

## Design and Simulation of Edge-Coupled Stripline Band Pass Filter for U band

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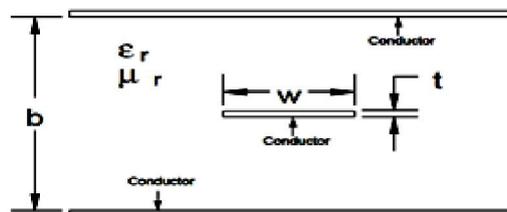
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**ABSTRACT:** In this paper, a band pass filter structure using Ansoft designer software and Matlab software simulation tool are presented. The filter is operated at U Band range in higher order 50 GHz edge-coupled Stripline band pass filter for different microwave application. For the proposed work we consider simulation using Roger R03203 substrate with dielectric constant of 3.02, Conductor Thickness 0.035 mm and Substrate Height 0.787 mm. This filter is design at a center frequency of 50 GHz with 8 GHz bandwidth. Simulation results show that the filter operation is optimum & best in this range and results show good performance and agree well with the high frequency EM full wave simulation. In this paper, band pass filter development with the assistance of the Richards-Kuroda Transformation method, is used. Moreover, measured S parameters denote the center frequency is also strongly influenced by the variation of Roger's material's dielectric constants. By analyzing the characteristics at center frequency of the filter, both theoretical and simulated data are accumulated for broadening application filed. The band pass filter exhibits advantages of small size and high reliability compared to conventional planar filter structure, which makes the band pass filter suitable for U Band communicational application. This filter shows attractive characteristics for BPF applications.

**KEYWORDS:** Stripline, Dielectric substrate, Chebyshev band pass filter, U band spectrum, Band pass filter.

### 1 INTRODUCTION

In this paper design and simulation of an edge-coupled bandpass filter realized in stripline technology is presented. The presented process includes the estimation of filter parameters using analytical formulas, the simulation of ideal and stripline transmission line models in a circuit simulator. Stripline 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 Stripline Band pass filter

These transmission lines are compact edge-coupled stripline is used instead of microstrip line as because stripline does not suffer from dispersion losses and its propagation mode is TEM mode. Hence it is the preferred structured for coupled-line filters. Stripline is much harder fabricate than microstrip, and because of the second ground plane, the strip widths are much narrower for a given impedance and board thickness than for microstrip line [1],[2]-[3].

We describe the design and simulation of a stripline bandpass filter with Chebyshev filter response [4]. The process of designing the filter includes the usage of formulations, MATLAB software use as an equation solver and Ansoft Designer v2.2 as the circuit simulator [7]. A bandpass filter is an important component must be found in the transmitter or receiver. Bandpass 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[6]-[11]. In designing the bandpass filter, we are faced the questions, what is the maximal loss inside the pass region, and the minimal attenuation in the reject/stop regions, and how the filter characteristics must look like in transition regions[10]. The development of the frequency bands in microwave filter, play an important role in many microwave applications. Through an investigation into and a subsequent implementation of filter theory, U band (40-60 GHz) range filters design is developed in this report [8],[9]-[10]. Filters are an essential part of communication and radar systems and are key items in the performance and cost of such systems [14], especially in the increasingly congested spectrum. A frequency range from 10 GHz to 66 GHz is planned as part of network standardization for point-to-point connections.

**2 RESEARCH METHODOLOGY**

**2.1 DESIGN AND SIMULATION OF CHEBYSHEV BAND PASS FILTER**

The BPF circuit is simulated with Ansoft Designer Student Version 2.2 Software in order to predict the performance of the filter. Few parameters in the circuit are analyzed and have a good relationship to microwave theory. 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 [5] 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  $g_0 = 1$ ,  $g_1 = 1.5963$ ,  $g_2 = 10967$ ,  $g_3 = 1.5963$ ,  $g_4 = 1.000$  for simulated third order filter. The band pass filter is realized as a cascade of n+1 coupled line sections as shown in table 1.

*Table 1. Specifications of Edge-Coupled Stripline Band Pass Filter for U band Application*

<b>Specifications of Dielectric Material From ROGERS Corporation. RT/duroid® 3203 microwave laminates are PTFE Ceramic Reinforced Woven Glass composites designed for electronic and microwave circuit applications requiring a high dielectric constant. Dielectric Material Used Rogers R03203 from Rogers High frequency Material.</b>		
1).	Input and Output Impedance:	Z = 50 Ohms
2).	Pass band ripple of	$S_{21}$ : 0.5 dB
3).	Filter Order:	n = 3
4).	Pass band Centre Frequency: 50 GHz for U band	
5).	Ripple Bandwidth:	8 GHz
6).	Substrate:	Rogers R03203
7).	Conductor Thickness:	0.035 mm
8).	Dielectric Constant:	3.02
9).	Loss Tangent:	0.0016
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  $Z_{oo}$  and  $Z_{oe}$ , are shown in table 3, are almost identical to that of the n=3 order approach, except an additional coupling section is used to represent the increased order. This similar result of ideal filter design is evidence that, according to the formulation, a n=3 order filter should be sufficient and get perfect simulated result. The filter design wizard (FDW) in Ansoft Designer was again utilized to formulate the lengths and widths of the physical circuit from given input of filter design and material properties. Rogers R03203 was again chosen as the dielectric, but the center frequency was chosen in U band at 50 GHz.

