

# Compact Design of V-Band Edge-Coupled Stripline Bandpass Filter

Jaitesh Upadhyay, Ajay Saini

**Abstract**— In this paper, we present some evolving applications of broadband wireless communications, and use tables and graphs to show research progress from the literature on various radio-frequencies (RF). We focus primarily on stripline based technologies, as these provide the best means of implementing very low-cost, highly integrated 60-GHz mm-wave edge-coupled stripline bandpass filter circuits. In addition, the paper illuminates characterization techniques that are required to competently design mm-wave devices in RT/duroid 5880 substrate, and illustrates effects of the 60-GHz RF propagation channel for both in-building and outdoor use. For the proposed work we consider simulation using RT/duroid 5880 substrate with dielectric constant of 2.20, Conductor Thickness 0.035 mm and Substrate Height 0.508 mm. The values for the passive components are calculated using MATLAB code and to reach the final conclusion which will describe the results to Ansoft Designer simulation results.

**Index Terms**— Stripline transmission line, RT/duroid 5880 substrate, Chebyshev band pass filter, V-band spectrum (60 GHz), Millimeter-wave wireless communication.

## I. INTRODUCTION

In this paper design 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. These transmission lines are compact. V-band uses millimeter-wave stepped-frequency radar operating from 60 GHz for sensing applications[1].

The V-band is mainly used for scientific research. This band is commonly used in radio astronomy and remote sensing. Ground-based radio astronomy is limited to high altitude sites such as Kitt Peak and Atacama Large Millimeter Array (ALMA) due to atmospheric absorption issues. Satellite-based remote sensing near 60 GHz can determine temperature in the upper atmosphere by measuring radiation emitted from oxygen molecules that is a function of temperature and pressure [2].

The ITU non-exclusive passive frequency allocation at 57-59.3 is used for atmospheric monitoring in meteorological and climate sensing applications, and is important for these purposes due to the properties of oxygen absorption and emission in Earth's atmosphere. Currently operational U.S.

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Satellite sensors such as the Advanced Microwave Sounding Unit (AMSU) on one NASA satellite (Aqua) and four NOAA satellites and the Special Sensor Microwave Imager Sounder (SSM/I/S) on Department of Defense satellite F-16 make use of this frequency range. Extremely high frequency is the highest radio frequency band, a form of electromagnetic radiation. EHF runs the range of frequencies from 30 to 300 gigahertz, above which electromagnetic radiation is considered to be low (or far) infrared light, also referred to as terahertz radiation. Radio waves in this band have wavelengths from ten to one millimetre, giving it the name millimetre band or millimetre wave, sometimes abbreviated MMW or mmW [3].

Compared to lower bands, terrestrial radio signals in this band are extremely prone to atmospheric attenuation, making them of very little use over long distances. In particular, signals in the 56–64 GHz region are subject to a resonance of the oxygen molecule and are severely attenuated. Even over relatively short distances, rain fade is a serious problem, caused when absorption by rain reduces signal strength. In climates other than deserts absorption due to humidity also has an impact on propagation. While this absorption limits potential communications range, it also allows for smaller frequency reuse distances than lower frequencies [9].

A 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. The width of the strip, the thickness of the substrate and the relative permittivity of the substrate determine the characteristic impedance of the strip which is a transmission line. As shown in Fig.1, the central conductor need not be equally spaced between the ground planes. In the general case, the dielectric material may be different above and below the central conductor.

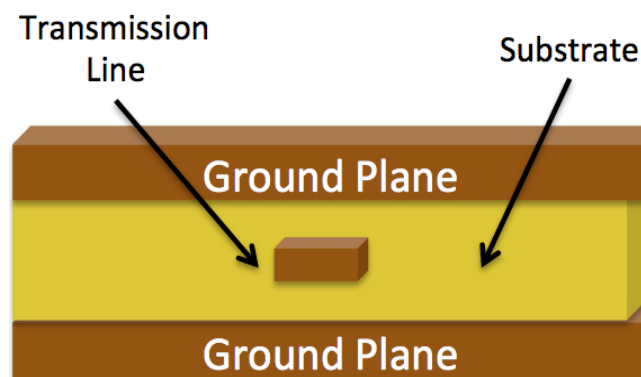


Fig. 1: Model used by Designer for Edge-Coupled Stripline Bandpass filter

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 [4]. 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, V-band (50-75 GHz) range filters design is developed in this report. The spectrum is used for communications services, cellular radio services, and other commercial and private mobile radio operations services. There has been a particularly marked growth in the microwave communications industry in recent years. This has contributed to both very demanding performance specifications for filters and the commercial pressures for low cost, high volume and quick delivery [2].

