ISSN : 2230-7109 (Online) | ISSN : 2230-9543 (Print)

Design and Simulation of Fifth Order Band-Pass Filter for S Band

[1]Md Rasheduzzaman Al-Amin, [2]Md. Omar Faruk Chowdhury
[1,2]Dept. of EEE, Bangladesh University of Business and Technology, Mirpur, Dhaka, Bangladesh

Abstract

This paper describes a procedure for designing 5th order edge coupled Microstrip band pass filter for S-Band. The presented process includes the estimation of filter parameters using analytical formulas, determination of the order of filter, finding the corresponding low-pass prototype structure, transforming the low-pass network into a bandpass configuration, scaling the bandpass configuration in both impedance and frequency for satisfying the specifications. The filter was simulated using Ansoft designer V2.2 software and implemented using Rogers RT/duroid 6002 substrate having dielectric constant of 2.94; conductor thickness is 0.021 mm and substrate height of 0.887 mm. This filter has been designed at a center frequency of 3 GHz with 1 GHz bandwidth. The overall performance of edge-coupled Microstrip bandpass filter is judged by its insertion loss and return loss over the pass band. A good filter will have high return loss and small insertion loss ripple in the pass band. It is seen that the simulated insertion loss is less than -0.58 dB and the return loss is greater than -34dB in the desired pass band.

Keywords

Band Pass Filter, Chebyshev, Edge-coupled, S Band, Microstrip

I. Introduction

Modern microwave and Radio Frequency (RF) engineering is an exciting and dynamic field, due in large part to the symbiosis between recent advances in modern electronic device technology and the explosion in demand for voice, data, and video communication capacity that started in the 1990s and continues through the present. Microwave and RF filters are widely used in the communication systems in order to discriminate between wanted and unwanted signal frequencies. The fields of microwave and RF engineering together encompass the design and implementation of electronic systems utilizing frequencies in the electromagnetic spectrum from approximately 300 kHz to over 100 GHz [1].

Emerging applications such as wireless communications continues to advance with the help of RF/microwave filters with ever more stringent requirements like higher performance, smaller size, Lighter weight and lower cost. Microstrip filters are used in various microwaves systems such as radars, measurement and test systems, satellite communications etc. It is extensively used in navigation and localization systems, civil and military surveillance systems, microwave imaging for civil and military applications etc. They provide advantages include low price, low volume, high selectivity and simple structure [2-3].

Most of the early research was carried out in the early 1960's, as summarized in (Cohn, 1968). These filters consist of a number of coupled dielectric disks mounted in a waveguide beyond cut off. In order to give important size reduction, a high dielectric constant must be used, but originally such dielectrics possessed excessive temperature sensitivity. Now this drawback has been overcome with the development of high-Q ceramics with temperature coefficients of expansion comparable to those of invar. One of the first dielectrics having improved frequency stability was reported by workers at Raytheon (Masse and Pucel, 1972. Considerable improvements carried out at Bell Telephone Laboratories and Murata Manufacturing Company of Japan was reported at the Workshop on filter Technology during the 1979 MTT-S International Microwave Symposium. Bell uses a barium titanate ceramic ($Ba_2Ti_{90}zO$) having a relative permittivity of 40, and achieves resonator Q's between 5000 and 10000 in the 2-7-GHz frequency range (Plourde and Linn, 1977; Ren, 1978). Filters may be constructed in all the common transmission media ranging from waveguides to microstrip, and the technique is, therefore, quite versatile. Substantial size reductions have been made, particularly in the 3.7-4.2 GHz and 5.9-6.4GHz waveguide bands, and the filters are stated to have low cost [2, 4].

The recent advances in novel materials and fabrication technologies, including High Temperature Superconductors (HTS), Low-Temperature Co-Fired Ceramics (LTCC), Monolithic Microwave Integrated Circuits (MMIC), Micro-Electro Mechanic System (MEMS), and micromachining technology, have stimulated the rapid development of new microstrip and other filters for RF/microwave applications. In the meantime, advances in Computer-Aided Design (CAD) tools such as full-wave Electromagnetic (EM) simulators have revolutionized filter design. The design starts with the filter specifications and continued with low pass filter prototype that is to normalize in term of impedance and frequency. The low pass filter can be converted into other desired frequency range and impedance level through transformation. Scaling and conversion are used to design high pass, band pass and band stop filter [3-4].