Table 2. Element values for equal ripple band-pass filter prototypes ( $g_0 = 1, \omega_c = 1, n = 1$  to 10 and 0.5 dB ripple)[5]

n	0.5 dB Ripple										
	$g_1$	$g_2$	$g_3$	$g_4$	$g_5$	$g_6$	$g_7$	$g_8$	$g_9$	$g_{10}$	$g_{11}$
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

2.2 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 order will be chosen to achieve the desired bandwidth while minimizing the physical size of the filter. The filter specification goals for return loss (scatter parameter  $S_{11}$ ) are >40 dB and for insertion loss (scatter parameter  $S_{21}$ ) <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.

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

$$n = \frac{\cosh^{-1} \sqrt{\frac{10^{\frac{L_T}{10}} - 1}{K - 1}}}{\cosh^{-1} \left( \frac{f}{f_c} \right)} = \frac{\cosh^{-1} \sqrt{\frac{10^{\frac{10}{10}} - 1}{10^5 - 1}}}{\cosh^{-1}(1.4)} = \frac{\cosh^{-1} \sqrt{73.759}}{\cosh^{-1}(1.4)} = \frac{2.840}{0.8670} = 3.27 \tag{2}$$

Where  $L_T$  is the minimum attenuation at frequency  $f_t$ , and  $K = 10^{(L_{ar}/10)}$ , with  $L_{ar}$  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.

The following equations are used to calculate the order for edge coupled band pass filter values. Using Fig. 2 we get the value of  $[f_t/f_c=1.4]$ .

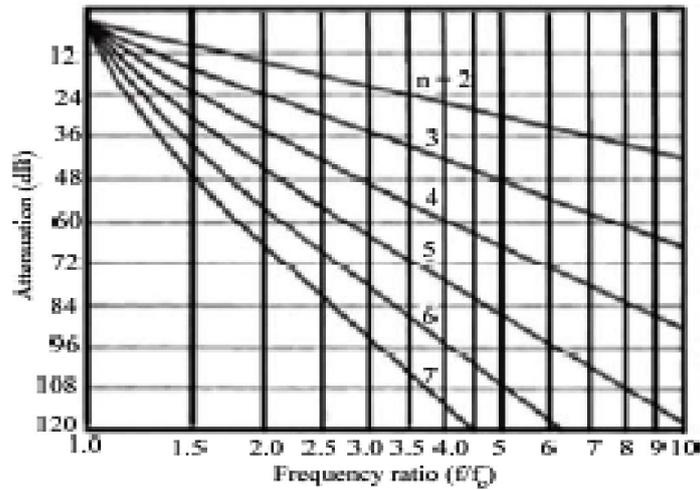


Fig. 2. Characteristics for a Chebyshev filter with 0.5dB ripple [9]

2.3 FIND THE LOW PASS PROTOTYPE

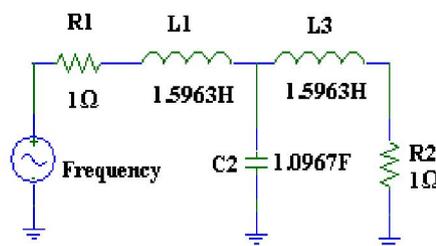


Fig. 3. Third order low pass prototype [8]

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.

2.4 TRANSFORMING THE LOW PASS INTO BAND PASS CONFIGURATION

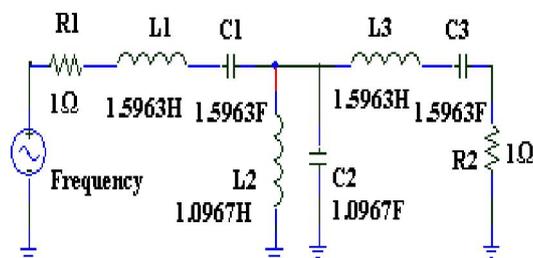


Fig. 4. Transformation third order low pass prototype to band pass prototype [8]

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

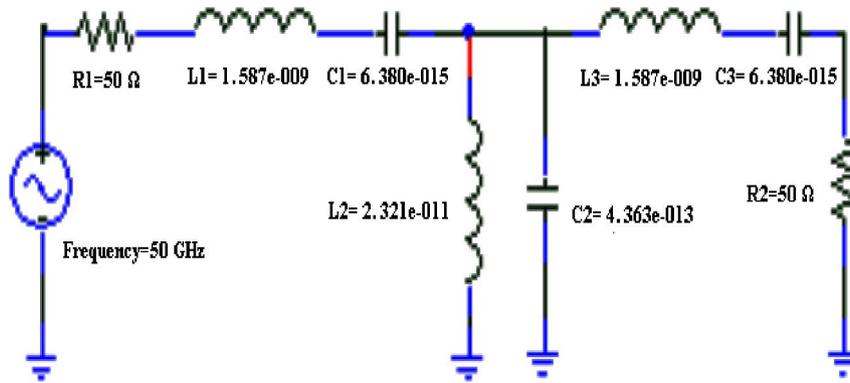
$$L_S = \left( \frac{1}{FBW \times \omega_0} \right) Z_0 \times g \tag{3}$$