**SPECIFICATIONS: TABLE 1.1**

Specifications of Dielectric material RT/duroid 5880 substracts designed for microwave circuit applications requiring a high dielectric constant.			
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:		60 GHz
5).	Ripple Bandwidth:		8 GHz
Board and Substrate Properties:			
6).	Substrate:		RT/duroid 5880
7).	Conductor Thickness:		0.035 mm
8).	Dielectric Constant:		2.20
9).	Loss Tangent:		0.0008
10).	Substrate Height:		0.508 mm

**Table 1.1: Specifications of Edge-Coupled Stripline Bandpass Filter for V-band [6]**

In this paper edge-coupled stripline bandpass filter (BPF) development with the assistance of the Richards-Kuroda Transformation method, on the basis of the known Chebyshev-Lowpass Filter, is presented. This suggested filter consist of four edge-coupled striplines. The use of the 56–64 GHz frequency band is a promising solution for Gigabit short range wireless communication systems. Up to 8 GHz unlicensed bandwidth was allocated around the world for various communication applications and the standardization is developing under the IEEE standard 802.15.3c, 802.15.11ad, and the European Computer Manufacturers Association (ECMA) standard 387. Another advantage beside the high unlicensed bandwidth is the fact to have low interference with other electrical systems in the vicinity. This is due to the high amount of energy absorption by oxygen molecules around 60 GHz [6,9]. The bandpass filter could either be realized using lumped component or distributed component. Lumped components consists of discrete elements like inductors, capacitors etc. Distributed elements consist of transmission line section which simulates various inductors and capacitors values. At very high frequency the practical inductors and capacitors losses their intrinsic characteristics. So it is hard to realized filters with lumped

elements. Transmission lines are easy to implement and compact at this frequency. Transmission lines are needed for connecting various circuit elements and systems. Therefore for microwave frequency (>3GHz) passive filter is usually realized using distributed circuit element such as transmission line. Open wire and Coaxial lines are commonly used for circuits operating at low frequencies. On the other hand Stripline, Microstrip line and Waveguides are operating at radio and microwave frequencies. In the design, three kinds of transmission lines were normally used: Waveguide Striplines, and Microstrip lines. Waveguides systems are bulky and expensive. Low-power and cheaper alternatives are Stripline and Microstrip. These transmission lines are compact. Edge-coupled stripline is used instead of microstrip line as stripline does not suffer from dispersion and its propagation mode is pure TEM mode. Hence it is the preferred structured for Edge-coupled Stripline [4, 5-7].

**The proposed filter is designed by following steps.**

**First step:** Determining the order (n) to be used.

**Second step:** Finding the corresponding low-pass prototype structure and convert into bandpass filter.

**Third step:** Find out the distributed realization using J inverter and  $Y_o$  is the characteristic admittance of the connecting transmission line.

**Forth step:** Calculate the characteristic impedances of ( $Z_{oe}$ ) even-mode and ( $Z_{oo}$ ) odd-mode of the parallel-coupled stripline transmission line based on the mathematical formulation and compare with simulated value.

**Fifth step:** Determine the Effective dielectric constant  $\epsilon_{re}$  and length  $L$  measurement based on the mathematical formulation.

**Six step:** Determine the w, s, and L using simulated layout.

**Seven step:** Analysis & Design are completed by using simulation software.

**Eight step:** Compare the result graph between two simulation software.

## II. DESIGN OF CHEBYSHEV BAND PASS FILTER:

The BPF circuit is simulated with Matlab & Ansoft Designer 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 [2] 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 [8].

