

# Design and Implementation of High Performance Miniature Uniplanar Microwave Low Pass Filter up to 15GHz

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## Abstract

**Objectives:** This work is introduced to design, implementation and specific analysis of printed miniature uniplanar micro strip low pass filter having a cut off of 15GHz on RT/duroid 6010.2 substrate. **Methods/Statistical analysis:** Besides, the paper examines simulated responses of three circuits which are predominantly lumped element circuit, stepped impedance and EM simulation with respect to conventional design circuit simulations where in both the design strategy will match the tested results. **Findings:** This proposed work comprises low pass filter design, lumped design and basic design by using only micro strip lines technology. The EM Structure sight design technique gives good sharp cut-off frequency response when compare with other technique towards low insertion loss which brings about having extraordinary concurrence for incredible relationship. Predominantly, AWR microwave office tool is used for designing and analysis. **Application/Improvements:** The proposed design configuration will have more extensive application in advancements like 5G, Satellite, radars, Port Vessel Traffic Services and military communication system.

**Keywords:** EM Structure, HMIC, Impedance Matching, Microwave Low Pass Filter, Micro Strip Lines

## 1. Introduction

Implementation of a wide assortment of today's filters devices furnished with lumped elements (capacitors and inductors), Hybrid Microwave Integrated Circuits (HMIC's), MMIC and LTCC is challenging. For defeating the difficulties in execution there is have to actualize filters in micro strip technology and the distance between the components of the filter has to be considered<sup>1</sup>. Some research recommends the use of uniplanar technology for filter designs. Uniplanar Low-Pass Filters are used to filter out the multi ordered harmonics; inter modulation and spurious signals easily. This works goes for planning and executing a low pass filter that would be a sharp cut off at 15 GHz frequency with appropriate responses which can accomplish great outcomes even after fabric implementations.

Nowadays, customary LC Ladder filters design strategies are once in a while utilized as a part of communication technology<sup>2</sup>. In this work, the ninth order analog low-pass filters are design and simulated using AWR Tool. At that point lumped LC segments are changed over into conveyed components (miniaturized scale strip lines) for execution of LPF. Also, LC configuration is contrasted and miniaturized scale strip and EM structure.

## 2. Research Background and Collected Data

A Chebyshev based Low Pass Micro Strip Filter designed utilizing Richanrd's Transformation and Kuroda Identities and tested by a spectrum analyser limiting only up to 1.5

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to 2 GHz<sup>3</sup>. Because of defective manufacture and association of SMA Connecters there is parcel of variety in the results between simulated and tested data. A reduced LPF utilizing single folded stepped impedance hairpin resonator with 2 GHz cut-off frequency. Advance the high capacitance impact smothers and expand the spurious signs<sup>4</sup>. The Design of Printed Micro Strip Low Pass Filter in light of 15 mils Alumina substrate which is contrasted and immaculate EM structure and EM Sight<sup>5</sup>. This work introduced more proficient half breed approach that consolidates EM examination (utilizing X-Models) with ordinary circuit recreations in AWR microwave office tool up to 18GHz; however the work couldn't implement and check those results.

### 3. Micro Strip Filter Design Steps and Analysis

Filters are utilized for disposing of undesirable frequencies and for passing required electromagnetic frequencies waves. It is a two-port gadget that assumes the critical part in controlling the frequency reaction at certain point crosswise over segment in a microwave system and it is shown in Figure 1.

Channels are planned utilizing two techniques: Image Parameters strategy and Insertion Loss technique. Image Parameters strategy is comprised of two phases of less complex two-port filter segments associated in the arrangement to get the required cut-off frequencies and attenuation (Return losses and Insertion loss) attributes,

yet it won't bolster qualities specification of a frequency response everywhere throughout the working band and this system will get to be distinctly iterative to accomplish the focused-on particulars<sup>6,7</sup>. Insertions Loss method is more cutting-edge method contrasted with image parameters which utilize arrange blend procedures to outline filters with a totally identified frequency responses. The strategy is improving by utilizing standard standardized plot and lessened the multifaceted nature in fundamental lumped component designs. Both techniques will give the parametric estimations of lumped components and can compute the estimation of the components shown in Table 1.

