Scientific Journal of Impact Factor(SJIF): 3.134
e-ISSN(O): 2348-4470
p-ISSN(P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 2,Issue 4, April -2015

# AN EASY WAY TO DESIGN AND ANALYZE A MICROSTRIP LOW PASS FILTER USING ADS FORX-BAND

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***Abstract—****The increasing demand for radiofrequency and microwave devices in the challenging fields of communication engineering has paved way for integrating the devices and making it as tiny as possible. This demands the need for microstrip devices which occupy less space and are of much reduced size as compared to the devices made of lumped components. This paper describes the design and analysis of a micro strip Butterworth low-pass filter using insertion loss technique in X-band range that has a cut-off frequency at 10GHz with a sharp rejection of more than 100dB. This cut-off range makes it a very useful device in Radar applications. The design of this low-pass filter was simulated by using the schematic and Electromagnetic Simulation in Agilent's Advanced Design System (ADS) software tool.*

***Index Terms—****ADS, Attenuation, Butterworth, Harmonic suppression, Insertion loss, Low-pass, Microstrip, Periodic structure, X-band.*

## I. INTRODUCTION

In the present scenario, microstrip filters certainly find a verycrucial place in RF microwave applications. They are most widelypreferred for selecting or confining the microwave signalswithin specified spectral ranges. The challenges on themicrowave filters with requirements such as improvedperformance, miniature size, lighter weight, and lowercost are ever increasing with the emerging applications ofwireless communications [8].

Microstrip is an electrical transmission line, is fabricated using PCB technology and is used for microwave applications. Micro strip is much cheaper than traditional waveguide technology and is far lighter and more compact. The negatives of micro strip would be lower power handling capacity and higher losses. Since microstrip is not enclosed it is more susceptible to cross talk and unwanted radiation.

Low-pass filters are used to eliminate higher order harmonics and spurious of mixers, voltage controlled oscillators, low noise amplifiers and power amplifiers. Thus they find a very important application in the major blocks of an RF communication system. [11] Filter designs above 500 MHz are very difficult to realize using lumped components since the wavelength becomes comparable to the physical

element dimensions thus resulting in many losses and hence degrading the system performance.[3] Practical filters are therefore realized using distributed elements. In order to achieve sharp cut-off frequency, more sections are required and thus larger the order of the filter, sharper will be the frequency response of the filter. In this paper we use an order of 7 that gives a very sharp response at 10GHz thus making the filter very useful for applications where sharp rejection ratio is required.

Most of the beginners find it really difficult to design a filter using microstrip. This paper would give you an insight on how to begin with designing a filter and obtain the desired frequency response at the cut-off frequency using Agilent's Advanced Design Systems Software Simulation tool.

Let us not discuss on the literature and history of low pass microstrip filters that can be easily read through in text books and can be referred on internet. The design on lumped elements can be easily studied and analyzed using any reference guides. We can start focusing directly on the design of the microstrip filter rather than discussing about its history.

## II. FILTER SPECIFICATIONS AND DESIGN METHODOLOGY

The goal of this paper would be to design a low-pass filter whose input and output impedances are matched to 50Ω impedance and that has a cut-off frequency of 10GHz, maximally flat Butterworth filter with a sharp rejection of greater than 100dB in X-band range. We use the Alumina substrate with relative permittivity of 9.6 and the thickness of the substrate as 1.6mm. We also analyze the circuits for electrical lengths of 230º and 90º and also analyze the filter behavior when the T

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element is adopted in ADS tool.

To realize the low-pass filter using distributed elements, various transformations are used- namely Richard's transformation, Kuroda's identities and the concept of unit elements. Few steps are followed to design the filter. They are: (1) First select the normalized filter parameters to meet the design specification. (2) Replace the L and C with equivalent $\lambda/8$ transmission lines (3) Then convert the series stubs to shunt stubs using unit element concept and Kuroda's identity (4) De-normalize the transmission lines using impedance transformation. [3] [1]

First we need to know the prototype of the filter. Fig.1 shows the equivalent realizations of a general multisection LPF using normalized elements. $g_{N+1}$ represents the load and is resistor if the last element is a shunt capacitor and a conductance if the last element is a series inductor. $g_m$ is inductance for series element and capacitance for shunt element.