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

$$C_P = \left( \frac{1}{FBW \times \omega_0} \right) \frac{g}{Z_0} \tag{5}$$

$$L_P = \left( \frac{FBW}{\omega_0} \right) \frac{Z_0}{g} \tag{6}$$

**2.5 SCALING THE BAND PASS CONFIGURATION IN BOTH IMPEDANCE AND FREQUENCY**



**Fig. 5. Band pass prototype for designed at center frequency 50GHz**

**2.6 EVEN AND ODD MODES IN A COUPLED TRANSMISSION LINE**

Calculation of Odd and Even Resistances to design the stripline filter, an approximate calculation is made based on the design equations [16]-[18]. The no of stages (n) = 3. The characteristic impedance  $Z_0$  is typically 50 Ohms. The unitary bandwidth BW is given by

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

$$FBW = \frac{(54 \times 10^9 - 46 \times 10^9)}{50 \times 10^9} \approx .16 \tag{7}$$

$$\frac{J_{01}}{Y_0} = \sqrt{\frac{\pi FBW}{2 g_0 g_1}} \tag{8}$$

$$\frac{J_{j,j+1}}{Y_0} = \frac{\pi FBW}{2} \frac{1}{\sqrt{g_j g_{j+1}}} \text{ For } j=1 \text{ to } n-1 \tag{9}$$

$$\frac{J_{n,n+1}}{Y_0} = \sqrt{\frac{\pi FBW}{2 g_n g_{n+1}}} \tag{10}$$

Where  $g_0, g_1, \dots, g_n$  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. The equation above will be used in end-coupled line filter because the both types of filter can have the same low-pass network representation. However, the implementation will be different [15].

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

$$(Z_{0e})_{j,j+1} = \frac{1}{Y_0} \left[ 1 + \frac{J_{j,j+1}}{Y_0} + \left( \frac{J_{j,j+1}}{Y_0} \right)^2 \right] \text{ for } j=0 \text{ to } n \tag{11}$$

$$(Z_{0o})_{j,j+1} = \frac{1}{Y_0} \left[ 1 - \frac{J_{j,j+1}}{Y_0} + \left( \frac{J_{j,j+1}}{Y_0} \right)^2 \right] \quad \text{for } j=0 \text{ to } n \quad (12)$$

**Table 3. Circuit design parameters (impedance value from FDW and calculated impedance value) of the 3<sup>rd</sup> Order, parallel-coupled strip line band pass filter**

j	$J_{j,j+1}/Y_0$	$(Z_{oe})_{j,j+1} (\Omega)$ (Derived Results)	$(Z_{oo})_{j,j+1} (\Omega)$ (Derived Results)	$(Z_{oe})_{j,j+1} (\Omega)$ (Simulated results)	$(Z_{oo})_{j,j+1} (\Omega)$ (Simulated results)
0	0.3968	77.71	38.03	78.45	37.95
1	0.1900	61.30	42.30	61.85	42.06
2	0.1900	61.30	42.30	61.85	42.06
3	0.3968	77.71	38.03	78.45	37.95

## 2.7 EFFECTIVE DIELECTRIC CONSTANT AND LENGTH MEASUREMENT

### 2.7.1 FOR W=.4311MM (STANDARD VALUE)

$$\epsilon_{re} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \frac{1}{\sqrt{1 + \frac{12h}{W}}} = 2.22106 \text{ mm} \quad (13)$$

Thus the required length,  $\ell = \frac{\lambda_g}{4} = \frac{c}{4f\sqrt{\epsilon_{re}}} = 1.0064 \text{ mm}$

(14)

The length of the resonator requires for third order coupled line filter will have four, quarter wavelength segments. So final filter length is:

$$L = (n+1) \times \ell = (3+1) \times 1.0064 = 4.0256 \text{ mm} \quad (15)$$

### 2.7.2 FOR W=.3911 (CALCULATE VALUE BY SIMULATION)

$$\epsilon_{re} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \frac{1}{\sqrt{1 + \frac{12h}{W}}} = 2.211408 \text{ mm} \quad (16)$$

Thus the required length,  $\ell = \frac{\lambda_g}{4} = \frac{c}{4f\sqrt{\epsilon_{re}}} = 1.0086 \text{ mm}$

(17)

The length of the resonator requires for third order coupled line filter will have four, quarter wavelength segments. So final filter length is:

$$L = (n+1) \times \ell = (3+1) \times 1.0086 = 4.0347 \text{ mm} \quad (18)$$

## 3 SIMULATED RESULT AND DISCUSSION

In this section we discuss and compare the results obtained from Ansoft Designer/Nexxim SV2.2 Simulation Software and Matlab software. The frequency sweep for the linear simulation of the Advanced numerical models were performed from 40 to 60 GHz in 0.1 GHz steps.