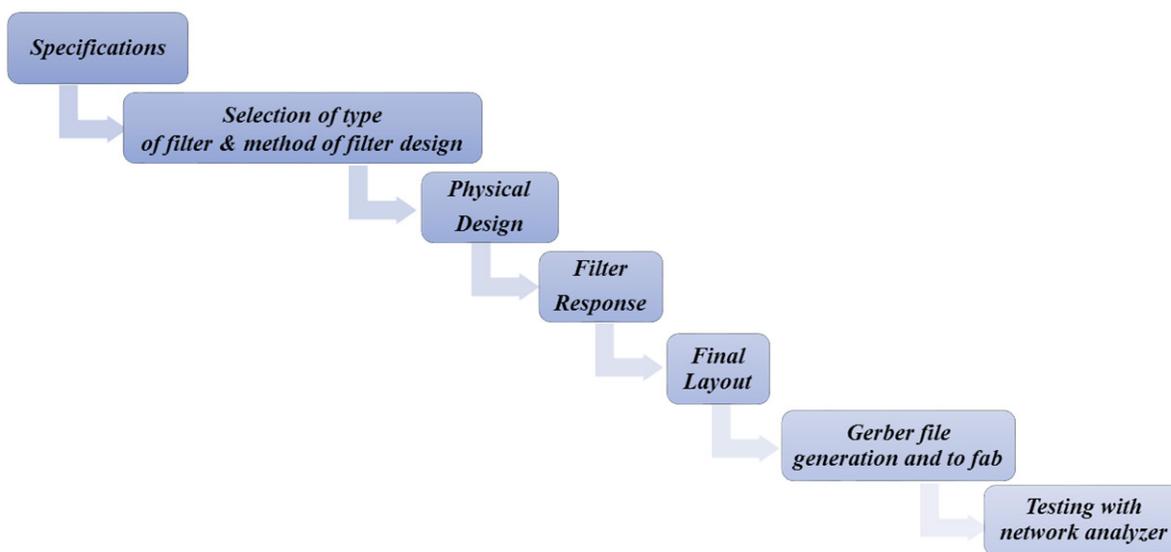
**Table 1.** Filter parameters briefed to understand how the filter parameters are interlinked

Order 'N'	Rejection/Attenuation	Insertion loss	BW	'Q'	Group Delay
More	More	More	Less	More	More

### 4. Process and Design

Due to its ideal approximation response, Chebyshev-I approach is used for designing of the filter, which has specified order and ripple. The design specifications of the low pass filter are listed in following points:

- Input and output are matched to a 50-ohm impedance with cut off frequency of 15 GHz
- Equiripple of 3 dB



**Figure 1.** Detail steps followed for design and implementation of the low pass filter.

- Insertion loss of 40 dB at twice the cut off frequency
- Return loss of 20 dB

And the authors implement it in a RT/duroid 6010.2 LM substrate with the following characteristics:

- Relative dielectric constant is 10.2
- Dielectric loss tangent of 0.0027
- Thickness of 0.13 mm

### 4.1 Design Using Lumped Elements

The lumped component show decreases the unpredictability and gives parametric depiction of the conduct of spatially conveyed physical systems (Generally, Micro strip lines or stubs). It has applications in electrical systems (counting hardware), mechanical multibody systems, heat transfer and acoustics<sup>3</sup>. The order N (and henceforth, count of components) of a Chebyshev filter will be calculated using its characteristics as takes after

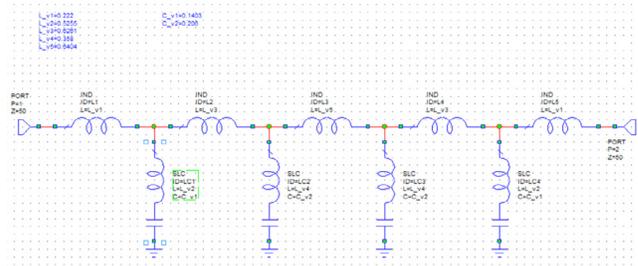
$$N = \frac{\cos^{-1} \sqrt{\frac{(10^{0.1 \times IL} - 1)}{(10^{0.1 \times \alpha} - 1)}}}{\cos^{-1} \frac{\omega}{\omega_c}} \quad (1)$$

The filter designed for the specification whose cut-off frequency of 15GHz. From the equation 1 order of the filter is observed to be 9. For this proposed design prototype are displayed (Figure 2):

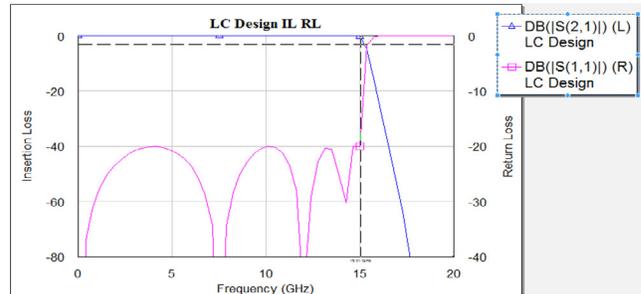
$$g_0 = g_{10} = 1, g_1 = g_9 = 1.7505, g_2 = g_8 = 1.26678, g_3 = g_7 = 2.6678, g_4 = g_6 = 1.3673 \text{ and } g_5 = 2.7240$$

S (2,1) and S (1,2): Figure 2b This parameter gives the data about the insertion loss confronted by the circuit amid the passband and stopband conditions. The Insertion loss is the loss that happens because of addition of the part between the Input and the output port because of its lossy characteristics of the components. In this way, the insertion loss ought to be around 0dB for passband and higher in size if there should a rise an occurrence of stopband around 40dB or 60dB to give sufficient attenuation to the signal.