**Determining the Number of Sections (n):**

The bandpass filter is designed to have a 0.5dB equal-ripple response, with an attenuation of 50 dB at 60GHz. From the amplitude versus normalized frequency graph in [1-2], the number of stages required, N is found to be 3. The bandpass filter is realized as a cascade of  $n+1$  coupled line sections as shown in Fig. 3. 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 [10].

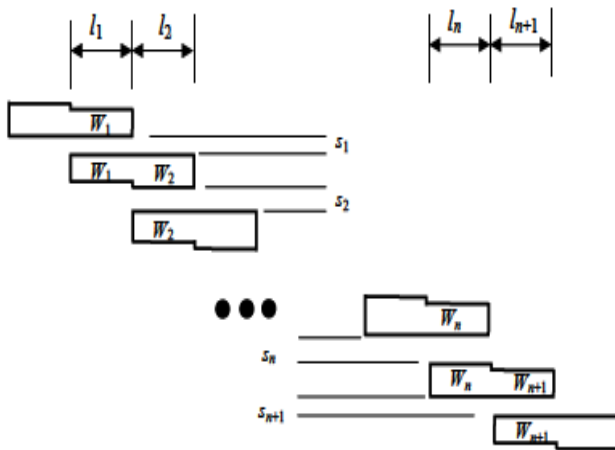


Fig. 3: Bandpass filter is realized as a cascade of n+1 coupled line sections

This filter type is known as parallel-coupled filter. The strips are arranged parallel close to each other, so that they are coupled with certain coupling factors.

#### 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 Z<sub>0</sub> is typically 50 Ohms. The unitary bandwidth BW is given by

$$\text{where } BW = \frac{(\omega_2 - \omega_1)}{\omega_0} \text{ is the fractional} \quad (1)$$

$$FBW = \frac{(64 \times 10^9 - 56 \times 10^9)}{60 \times 10^9} \approx .1333 \quad (2)$$

$$\frac{J_{0,1}}{Y_0} = \sqrt{\frac{\pi FBW}{2 g_0 g_1}} \quad (3)$$

$$\frac{J_{j,j+1}}{Y_0} = \frac{\pi FBW}{2} \frac{1}{\sqrt{g_j g_{j+1}}} \text{ for } j=1 \text{ to } n-1 \quad (4)$$

$$\frac{J_{n,n+1}}{Y_0} = \sqrt{\frac{\pi FBW}{2 g_n g_{n+1}}} \quad (5)$$

Where g<sub>0</sub>, g<sub>1</sub>,... g<sub>n</sub> are the element of a ladder-type low-pass prototype with a Normalized cutoff Ω<sub>c</sub> = 1, and FBW is the fractional bandwidth of band-pass filter.

J<sub>j,j+1</sub> are the characteristic admittances of J-inverters and Y<sub>0</sub> is the characteristic admittance of the terminating lines. The equation above will be use 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 [11-12]. 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

$$(Z_{0e})_{j,j+1} = \frac{1}{Y_0} \left[ 1 + \frac{J_{j,j+1}}{Y_0} + \left( \frac{J_{j,j+1}}{Y_0} \right)^2 \right] \text{ for } j=0 \text{ to } n \quad (6)$$

$$(Z_{0o})_{j,j+1} = \frac{1}{Y_0} \left[ 1 - \frac{J_{j,j+1}}{Y_0} + \left( \frac{J_{j,j+1}}{Y_0} \right)^2 \right] \text{ for } j=0 \text{ to } n \quad (7)$$

#### 4 Effective Dielectric Constant And Length Measurement : For W=0.3865 mm (Standard value):

$$\epsilon_{re} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \frac{1}{\sqrt{1 + \frac{12h}{W}}} \quad (8)$$

Thus the required length,

$$\ell = \frac{\lambda_g}{4} = \frac{c}{4f\sqrt{\epsilon_{re}}} = \frac{3 \times 10^8}{4 \times 60 \times 10^9 \times \sqrt{1.8598}} = 0.9166 \text{ mm} \quad (9)$$