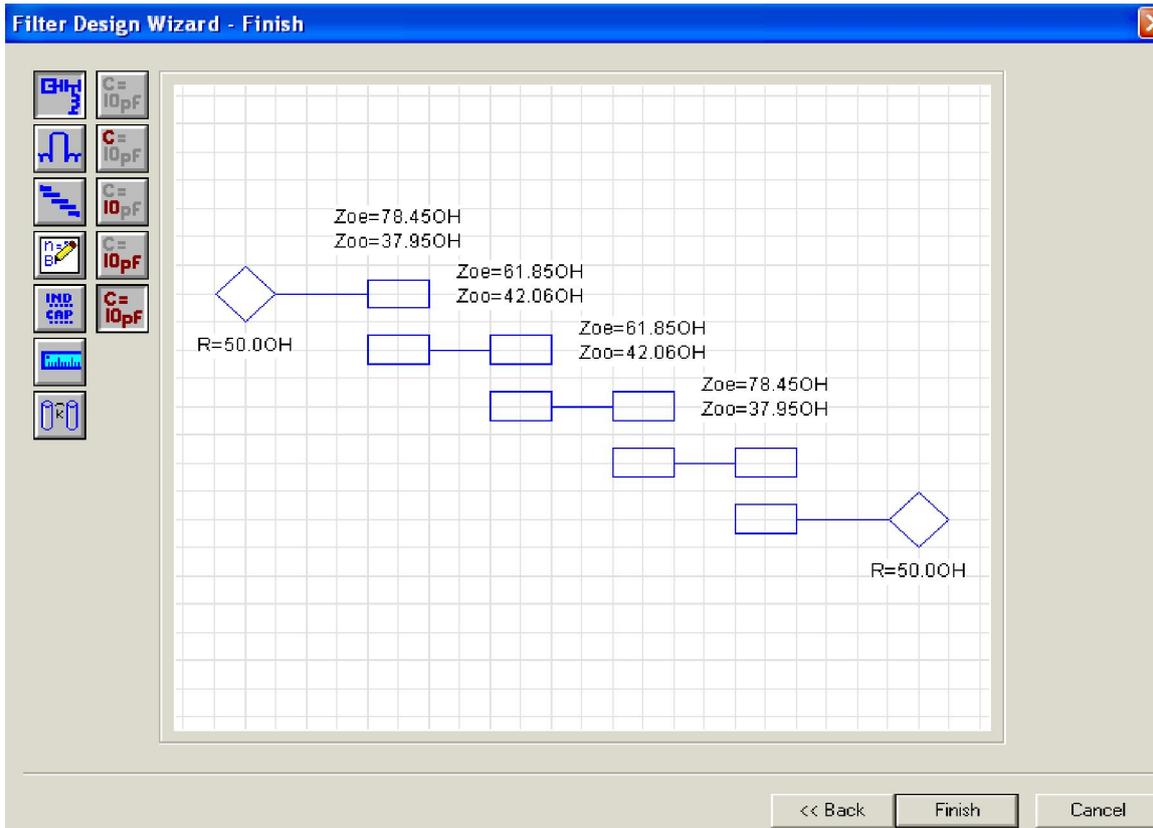


Fig. 6. Software Result of Odd and Even Impedances of 3<sup>rd</sup> order Edge-coupled Stripline Band pass Filter