S (1,1) and S (2,2): The return loss is the measurement which is defined as the ratio of the power in the reflected wave to the power the input wave in terms represented in dB. This parameter provides the information about ripple factor. Ripples are fundamentally created because of impedance mismatch on account of which a few signals are reflected back and meddle with the approaching signs which ought to be less in the event of pass band and higher if there should a rise an occurrence of stopband.



(a)



(b)

**Figure 2.** Basic lumped elements design using theoretical calculation (a) Lumped elements design schematic in AWR tool (b) Insertion and return loss measurements of the designed LC circuit.

### 4.2 Insertion Loss Methods

The Insertion loss design method will follow the relationship which is displayed in equation 2

$$P_{LR} = \frac{\text{Power available from the source}}{\text{Power delivered to load}} = \frac{P_{inc}}{P_{load}} = \frac{1}{1 - |\Gamma(\omega)|^2} \quad (2)$$

Where  $\Gamma$  is the reflection coefficient looking into the filter.

$$|\Gamma(\omega)|^2 = \frac{f_1(\omega^2)}{f_1(\omega^2) + f_2(\omega^2)} \quad (3)$$

$$P_{LR} = 1 + \frac{f_1(\omega^2)}{f_1(\omega^2)} \quad (4)$$

Where  $f_1(\omega^2)$  and  $f_2(\omega^2)$  are real polynomials in  $\omega^2$ .

Likewise, the magnitude of the gain of the 2-port network will be finding in the equation 5

$$|G(\omega)| = \frac{1}{\sqrt{P_{LR}}} = \frac{1}{\sqrt{1 + \frac{f_1(\omega^2)}{f_2(\omega^2)}}} \quad (5)$$

Since, the  $P_{LR}$  is specified,  $\Gamma(\omega)$  are not variable function. So, the IL method is same as the impedance-matching methods.

### 4.3 Chebyshev Polynomials Design Equations

The Chebyshev polynomials are utilizing the co-efficient of insertion loss method,

$$|G(\omega)| = \frac{1}{\sqrt{1 + \zeta T_N^2(\bar{\omega})}} \quad N = 1,2,3 \dots \quad (6)$$

Where  $\zeta$  is a constant,  $\bar{\omega}$  is normalized frequency, and  $T_N(\omega)$  is a Chebyshev polynomial of the first kind and degree  $N$

The insertion loss of is calculated by using the equation 7:

$$IL = -20 \log_{10} \left[ \frac{1}{\sqrt{1 + \zeta T_N^2\left(\frac{\omega}{\omega_c}\right)}} \right] = 10 \log_{10} \left[ 1 + \zeta T_N^2\left(\frac{\omega}{\omega_c}\right) \right] \quad (7)$$

Or

$$IL = \begin{cases} 10 \log_{10} \left[ 1 + \zeta \cos^2 \left( N \cos^{-1} \frac{\omega}{\omega_c} \right) \right] & 0 \leq \omega \leq \omega_c \\ 10 \log_{10} \left[ 1 + \zeta \cosh^2 \left( N \cosh^{-1} \frac{\omega}{\omega_c} \right) \right] & \omega_c < \omega \end{cases} \quad (8)$$

Where

$$\omega = \omega_c \pm (\omega_2 - \omega_1) \quad \text{and}$$

$$\zeta = 10^{\frac{0.1}{\alpha}} - 1$$

$\alpha$  is the ripple amplitude in dB. Where  $IL$  is required insertion loss in dB at  $\omega$  frequency.

### 4.4 Micro Strip, Substrate Model, Extract and Stack Up

Micro strip line consists of thin strip conductor and low-loss dielectric material built over ground plane. Electromagnetic Waves travel in micro strip line both in the dielectric medium and air media.

$\epsilon_r$  is the permittivity of the substrate material relative to the permittivity of free space  $\epsilon_0 = 8.85e-12 \text{ F/M}^2$

$T$  and is the dielectric loss tangent of the substrate material:  $T = \tan \delta = \epsilon_r'' / \epsilon_r'$  where  $\epsilon_r = \epsilon_r' - j\epsilon_r''$

$\rho$  is the bulk resistivity of conductor metal normalized to gold (that is, to  $2.44 \times 10^{-8} \Omega \cdot \text{m}$ )

So actual metal bulk resistivity =  $2.44 \times 10^{-8} \Omega \cdot \rho \cdot m$ .  $H$  and  $T$  are cross sectional dimensional variables given in default length units.

The EXTRACT block is a simulation control that permits a gathering of related schematic components to be electrically demonstrated by means of a physical simulation (EM simulation, parasitic extraction, etc.) of the layout of these components (Figure 3). On simulating, the layout cells of all the associated components are ported to an EM document and are simulated. Later, the electrical results are automatically merged back into the schematic and simulation of the whole schematic is performed.