In this paper design of an edge-coupled bandpass filter realized in microstrip technology is presented. The presented process includes the estimation of filter parameters using analytical formulas, the simulation of microstrip technology in a circuit simulator. In this study, we will use Ansoft designer V2.2 Software to measure the insertion loss and return loss of the designed filter over the pass band of S band (2GHz to 4GHz).

II. Research Methodology

Chebyshev filter exhibits a better performance compared to Butterworth filter in terms of frequency response. The insertion loss method which is the most commonly used method is adopted in the design as the network synthesis characteristics allows accuracy in frequency response analysis. The steps followed for designing an edge-coupled band pass filter are: determination of the order of filter and type of approximation functions, determination of the corresponding low-pass prototype, transformation of the low-pass prototype into a band pass configuration, impedance and frequency scaling of the band pass configuration, transformation of the lumped circuit element into distributed elements.

The insertion loss method of filter design provides lumped element circuits. For microwave applications such designs usually must be modified to use distributed elements consisting of transmission line sections. The insertion loss method allows a high degree of control over the pass band and stop band amplitude and phase characteristics, with a systematic way to synthesize a desired response. The necessary design tradeoffs can be evaluated to best meet the application requirements. If, for example, a minimum insertion loss is most important, a binomial response could be used; a Chebyshev response would satisfy a requirement for the sharpest cutoff. If it is possible to sacrifice the attenuation rate, a better phase response can be obtained by using a linear phase filter design. And in all cases, the insertion loss method allows filter performance to be improved in a straightforward manner, at the expense of a higher order filter. For the filter prototypes to be discussed here in this study, the order of the filter is equal to the number of reactive elements [2-6].

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. Chebyshev filter is selected because this filter has steeper initial descent in stop band unlike other filters Chebyshev filters have narrower pass band response in trade for more ripples in the pass band Section. The specifications of the dielectric material and of the filter are listed in Table 1 and 2.

Table 1: Specifications of Dielectric Material

1	Substrate	Rogers RT/duroid 6002
2	Conductor thickness	0.012 mm
3	Dielectric constant	2.94
4	Substrate height	0.887 mm

Table 2: Design Specifications of the Filter

1	Input output impedance	Z= 50 Ohms
2	Pass band ripple	0.5
3	Filter order	n=5
4	Pass band centre frequency	3GHz
5	Ripple bandwidth	1 GHz

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	1.0000			
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	1.9841

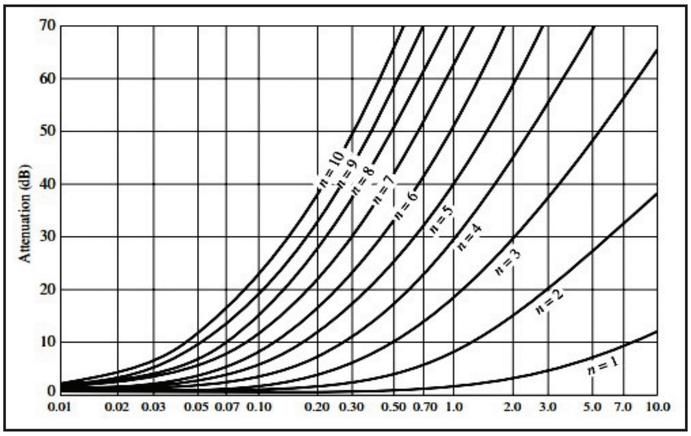
Fig. 1: Element Values for Equal Ripple Band-Pass Filter Prototypes ($g_0 = 1$, $\omega_c = 2$, n = 1 to 10 and 0.5 dB ripple)

With the help of the attenuation characteristics for a Chebyshev filter with 0.5 ripples shown in figure 2, the order of the filter is determined. Fifth order filter is chosen in this work in order to satisfy the design specification. The filter order will be chosen to achieve the desired bandwidth while minimizing the physical size of the filter. The required order for a filter meeting the given specifications is calculated below using equations (1), (2).

$$n = \frac{\cosh^{-1}\sqrt{\frac{10^{\frac{L_T}{10}}-1}{k-1}}}{\cosh^{-1}\left(\frac{f}{f_c}\right)} = \frac{\cosh^{-1}\sqrt{\frac{10^{\frac{45}{10}}-1}{10^{.5}-1}}}{\cosh^{-1}(1.5)} = 5.70 \quad (1)$$

$$K = 10^{\frac{L_{ar}}{10}} \quad (2)$$

Where L_T is the minimum attenuation at frequency f_t and L_{ar} is 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.