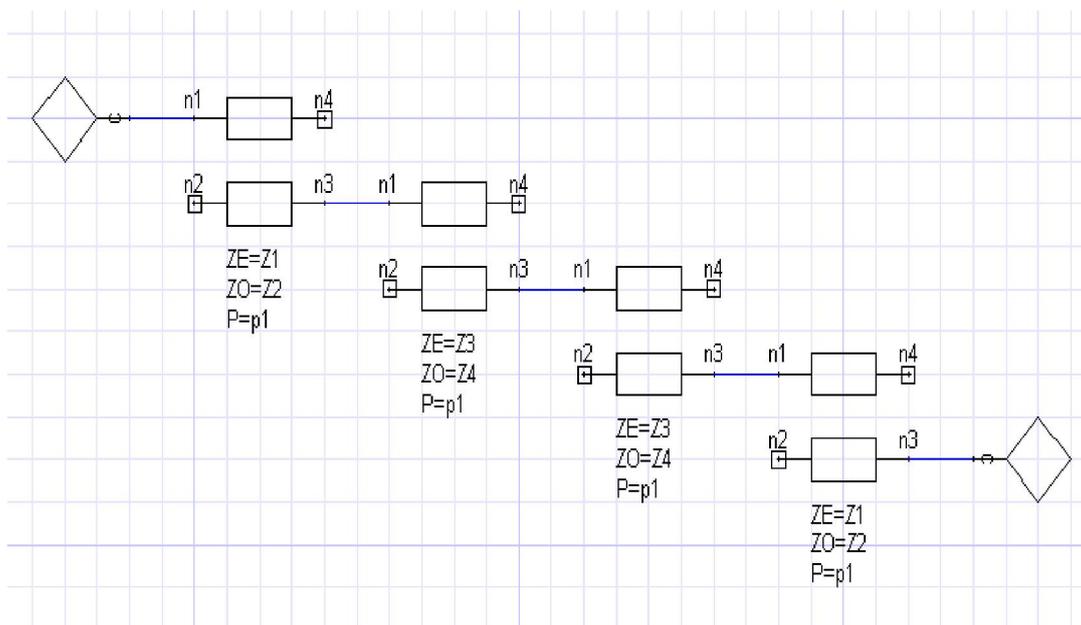


Fig. 7. Electrical Model of 3<sup>rd</sup> order Edge-coupled Stripline Band pass Filter ideal transmission lines

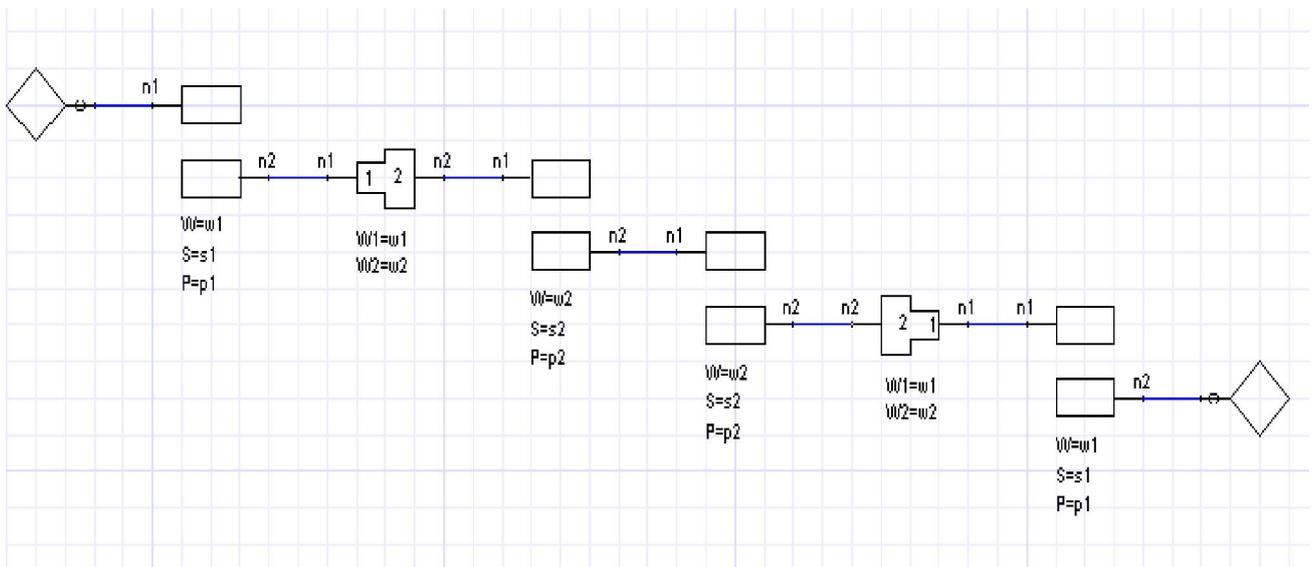


Fig. 8. Tuned Chebyshev bandpass filter made from Physical Model of 3<sup>rd</sup> order Edge-coupled Stripline Band pass Filter