The length of the resonator requires for third order coupled line filter will have four, quarter wave-length segments. So final filter length is L = (n+1) × l = (3+1) × 0.9166 = 3.664 mm (10)

J	J <sub>j,j+1</sub> /Y <sub>0</sub>	(Z <sub>ee</sub> ) <sub>j,j+1</sub> (Ω) (Derived results)	(Z <sub>oo</sub> ) <sub>j,j+1</sub> (Ω) (Derived results)	(Z <sub>ee</sub> ) <sub>j,j+1</sub> (Ω) (Simulated results)	(Z <sub>oo</sub> ) <sub>j,j+1</sub> (Ω) (Simulated results)
0	.3622	74.6711	38.4492	75.21	38.37
1	.1583	59.1674	43.3382	59.53	43.15
2	.1583	59.1674	43.3382	59.53	43.15
3	.3622	74.6711	38.4492	75.21	38.37

Table 1.2: Circuit Design Parameters of the 3<sup>rd</sup> Order, Parallel-Coupled Stripline Bandpass Filter

#### III. SIMULATED RESULT & DISCUSSION

We discuss the results obtained from Ansoft software and Matlab software. The frequency sweep for the linear simulation of the advanced numerical models was performed from 33 to 50 GHz in 0.1 GHz steps.

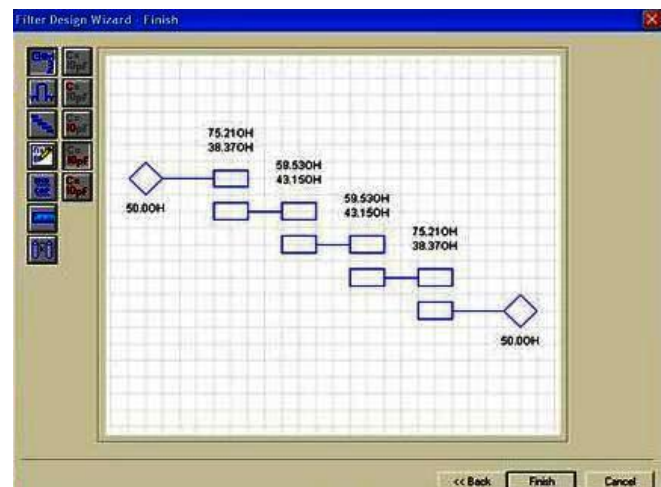


Fig.4. Software result of odd and even impedances response of 3<sup>rd</sup> order edge-coupled stripline bandpass filter



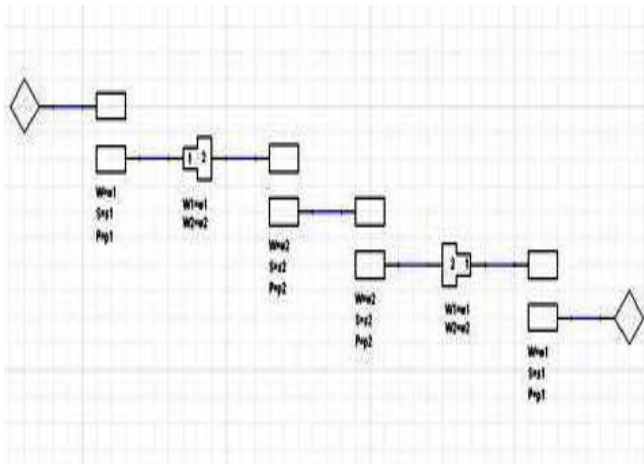


Fig. 5: Tuned Chebyshev Band Pass Filter Made From Physical Model Configuration of 3<sup>rd</sup> Order Edge-Coupled Stripline Bandpass Filter