Frequency ratio (f/f_c)

Fig. 2: Characteristics for a Chebyshev Filter With 0.5dB Ripple

The bandpass filter is designed to have a 0.5dB equal-ripple response, with an attenuation of 50 dB at 1GHz. From the amplitude versus normalized frequency graph in the number of stages required, N is found to be 5.

Referring to the table and fig. 1, the following coefficients for a fifth order Chebyshev filter has been found out [2, 7]. Normalized element values for 0.5 dB ripple low-pass chebyshev filter obtained from fig. 2 are $g_0 = 1$, $g_1 = 1.7058$, $g_2 = 1.2296$, $g_3 = 2.5408$, $g_4 = 1.2296$, $g_5 = 1.7058$, $g_6 = 1.0000$ for simulated fifth order filter. The band pass filter is realized as a cascade of n+1 coupled line. After getting a low pass filter prototype values, it is transformed into a bandpass design. Although, low pass filter is transformed into bandpass filter design, the attenuation bandwidth ratios remain the same such as shown in equation (3).

$$\frac{BW}{BW_C} = \frac{f}{f_C} \quad (3)$$

Where, BW = bandwidth at the required value of attenuation BWc= 3dB bandwidth of bandpass filter. The actual transformation from low pass to bandpass configuration is accomplished by resonating each low pass element with an element of the opposite type and the same value. All shunt elements of low pass prototype circuit become parallel-resonant circuits, and all series elements become series-resonant circuit. The corresponding transformation of low pass network into bandpass configuration for fifth-order Chebyshev filter is shown in fig. 3 [5-6].

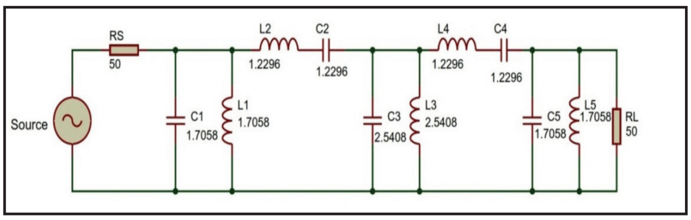


Fig. 3: Conversion of Low Pass Filter to Band Pass Filter

To complete the design, the transformed filter is then frequency-scaled and impedance-scaled using the following formulas. For parallel-resonant branches the values are found out by equation (4), (5).

$$C = \frac{B}{2\pi {f_0}^2 C_n R} \quad (4)$$

$$L = \frac{RL_n}{2\pi R} \quad (5)$$

Where, in all cases, R=the final load impedance,
B=the 3-dB bandwidth of the final design,
f_0 =the geometric center frequency of the final design,
L_n=the normalized inductor bandpass element values,
C_n=the normalized capacitor bandpass element values.

Parallel resonant branches

$$C_1' = \frac{C_n}{2\pi RB} = \frac{C_1}{2\pi RB} = \frac{1.7058}{2\pi\times 50\times 1\times 10^9} = 5.42 \text{ pF} \quad (6)$$

$$L_1' = \frac{RB}{2\pi {f_0}^2 L_n} = \frac{50\times 10^9}{2\pi\times (3\times 10^9)^2\times 1.7058} = 0.51 \text{ nH} \quad (7)$$

For series resonant branches:

$$L_2' = \frac{RL_n}{2\pi B} = \frac{50\times 1.2296}{2\pi\times 1\times 10^9} = 9.78 \text{ nH} \quad (8)$$

$$C_2' = \frac{B}{2\pi {f_0}^2 C_n R} = \frac{1\times 10^9}{2\pi\times (3\times 10^9)^2\times 1.2296\times 50} = 0.29\text{pF} \quad (9)$$

Again, Parallel resonant branches

$$C_3' = \frac{C_3}{2\pi RB} = \frac{2.5408}{2\pi\times 50\times 1\times 10^9} = 8.09 \text{ pF} \quad (10)$$

After transforming the low pass prototype into band pass network using equation 6-10, the filter is then frequency-scaled and impedance-scaled. Richard's transformation and Kuroda's identities are used to accomplish the conversion from the lumped and distributed circuit designs using equation 11-16. Each section of coupled microstrip contains three parameters. The three parameters of the Microstrip line are namely Width (W), diameter or the height of the substrate (d) and separation (S) of the edge-coupled filter. The three parameters are determined from the odd and even mode impedance (Z_{oo} & Z_{oe}) of each coupled line. Z_{oo} and Z_{oe} are in turn depends on the gain of the corresponding admittance inverter J [7-8].

