39\times10^9\times\sqrt{4.1867}} = .939mm \quad \textbf{(16)}$$

The length of the resonator requires for third order coupled line filter will have four, quarter wavelength segments. So final filter length is= **(n+1)** × ***l= (3+1) ×.939=3.756mm***

Therefore, the designed filter shows attractive characteristics for BPF applications.

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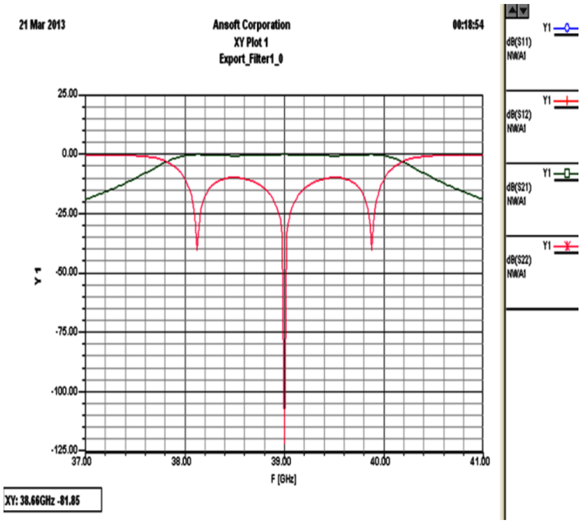

Fig. 14: Simulated result for insertion loss and return loss response of 3rd order edge-coupled strip line band pass filter

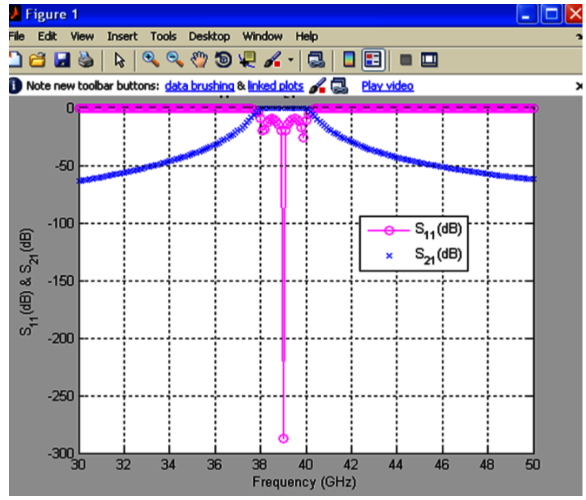

Fig. 15: MATLAB plot of S11 and S21 versus frequency with the code giving the center frequency as 39 GHz. simulated result by MATLAB simulated tool

Modeled performance is shown in Fig.14 simulated insertion loss and return loss result of 3rd order edge-coupled stripline band pass filter EM analysis results from Ansoft Designer, which indicates that the response satisfies the design criteria along with shown in Fig.15 simulated result by MATLAB simulated tool. Reflection regarding in accuracies present the between the two simulators results and simulation results show that the filter operation is optimum over the frequency range 38 GHz to 40 GHz which is best in this range. The simulated insertion loss is less than 0.5 dB in pass band. Also the response is flat and uniform over the entire pass-band. In addition, reflection coefficient is 0.00001 which is nearly equal to 0 and a perfect match exists.The filter is almost matched to the characteristic impedance (*Zo*), 50 Ohms. Also it is observed that the phase varies linearly with frequency.

Filters are an essential part of communication and radar systems and are key items in the performance and cost of such systems, especially in the increasingly congested spectrum. The spectrum is used for fixed point-to-point microwave operations that would provide communications infrastructure such as "backhaul" and "backbone" communications links for services including broadband personal communications services, cellular radio services, and other commercial and private mobile radio operations services.

IV. CONCLUSION

Experimental implementation of this work involves the Roger R06006 substrate with dielectric constant of 6.45 dielectric characterizations at microwave frequencies. Third-order strip line edge-coupled band pass filter is used in order to realize these objectives. The two parameters insertion loss and return loss are to analyze to obtain a good performance of filter. A good filter will be high return loss and small insertion loss ripple in pass band.The simulated insertion loss is less than 0.5 dB in the desired pass band and the simulated return loss is almost greater than 50 dB at center frequency. Design an edge-coupled stripline band-pass filter centered at 39 GHz with a 2 GHz bandwidth based on chebyshev approximation. As predicted, the simulation in Ansoft Designer the pass band center frequency by about 39GHz. This is the focus of continued optimizations in designer, in an attempt to have results predict S11 to be less than -10dB throughout our pass band. For a lossless filter, with an insertion loss having a maximum ripple of .5dB, the return loss must be 40dB or higher.

Successful simulations have been presented. No major problems are expected. All Simulated result is nearly closed. The Matlab tool's characteristic impedance value agrees extremely closely with Ansoft Designer.

Simulation results the authors agree that the errors are not overly extensive and the presented process may be considered a successfully use for microwave in 39 GHz for microwave application.

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