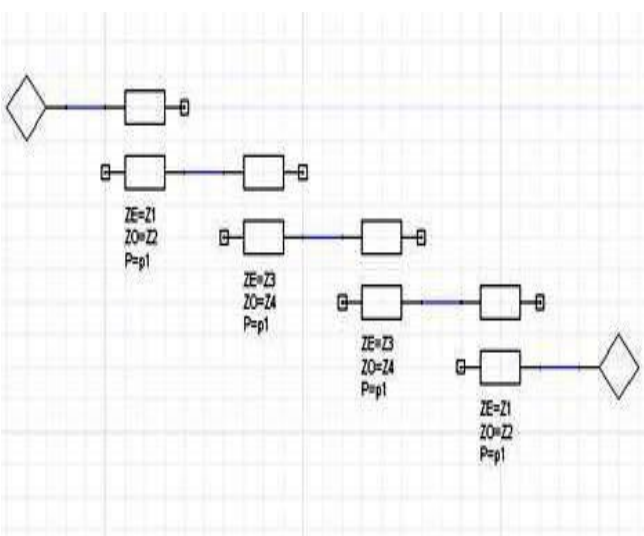


Fig. 6: Electrical Model Configuration of 3<sup>rd</sup> Order Edge-Coupled Stripline Bandpass Filter

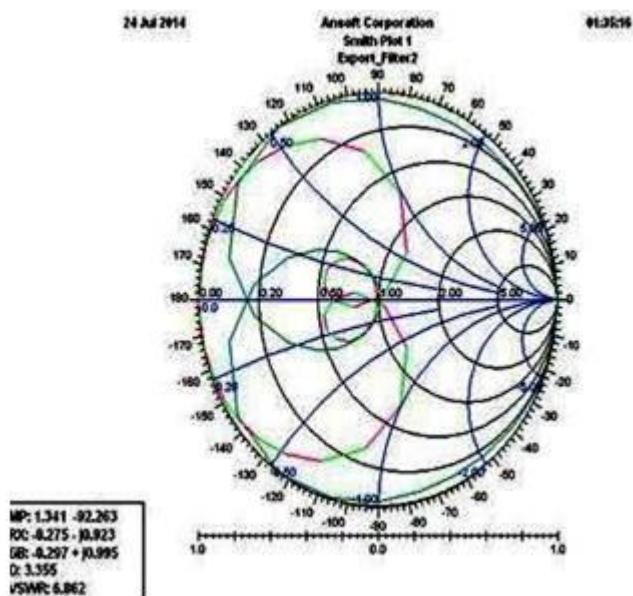


Fig. 7: Simulated Smith Chart Result of 3<sup>rd</sup> Order Edge-Coupled Stripline Bandpass Filter

Smith chart to be used for problems involving any characteristic or system impedance which is represented by the center point of the chart. The most commonly used normalization impedance is 50 ohms. Once an answer is obtained through the graphical constructions described in Fig. 7, it is straightforward to convert between normalised impedance (or normalised admittance) and the corresponding unnormalized value by multiplying by the characteristic impedance (admittance).

Reflection coefficients can be read directly from the chart as they are unitless parameters. Any actual reflection coefficient must have a magnitude of less than or equal to unity so, at the test frequency, this may be expressed by a point inside a circle of unity radius. The Smith chart is actually constructed on such a polar diagram.

The Smith chart scaling is designed in such a way that reflection coefficient can be converted to normalised impedance or vice versa. Using the Smith chart, the normalised impedance may be obtained with appreciable accuracy by plotting the point representing the reflection coefficient treating the Smith chart as a polar diagram and then reading its value directly using the characteristic Smith chart scaling. This technique is a graphical alternative to substituting the values in the equations [8].

Smith chart is a set of constant resistance and constant reactance circle draw on complex gamma plane. One especially point and that is center of smith chart at that is intersection of  $r=1$  and  $x=0$  on the line. This mark a point on smith chart represents match condition so the impedance lines on the center which cross ponds to the magnitude of reflection coefficient zero.