$$J_n = \frac{1}{2Z_0}\frac{\pi\Delta}{\sqrt{g_{n-1}g_n}} \quad (11)$$

$$J_{N+1} = \frac{1}{Z_0}\sqrt{\frac{\pi\Delta}{2g_N g_{N+1}}} \quad (12)$$

$$Z_{0e} = Z_0(1 + JZ_0 + (JZ_0)^2) \quad (13)$$

$$Z_{0o} = Z_0(1 - JZ_0 + (JZ_0)^2) \quad (14)$$

$$\Delta = \frac{f_2 - f_1}{f_0} \quad (15)$$

Richard's transformation and kuroda's identities are used and the values of the odd and even mode impedance, admittance inverter J are tabulated in Table 3. The fractional bandwidth (∆) is

$$\Delta = \frac{\omega_2 - \omega_1}{\omega_c} \quad (16)$$

Where ω_2 and ω_1 are upper and lower edges of the pass-band.

Table 3: Determination of Even and Odd Characteristics Impedances

N	g_n	$Z_o j_n$	Z_{oe}	z_{oo}
1	1.7058	0.0079377	50.400	49.6062
2	1.2296	0.0071584	50.3604	49.6446
3	2.5408	0.005865	50.2449	49.7084
4	1.2296	0.005865	50.2449	49.7084
5	1.7058	0.0071584	50.3604	49.6446
6	1	0.0079377	50.400	49.6062

III. Results and Discussion

Insertion loss and return loss are the two parameters for analyzing the performance of filter. A good filter has higher return loss and smaller insertion loss ripple in the pass band. Return loss measurement is used to evaluate the impedance match of a filter. As the match between the characteristic impedance (Z_o) and the load impedance improves the reflected wave becomes smaller. The related equations are shown in equations (17-19). Thus, reflection co-efficient as shown in the equation gets lowered.

$$S_{11} = 10 \log\left(\frac{P_{reflected}}{P_{incident}}\right) \quad (17)$$

$$\Gamma = \frac{V_{reflected}}{V_{incident}} \quad (18)$$

$$S_{11} = 10 \log(\Gamma) \quad (19)$$

When the impedances match completely there remains no reflected wave and the reflection co-efficient becomes zero. When reflection co-efficient becomes equal to 1, complete mismatch is said to exist. Thus, the range for reflection coefficient is between zeros to one. The simulated results from Ansoft Designer Student Version 2.2 software are presented in this section for analyzing the performance of the designed and simulated band pass filter. The physical model configuration of 5th order edge-coupled microstrip band pass filter is shown in fig. 5. The Filter Design Wizard (FDW) simulated result for insertion loss and return loss response of 5th order edge-coupled Microstrip band pass filter is presented in fig. 6.

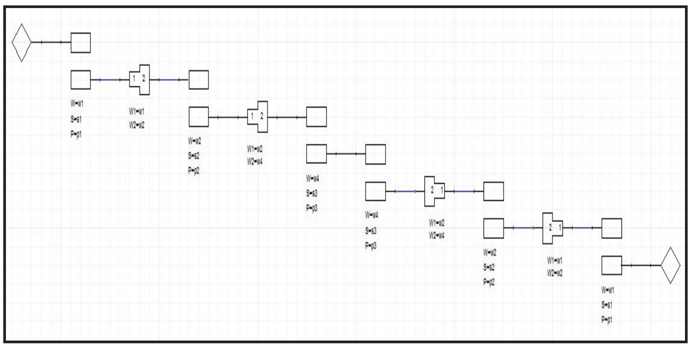


Fig. 5: Physical Model Configuration of 5th Order Edge-Coupled Microstrip Band Pass Filter