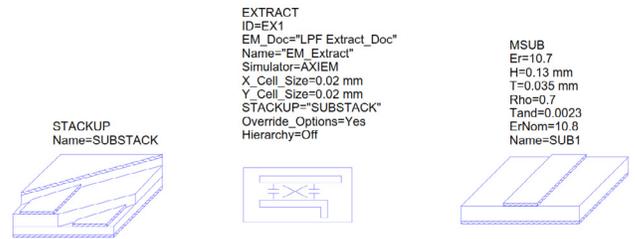


Figure 3. Micro strip primary parameter details, EM extract and stack up.

### 4.5 Micro Strip Design with AWR Microwave Office

The Basic filter is framed using micro strip lines components like MLIN, MLEF and MTEE micro strips models in AWR tool. Input/output ports are matched to 50ohms. Micro strip has relative dielectric constant,  $\epsilon_r = 10.2$ ,  $T = 0.13 \text{ mm}$  and  $Tand = 0.0027$  (Figure 4).

The low pass LC pair is designed with series arrangement L, since the direct conversion to transmission line stubs by Richard's transformation would bring about arrangement series stubs. Be that as it may, authors utilized the Kuroda identity for arrangement inductors to

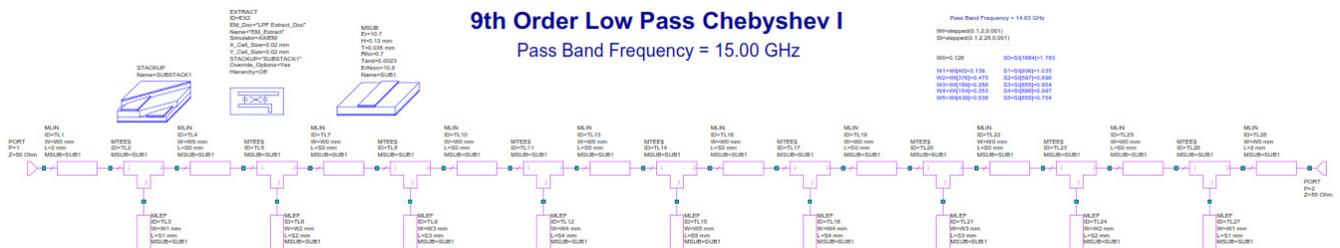


Figure 4. Distributed element design of 9th order low pass filter.

make a structure that has just arrangement transmission line segments and shunt open stubs. With a specific end goal to do this, outline ought to start by including unit components ( $l/8$  transmission lines of  $Z_0 = 1$ ) at each end of the filter, so that there will be structures that are of the type of the Kuroda identities.

## 5. Simulated Results

The layout of the micro strip filter which is used for fabrication is given below (Figure 5(a) and Figure 5(b)): Physical Dimension (1.2mm x 21mm).

**Layout:** layout is the distributed element layout that has been generated with the help of kuroda's identity and Richards transformation and port 1 and port 2 are basically the matching loads for connecting the connectors.

**Group delay:** A Group Delay estimation indicates how a device makes these recurrence segments get to be misaligned. In spite of the fact that it is unnoticeable, however it appeared in Figure 6(b) misaligning the stage between; a group of frequency components can destroy a signal. To put it plainly, all frequency components to encounter an indistinguishable measure of postponement from they go through a filter. So, it is must to stay steady in passband and change in stopband.

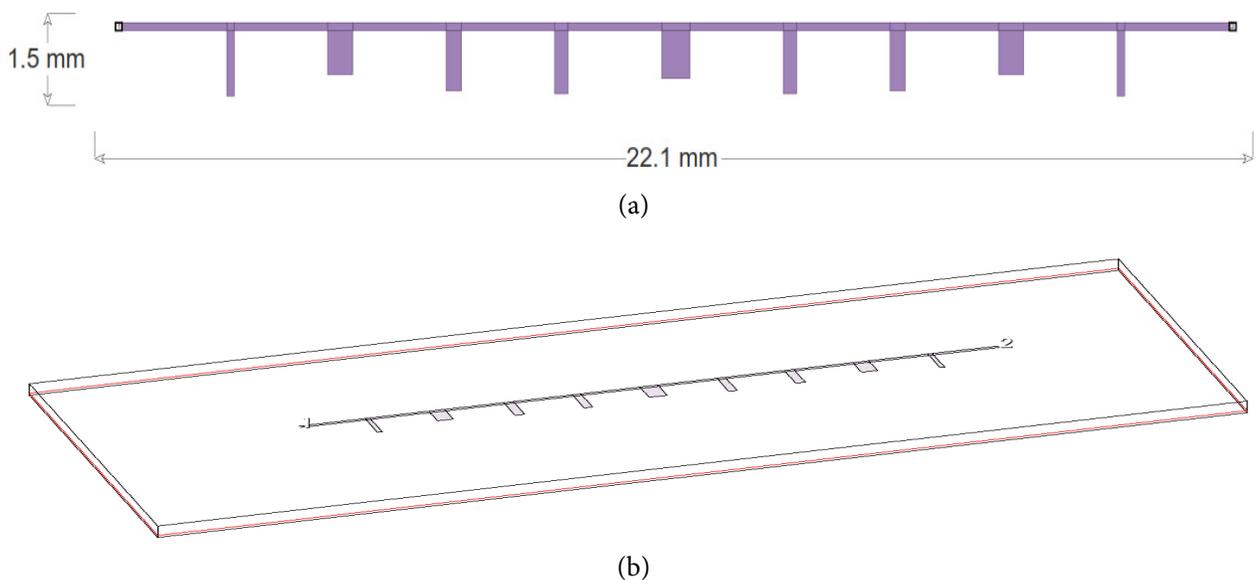
VSWR is likewise one of the estimations which utilize reflection coefficient as a part of its condition. It ought to stay consistent if there should be an occurrence of passband and shift in stopband. The correlations between the