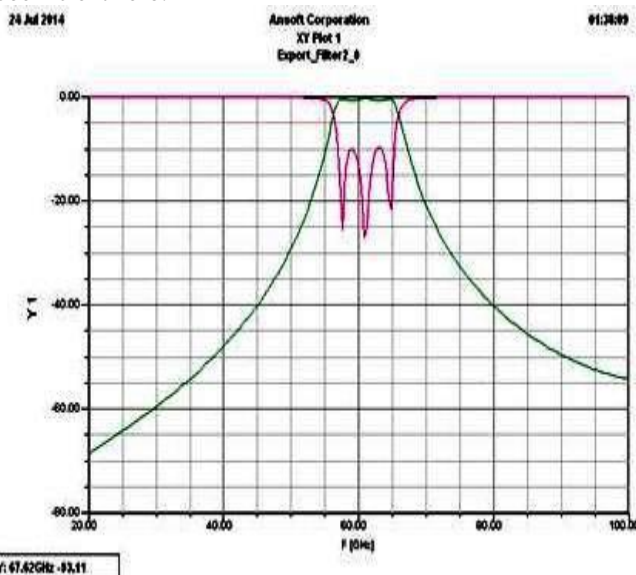


Fig. 8: Simulated result for Physical model insertion loss and return loss response of 3<sup>rd</sup> order edge-coupled stripline bandpass filter

Return loss is the loss of signal power resulting from the reflection caused at a discontinuity in a transmission line. Return loss is related to both standing wave ratio (SWR) and reflection coefficient ( $\Gamma$ ). Increasing return loss corresponds to lower SWR. Return loss is a measure of how well devices or lines are matched. A match is good if the return loss is high. A high return loss is desirable and results in a lower insertion loss. Return loss is used in modern practice in preference to SWR because it has better resolution for

small values of reflected wave. Insertion loss is a figure of merit for an electronic filter and this data is generally specified with a filter. Insertion loss is defined as a ratio of the signal level in a test configuration without the filter installed ( $|V_1|$ ) to the signal level with the filter installed ( $|V_2|$ ).

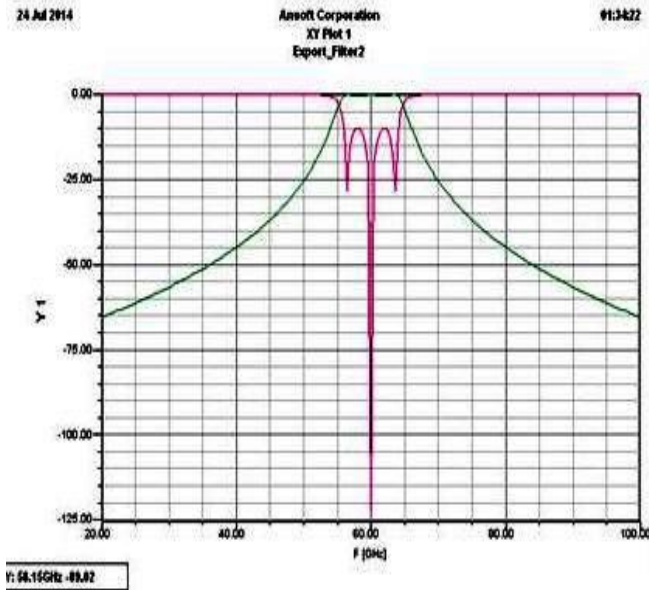


Fig. 9: Simulated result for Electrical model insertion loss and return loss response of 3<sup>rd</sup> order edge-coupled stripline bandpass filter

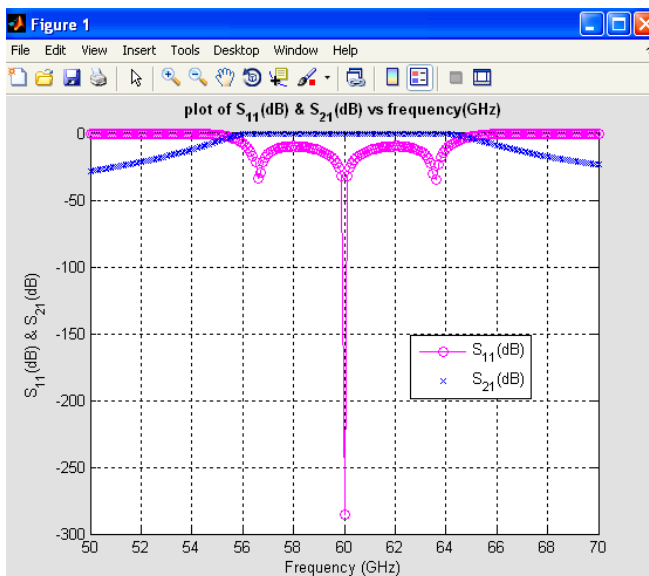


Fig. 10. Simulated result By MATLAB Simulated Tool of 3<sup>rd</sup> order Edge-coupled Stripline Bandpass Filter