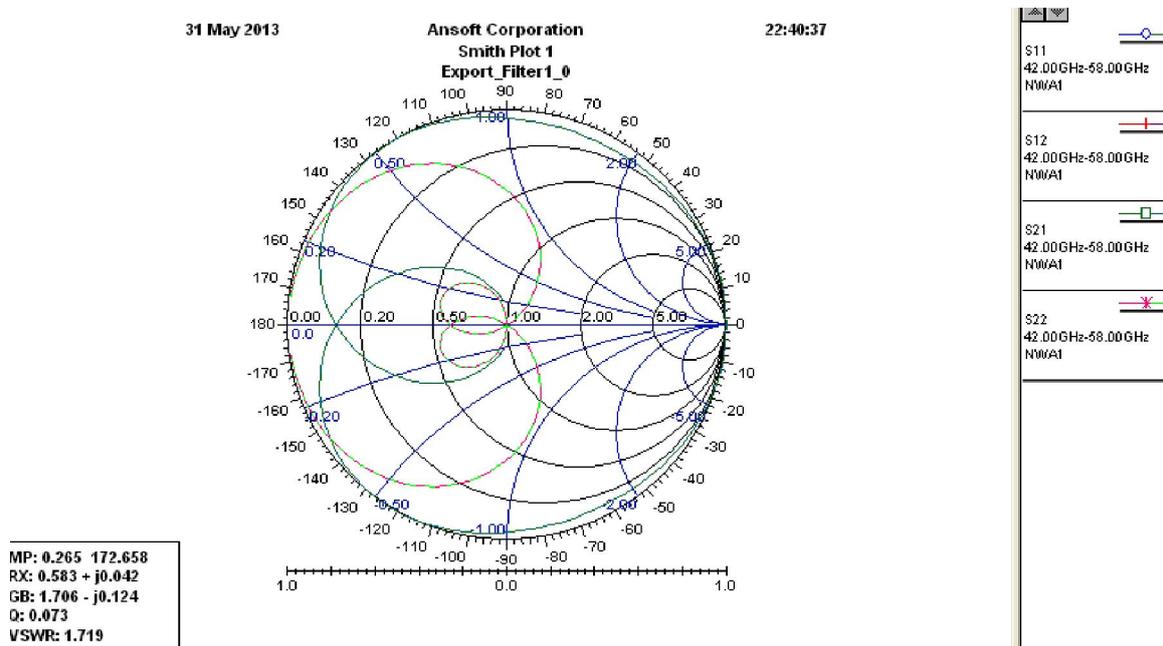
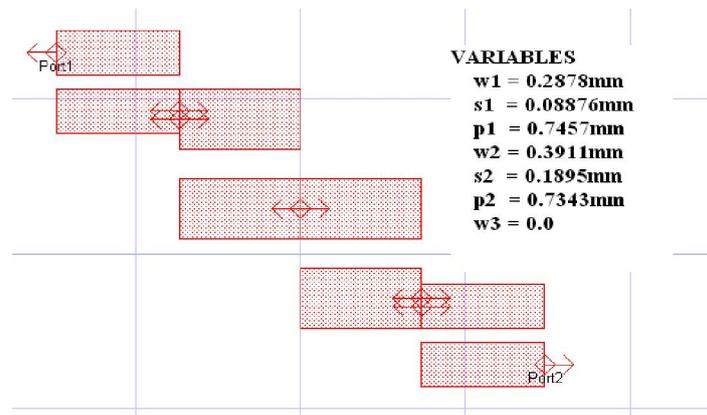


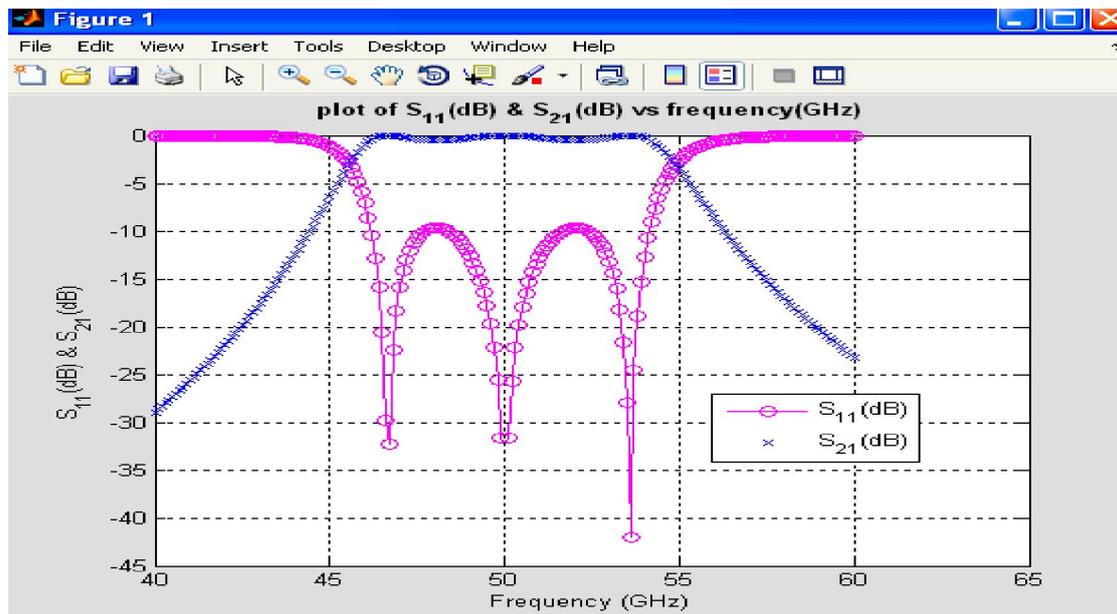
Fig. 9. Simulated Smith Chart impedance Result of 3<sup>rd</sup> order Edge-coupled Stripline Band pass Filter



**Fig. 10.** Detail dimensions of the Simulated Layout Model Result of 3<sup>rd</sup> order Edge-coupled Stripline Band pass Filter

We can determine the width of parallel-coupled striplines  $w$  and the distance between them  $s$ . 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. In layout Fig. 10 shows simulated layout model result of 3<sup>rd</sup> order edge-coupled stripline band pass filter and Fig 6 show the parallel-coupled band pass filter configuration 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 ( $Z_{oe}$ ) = 77.71  $\Omega$ , and ( $Z_{oo}$ ) = 38.03  $\Omega$ , we built a table 3 and which match the values of the impedance pair.