lumped components and EM reproductions are appeared in the Figure 7(a). Distributed element microwave configuration is utilized as a part of outlining a high frequency filter with reaction delivered by lumped element filter.

There are numerous restrictions connected with it. One, the inductor and capacitor are a segment which contains parasitic components<sup>8,9,10</sup>. Two, the capacitance and the inductance gave is at the scope of Pico Farad's and Nano Henry's. Essentially, the components in charge of its outline have detriments at higher frequencies. At lower frequencies, they work well, on the grounds that at lower frequencies the inductance gave by the parasitic component is little so it goes about as a short out though the parasitic capacitor will go about as open circuit so the response is not influenced. At higher frequencies, over 1GHz range, these parasitic components demonstrate obvious and impressive impacts on the reaction<sup>11,12,13</sup>. Third, it might be difficult to actualize the circuit for all intents and purposes in light of the fact that the sought estimation of the lumped component may not be accessible, which would influence the reaction. Fourth, the lumped components circuits are not ready to give sharp cut off attributes and a sufficient attenuation to signals are available in the stopband as the frequency is an estimated product. The plan is costlier for business utilize.

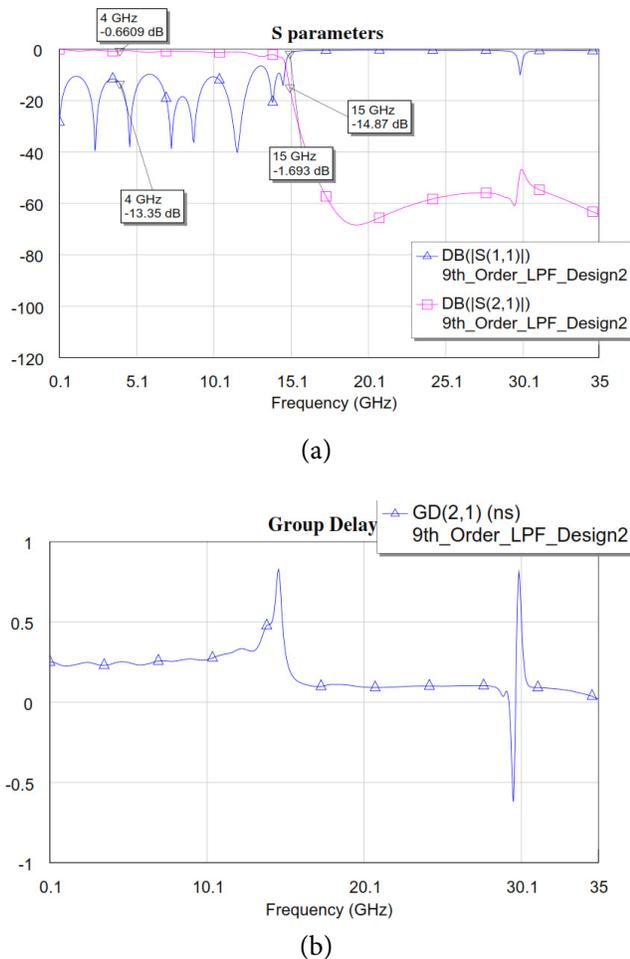
### 5.1 Electromagnetic Model

At frequency, more noteworthy than 3GHz it is obligatory for any micro strip configuration to experience EM simu-