Modeled performance is shown in Fig.10 simulated insertion loss and return loss result of 3<sup>rd</sup> order edge-coupled stripline bandpass filter EM analysis results from MATLAB, which indicates that the response satisfies the design criteria along with shown in Fig. 10 simulated result by MATLAB simulated tool. Reflection regarding in accuracies present in simulators result and simulation result show that the filter operation is optimum over the frequency range 56 GHz to 64 GHz which is best in this range. The simulated insertion loss is less than 0.1 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 ( $Z_0$ ), 50 Ohms. Also it is observed that the phase varies linearly with frequency.

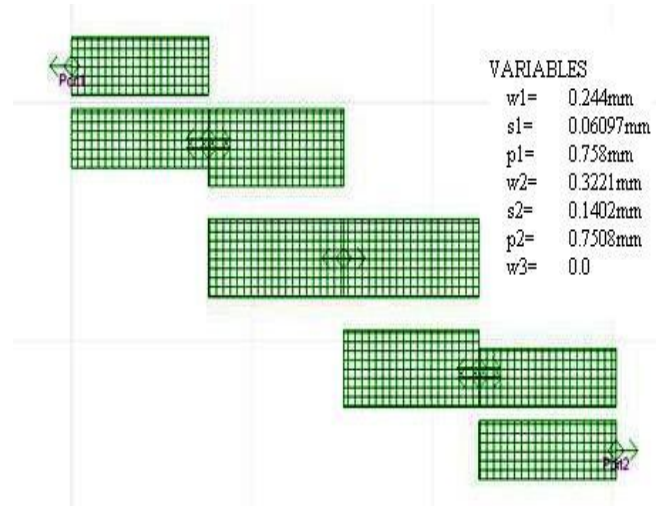


Fig.11: Detail dimensions of the simulated layout model result of 3<sup>rd</sup> order stripline edge-coupled bandpass filter

The Layout of the filter is generated from the schematic design Fig. 11. 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.11. According to layout we get  $w1=0.244$  mm and  $s1=0.06097$  mm. The same data will be also used for the fourth resonator. The MATLAB software is used for computation of design formulations including the response of filter & Ansoft Designer software was used for the purpose of designing and simulating edge-coupled band-pass filter responses are identical near pass-band region. 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 the .1 dB. The return loss is greater than 50 dB at center frequency.

#### IV. CONCLUSION

The overall performance of edge-coupled stripline bandpass filter can often judged by its simulated insertion loss and return loss result response. Design an edge-coupled stripline band-pass filter centered at 60 GHz with 8 GHz bandwidth based on chebyshev approximation. 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 filter is simulated with Ansoft Designer 2.2 software to simulated insertion loss is less than 0.1 dB in the desired pass band and the simulated return loss is greater than 30 dB at center frequency. Reflection coefficient is nearly equal to 0, perfect match. The Mathematical analysis was done for design and verified by writing a MATLAB code. The tool developed here is compared to two industry standard software packages, Ansoft Designer and Matlab. Ansoft Designer v2.2 simulation software was used to accurately arrive at the final design.

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. Experimental implementation of this work involves the RT/duroid 5880 substrate with dielectric constant of 2.20 dielectric characterizations at microwave frequencies. Third-order edge-coupled stripline band pass filter is used in order to realize these objectives. If more-accurate frequency response is required, more stages should be used. A coupled line bandpass filter was successfully designed by direct calculation and by using a CAD design tool. The Matlab tool's characteristic impedance value agrees extremely closely with Ansoft Designer. Successful simulations have been presented.



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