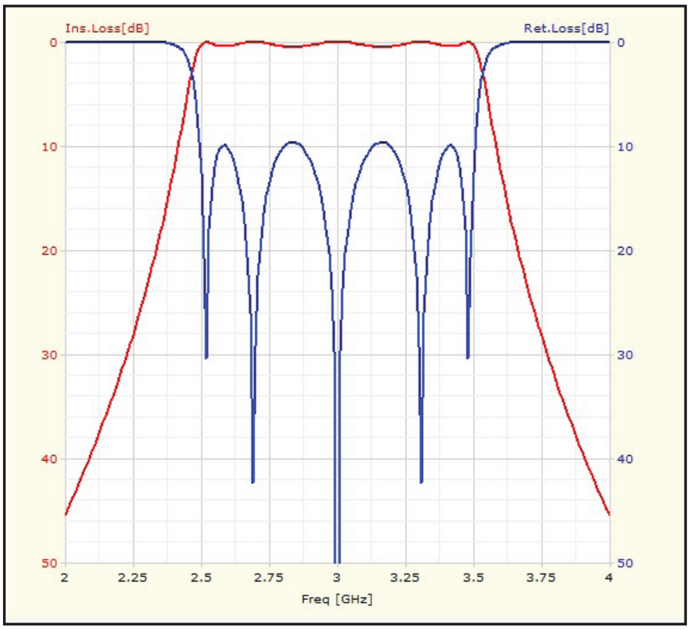


Fig. 6: Filter Design Wizard (FDW) Simulated result for insertion loss and return loss response of 5th order edge-coupled Microstrip band pass filter

The simulated result for insertion loss and return loss response of 5th order edge-coupled Microstrip band pass filter is shown in fig. 7. The 3D-Layout of 5th order edge-coupled Microstrip band pass filter are shown in the fig. 8. From the figure, it is seen that the insertion loss is less than -0.58 dB in pass band which is the characteristics of a good filter. Like a good filter, over the entire pass band the response is flat and uniform and return loss of almost -34 dB. Here the insertion loss is low in db. However, the Filter Design Wizard (FDW) simulated result for insertion loss and return loss response of 5th order edge-coupled microstrip band pass filter in the pass band fulfill the goals for) high return loss (-50 dB) and low insertion loss (-0.5 dB).

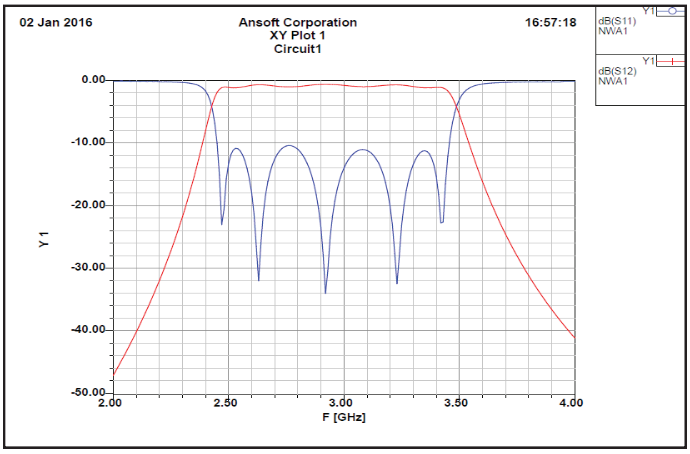


Fig. 7: Simulated Result for Insertion Loss and Return Loss Response of 5th Order Edge-Coupled Microstrip Band Pass Filter (Red Line =insertion loss, blue line=return loss)

IV. Conclusion

Filters are essential parts of communication and radar systems and are key items in the performance and cost of such systems, especially in the increasingly congested spectrum. This paper presents the design and simulation of a fifth order edge-coupled Microstrip band pass filter for operating at S band segment (2 – 4) GHz of the microwave frequency spectrum.