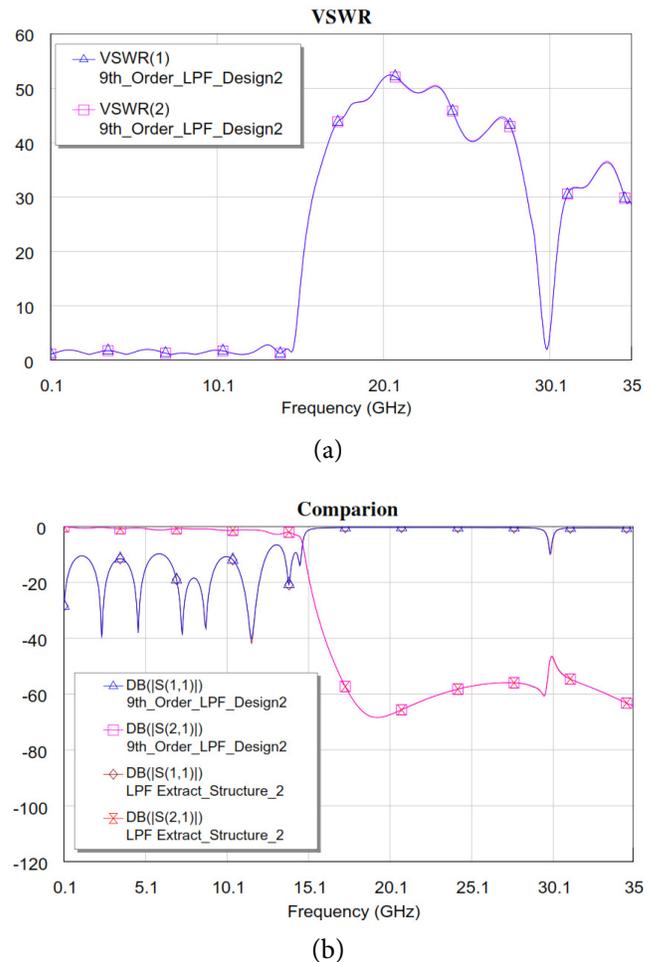
**Figure 5.** Layout overview (a) 2D layout of EM structures with dimension lines (b) Three dimensional EM structure design with enclosure box.

lation. EM simulation considers all the dielectric impact so the reaction of the schematic will lose some of its attributes and as the frequency goes increasingly elevated these reactions may change colossally<sup>5</sup>. Along these lines, at the higher frequency the EM Simulation is extremely important. At the same time, it is difficult to meet the specifications to expand the length of all resonators by associating a numerous coupled line in the middle of the two parts<sup>6</sup>. The various coupled lines can originate from a decent circuit hypothesis model, or it can be produced from an EM investigation. Increment the length of the additional line to diminish the middle recurrence of the filter. To abbreviate every one of the resonators, interface a negative length line. While not physical, circuit hypothesis and EM simulation programs have no issues in doing this investigation. Simply associate a numerous coupled line in the middle of the two parts. No compelling reason to rehash the whole EM investigation. Tune up the



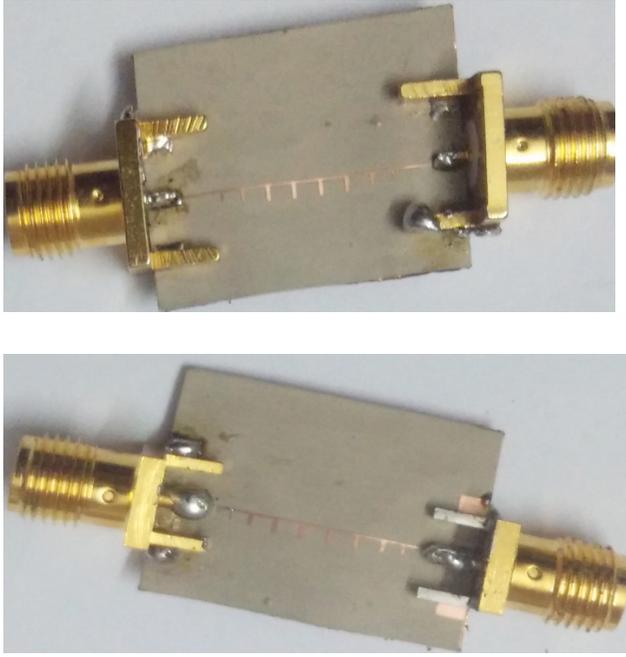
**Figure 6.** S-parameters analysis (a) Frequency response in rectangle plot of the LPF (b) Group delay responses in rectangle plot of the LPF.

design with circuit hypothesis, again iterative EM investigation to confirm the progressions, and after that create. Configuration conclusion, fast and simple: a tuneable EM investigation<sup>7</sup>. EM sight is composed utilizing EM layer= 2, an immaculate channel material, drawing layer of top copper transmitter, input port of impedance 50ohms.



**Figure 7.** Linear measurements with frequency analysis (a) VSWR response at input port VSWR (1) and output port VSWR (2) in rectangle plot of the LPF (b) Results comparison between EM simulation extract and normal design.

An EM simulation is prescribed to confirm the design exactness demonstrates the reproduction of planar 3D structures containing numerous metallization and dielectric layers. The structures can have interconnecting vias between layers or to ground. EM Sight utilizes the Galerkin Method of Moments (MoM) in the ghastly area, a to a great degree precise strategy for breaking down miniaturized scale strip, this system can give exact recreation comes about up to 100 GHz and past.