According to layout Fig. 10, we get  $w1=0.2878\text{mm}$  and  $s1=0.0887\text{mm}$  respectively. The length of the resonator required is  $l_1=1.0086\text{mm}$ , which must be geometrically reduced in order to take into account the fringe effects due to open end. The same data will be also used another for the fourth resonator.



**Fig. 11.** Simulated result By MATLAB Simulated Tool of 3<sup>rd</sup> order Edge-coupled Stripline Band pass Filter

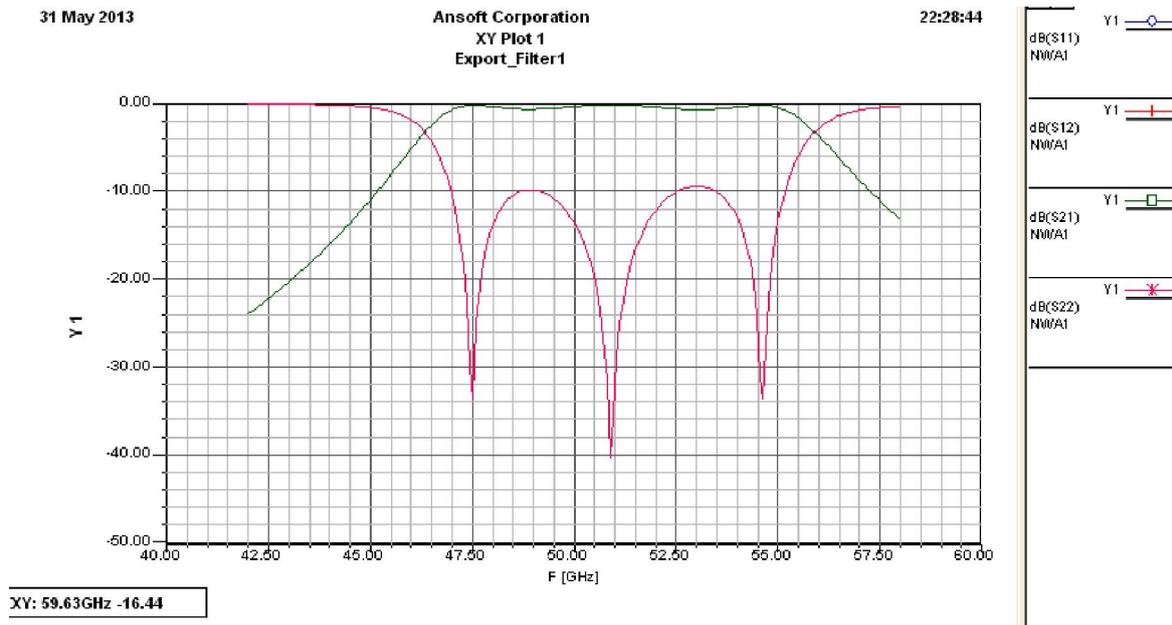


Fig. 12. Simulated Insertion Loss and Return Loss Result for physical model of 3<sup>rd</sup> order Edge-coupled Stripline Band pass Filter