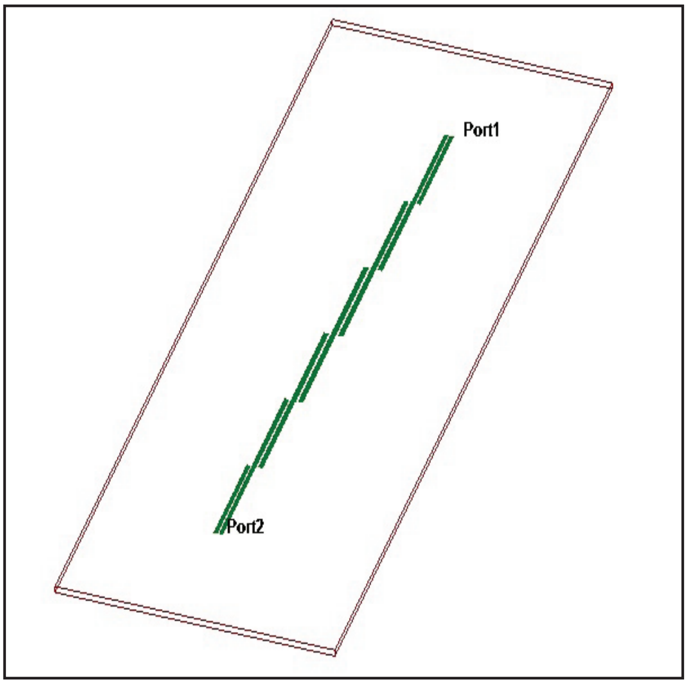


Fig. 8: 3D-Layout of 5th Order Edge-Coupled Microstrip Band Pass Filter

This filter has been designed at a center frequency of 3 GHz with 1 GHz bandwidth. This filter has been developed using Richards-Kuroda transformation method based Chebyshev low pass filter approximation. The filter was simulated using Ansoft designer V2.2. For the proposed work Roger RT/duroid 6002 was considered as substrate with dielectric constant of 2.94, conductor thickness is 0.021 mm and substrate height of 0.887 mm. Simulation results show that the filter operation is optimum & best in this band and the final achieved layout of the fifth order edge-coupled Microstrip band pass filter is suitable for installation at S band. Due to resource limitation, the work is confined to simulation only. However, the fabricated filter would be suitable for installation with different systems, sub-systems for microwave operations, communications satellite, Mobile phone, Wireless LAN, and GPS etc.

References

[1] Bowick, C.; Ajluni, C.; Blyler. J,“RF Circuit Design”, Second Edition. Newnes, 2008.
[2] Pozar, D.M,“Microwave engineering”, 2nd edition, John-Wiley & Sons, 1998.
[3] Borazjani, O.; Rezaee, A.,“Design, Simulation and Construction a Low Pass Microwave Filters on the Micro Strip Transmission Line”, International Journal of Computer Theory and Engineering, Vol. 4, No. 5, October 2012.
[4] Ruiz-Cruz, J. A.; Wang, C.; Zaki, K. A.,“Design and characterization of Advances in microwave filter design techniques,” Microwave Journal, Vol. 51, No. 11, pp. 26–44, Nov. 2008.
[5] Wai,H.Y.; Naing, Z.M.; Lwin, K. S.; ;Tun, H.M.,“Design and simulation of edge-coupled stripline band pass filter for Ka band application”, International conference on trends in Electrical, Electronics and Power Engineering, July 15-16, 2012.
[6] Al-Amin, M. R.; Chowdhury, S.S.; Islam, K.Z.,“Design and simulation of an Edge-coupled Band Pass Filter at X Band”, International Conference on Materials, Electronics

 ISSN : 2230-7109 (Online) | ISSN : 2230-9543 (Print)

& Information Engineering (ICMEIE -2015), held on June 5-6, 2015 at University of Rajshahi.

[7] Yan, Y. M.; Chang, Y. T.; Wang, H.; Wu, R. B.; Chen, C. H.,"Highly selective microstrip bandpass filters in Ka- band", In 32th Eur. Microwave Conf. Proc., 2002, pp. 1137-1140.

[8] Sulaiman, A. A.; Ain, M.F.; Hassan, S.I.S.,"Design of Hairpin Band Pass Filters for K-band Applications", IEEE International RF and Microwave Conference, 2008.

Md Rasheduzzaman Al-Amin received his B.Sc. degree in electrical and electronic engineering from the Islamic University of Technology (IUT), Gazipur, Bangladesh in 2011 where he is currently pursuing M.Sc. degree in electrical engineering. He was a Lecturer with the Electronic and Telecommunications Engineering Department, International Islamic University Chittagong, Bangladesh, from 2012 to 2014 and with Electrical and Electronic Engineering, Bangladesh university of Business and Technology from 2014 to 2015. He is currently a Lecturer of Electrical and Electronic Engineering with Ahsanullah university of Science and Technology in Bangladesh. His current research interests include design of different microwave filters, the generation and application of high-power microwaves.

Md. Omar Faruk Chowdhury received his B.Sc. degree in Electrical and Electronics Engineering from Islamic University of Technology (IUT), Gazipur, Bangladesh, in 2013. He is continuing his M.Sc degree in the same university. He was an assistant lecturer in International Islamic University Chittagong (IIUC) in 2015. Now he is working as a "Lecturer" in Bangladesh University of Business and Technology (BUBT), Bangladesh. His research interests include design of different microwave filters,, wireless ad-hoc network, florescent spectrogram etc.