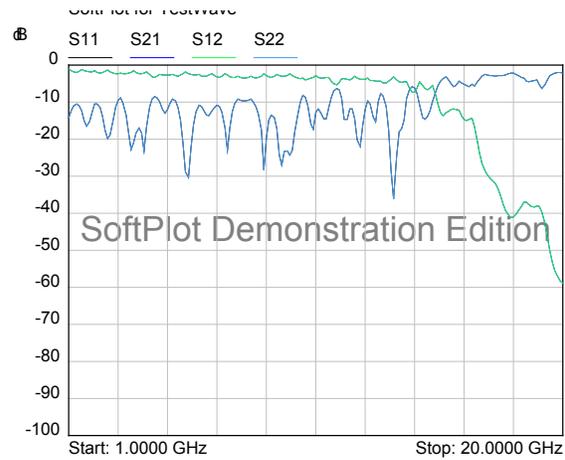


**Figure 8.** Snapshots of the final fabricated low pass filter circuit.

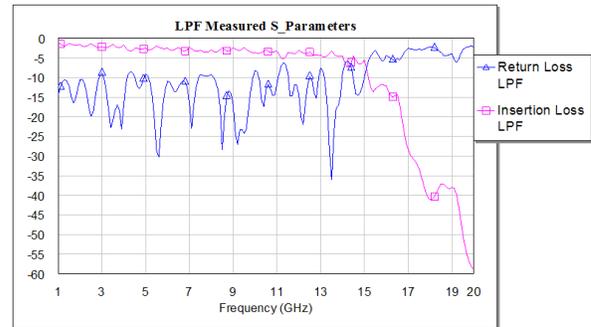
## 6. Manufacturing and Tested Results

At frequency, greater than 3GHz it is obligatory for any miniaturized scale strip configuration to experience EM simulation. EM simulation considers all the dielectric impact so the reaction of the schematic will lose some of its attributes and as the recurrence goes increasingly elevated these reactions may shift gigantically<sup>5</sup>. In this way, at the higher recurrence the EM Simulation is extremely fundamental. At the same time, it is difficult to meet the specifications to build the length of all resonators by interfacing a numerous coupled line in the middle of the two parts<sup>6</sup>. The various coupled lines can originate from a decent circuit hypothesis model, or it can be created from an EM analysis. Increase the length of the added line to decrease the centre frequency of the filter. Increment the length of the additional line to diminish the middle recurrence of the filter. To abbreviate every one of the resonators, associate a negative length line. While not physical, circuit hypothesis and EM investigation programs have no issues in doing this examination. Simply interface a various coupled line in the middle of the two parts. No compelling reason to rehash the whole EM investigation. Tune up the format with circuit hypothesis, again iterative EM investigation to confirm the progres-

sions, and after that manufacture. Design closure, quick and easy: a tuneable EM analysis<sup>7</sup>.



(a)



(b)

**Figure 9.** Frequency measurements of fabricated circuit in network analyser (a) Test wave results integrated to visual system of final fabricated circuit (b) Network analyser results of final fabricated circuit.

Once the plan of low pass filter prepared with all the frequency responses, the last stride in work was the assembling of the smaller scale strip low pass filter by the assistance of dimensional Gerber document era. Since the filter is smaller than usual and the substrate being delicate, manufacture part was done by the outsider. As considering fabricating, the procedure is to photolithography on a Printed Circuit Board (PCB)<sup>14,15,16</sup>. This is a basic and practical strategy used to produce filters in smaller scale strip innovation. It comprises of printing of plan on a straightforward sheet so as to cover this printed drawing

with the PCB.<sup>17,18,19,20</sup> Once the sheet was covered on the board, it was presented to UV illuminate to 5 to 10 minutes to expel a corrosive security layer from the board. Thus, the part of the board covered with the printed circuit won't be influenced by the UV light. Presently, uncover the board inside and the corrosive would expel copper from the parts which has been influenced by the UV light giving a copper miniaturized scale strip filter imprinted on the board. Later, with a specific end goal to take the estimations of the created filter, there was a requirement for binding the information and the output port where the test of vector system analyser is associated and the estimations are recorded<sup>21,22</sup>. The filter in the wake of being manufactured resembles this

Device is measured up to 20GHz with connector limitations and also Network Analyser calibration. It has been watched that Return Loss and Insertion Loss are fluctuating because of the Connector misfortunes furthermore uncalled for test zig as PCB thickness is little (Figure 9). Since (Figure 8) it is very small PCB thickness, in hybrid MIC technology it will be difficult to mount the connectors effectively and it's tedious.