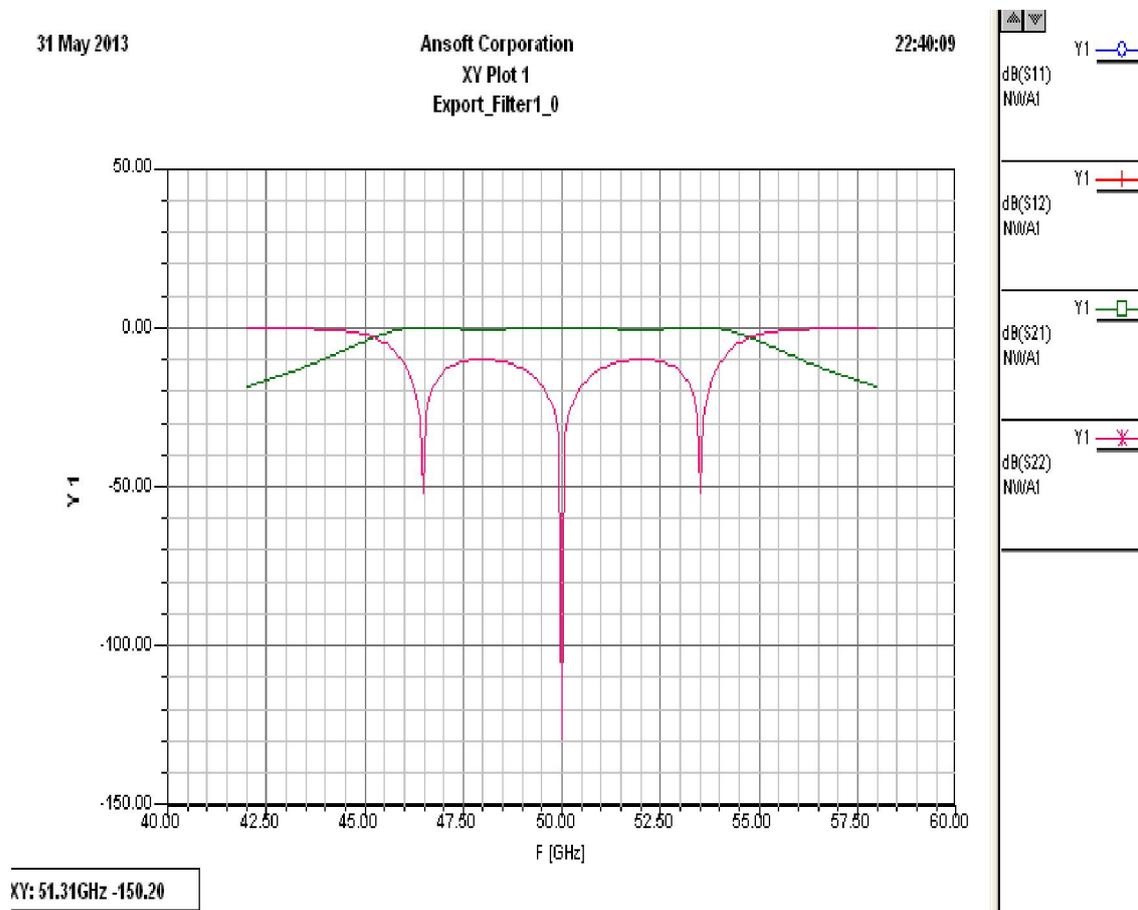


Fig. 13. Simulated Insertion Loss and Return Loss Result for electrical model of 3<sup>rd</sup> order Edge-coupled Stripline Band pass Filter

The result of such a procedure is shown in Fig. 11, Fig. 12 & Fig. 13 Comparisons were made between the Ansoft simulation and the Matlab results for the designs. As predicted, the simulation in Ansoft Designer the pass band center frequency by about 50 GHz. This is the focus of continued optimizations in designer, in an attempt to have results predict  $S_{11}$  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.

The overall performance of edge-coupled strip line band-pass filter can often be judged by its simulated insertion loss and return loss result response. All simulated results are nearly identical with the calculated results and also they are good agreement to the design specifications. Design an edge-coupled strip line band-pass filter centered at 50 GHz with a 8 GHz bandwidth based on Chebyshev approximation. The filter is based on the preceding formulation, MATLAB programs [11]-[12] and Ansoft Designer design entitled edge-coupled strip line band-pass filter has been developed. Simulation results the authors agree that the errors are not overly extensive and the presented process may be considered a success.

Modeled performance is shown in Fig. 12-13 Simulated Insertion Loss and Return Loss Result of 3<sup>rd</sup> order Stripline Edge coupled Band pass Filter. EM analysis results from Ansoft Designer, which indicates that the response satisfies the design criteria [13]. These plots show the passband, stopband, return loss results of the Ansoft Designer simulation, along with shown in Fig. 9 a Smith chart plot of input/output impedance. These plots show that the Ansoft Designer model meets the filter's design criteria. 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. Therefore, the designed filter shows attractive characteristics for BPF applications.

#### 4 CONCLUSION

This technique was implement for an efficient method to design microwave filters with modern simulation software, using standard techniques of many microwave designed has been reviewed. The mathematical analysis was done for each design and verified by written a MATLAB code. The effects due to conductor and dielectric losses were ignored in the code. Ansoft Designer v2.2 was used to accurately arrive at the final design. Comparisons were made between the Ansoft Designer simulation and the designs involving MATLAB code section. All simulated results are nearly with the calculated results with best agreement to the design specifications. This paper describes a procedure for designing edge coupled strip line band pass filter. Experimental implementation of this work involves the Roger R03203 substrate with dielectric constant of 3.02 dielectric characterizations at microwave frequencies. Third-order stripline edge-coupled band pass filter is used in order to realize these objectives. The filter is simulated with Ansoft Designer 2.2 software and MATLAB to predict the performance of filter.

The simulated insertion loss is less than 0.5 dB in the desired passband and the simulated return loss is almost greater than 50 dB at center frequency. Design an edge-coupled bandpass filter centered at 50 GHz with a 8 GHz bandwidth based on Chebyshev approximation. As predicted, the simulation in Ansoft designer the passband center frequency by about 50 GHz. This is the focus of continued optimizations in Designer, in an attempt to have results predict  $S_{11}$  to be less than -10dB throughout our passband. For a lossless filter, with an insertion loss having a maximum ripple of .5dB, the return loss must be 40dB or higher. 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 U band at 50 GHz for microwave application.

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