## 7. Conclusion

The designed holds the possibility to satisfy the future needs of our innovation as has a place with the Super high recurrence band and it covers X band and a piece of Ku band which is utilized for satellite communication and microwave applications. The proposed work started with lumped element filter design with insertion loss method. This approach was not able to provide the desired amount of sharpness that should be obtained in case of stop band whereas the distributed element showed quite a level of sharp cut off characteristics which can be observed in the respective responses. The distributed element circuit is computed with the help of kuruda's identity and Richard's transform and the corresponding length and widths of the stubs are obtained. The calculated filter parameters of analysed circuits are applied to design a filter. The software platform used in this designing purpose is AWR. This software is used especially in leading industries working on MMICs which include Low Noise Amplifiers (LNAs), RF and IF filters. A filter of mentioned specifications is designed. The corresponding waveforms are obtained. The scope of responses accomplished can be known by watching the yields of the parameters, for example, Insertion Loss, Ripple Factor, Group Delay,

VSWR. At that point the design of the circulated component small scale strip filter is acquired utilizing the product itself. Also, results were gotten by manual tuning and streamlining. The advanced circuit is changed over into its comparing Gerber file (gbr/gds) which is named as the format and after that it is engraved on the substrate RT/Duroid 6010.2LM and by experiencing the manufacture steps the given circuit is outlined and tried.

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## Appendices

### Chebyshev Design formula

$\beta = \text{Incoth}(L_r/40 \log e)$  where  $L_r$  in dB corresponds to ripple in the passband

$$v = \sin(\beta/2N)$$

$$g_0 = 1; g_1 = (2/v) \sin(\pi/2N); g_m = (1/g_{m-1}) \chi \{4 \sin[(2m-1)\pi/2N] \sin[(2m-3)\pi/2N]\} / v^2 + \sin^2[(m-1)\pi/N]$$

Calculations for Lumped Element Circuit

$$L_1 = 0.21 \text{ nH}; C_1 = 0.219 \text{ pF}; L_2 = 0.712 \text{ nH}; C_2 = 0.313 \text{ pF}; L_3 = 0.8 \text{ nH}; C_3 = 0.316 \text{ pF}; L_4 = 0.717 \text{ nH}; C_4 = 0.219 \text{ pF}; L_5 = 0.21 \text{ nH}$$

Micro strip Formula

$$A = (Z/60) \sqrt{\frac{\epsilon_r + 1}{2} + \left\{ \left[ \frac{\epsilon_r - 1}{\epsilon_r + 1} \right] \right\}}$$

$$(0.23 + (0.11/\epsilon_r))$$

$$w/d = 8e^2/e^{2A} - 2$$

$$\epsilon_{eff} = (\epsilon_r + 1)/2 + (\epsilon_r - 1)/2 \chi(1/(1 + 12(d/w)))$$

$$\lambda = \frac{c}{f \sqrt{\epsilon_{eff}}}$$

$$l = \frac{\lambda}{8}$$

Calculation for micro strip

Strip Numbers Theoretical Simulated

Strip Number 1 L=1.0535 mm, W=0.1597 mm L=2 mm, W=0.126 mm

Strip Number 2 L=1.0497 mm, W=0.3776 mm L=1.035 mm, W=0.139 mm

Strip Number 3 L=90.755 mm, W=18.2794 mm L=1.783 mm, W=0.126 mm

Strip Number 4 L=1.012 mm, W=2.9404 mm L=0.696 mm, W=0.475 mm

Strip Number 5 L=1.0453 mm, W=0.6420 mm L=1.783 mm, W=0.126 mm

Strip Number 6 L=1.03525 mm, W=1.2720 mm L=0.954 mm, W=0.288 mm

Strip Number 7 L=1.05527 mm, W=0.1783 mm L=1.783 mm, W=0.126 mm

Strip Number 8 L=1.05527 mm, W=0.06522 mm L=0.997 mm, W=0.253 mm

Strip Number 9 L=99.979 mm, W=3.9682 mm L=1.783 mm, W=0.126 mm

Strip Number 10 L=1.05527 mm, W=0.6522 mm L=0.754 mm, W=0.538 mm

Strip Number 11 L=1.05325 mm, W=0.1783 mm L=1.783 mm, W=0.126 mm

Strip Number 12 L=1.03525 mm, W=1.2720 mm L=0.997 mm, W=0.253 mm

Strip Number 13 L=1.045 mm, W=0.6420 mm L=1.783 mm, W=0.126 mm

Strip Number 14 L=1.012 mm, W=2.9404 mm L=0.954 mm, W=0.288 mm

Strip Number 15 L=90.755 mm, W=18.2794 mm L=1.783 mm, W=0.126 mm

Strip Number 16 L=1.0497 mm, W=0.3776 mm L=0.696 mm, W=0.475 mm

Strip Number 17 L=1.0535 mm, W=0.1597 mm L=1.783 mm, W=0.126 mm

Strip Number 18 L=1.035 mm, W=0.139 mm

Strip Number 19 L=2 mm, W=0.126 mm