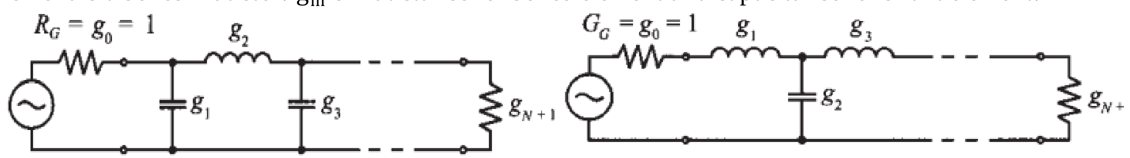



Fig.1 Realization of multi section LPF with normalized elements

TABLE 1
Values Of $g_m$ For Maximally Low Pass Filter

| N | $g_1$ | $g_2$ | $g_3$ | $g_4$ | $g_5$ | $g_6$ | $g_7$ | $g_8$ | $g_9$ | $g_{10}$ | $g_{11}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2.0000 | 1.0000 | | | | | | | | | |
| 2 | 1.4142 | 1.4142 | 1.0000 | | | | | | | | |
| 3 | 1.0000 | 2.0000 | 1.0000 | 1.0000 | | | | | | | |
| 4 | 0.7654 | 1.8478 | 1.8478 | 0.7654 | 1.0000 | | | | | | |
| 5 | 0.6180 | 1.6180 | 2.0000 | 1.6180 | 0.6180 | 1.0000 | | | | | |
| 6 | 0.5176 | 1.4142 | 1.9318 | 1.9318 | 1.4142 | 0.5176 | 1.0000 | | | | |
| 7 | 0.4450 | 1.2470 | 1.8019 | 2.0000 | 1.8019 | 1.2470 | 0.4450 | 1.0000 | | | |
| 8 | 0.3902 | 1.1111 | 1.6629 | 1.9615 | 1.9615 | 1.6629 | 1.1111 | 0.3902 | 1.0000 | | |
| 9 | 0.3473 | 1.0000 | 1.5321 | 1.8794 | 2.0000 | 1.8794 | 1.5321 | 1.0000 | 0.3473 | 1.0000 | |
| 10 | 0.3129 | 0.9080 | 1.4142 | 1.7820 | 1.9754 | 1.9754 | 1.7820 | 1.4142 | 0.9080 | 0.3129 | 1.0000 |

After deciding the prototype filter, we need to find the coefficients for the maximally flat Butterworth filter This can

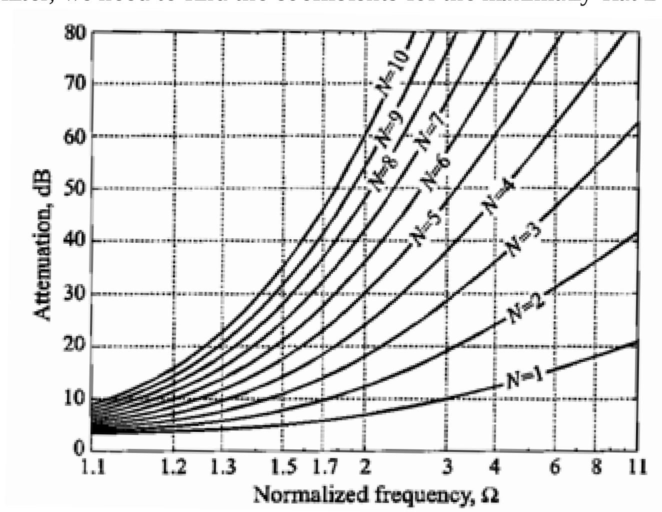



Fig.2 Attenuation vs. Normalized frequency behavior for Butterworth Low pass filter

be found from Table 1 shown below which is based on cut-off frequency of $w_c$. = 1.

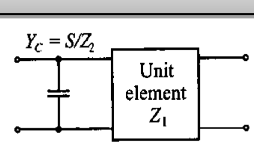
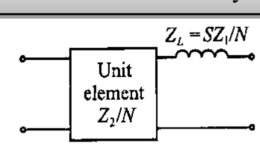
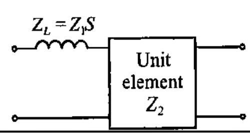
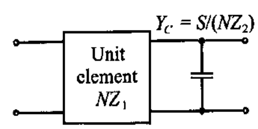
The attenuation versus normalized frequency behavior can be found for various orders of the filter as shown in fig. Prior to deciding the coefficients of the filter, order of the filter needs to be found. This is decided from the attenuation required at the desired frequency from this figure. [3

To arrive at a practical filter realization, the lumped components are converted to distributed elements. Richardson transformation gives the replacement of lumped inductors to short circuit stubs of characteristic impedance $Z_o$ = L and lumped capacitors to open circuit stubs with $Z_o$ = 1/C as seen from the equations (1) and (2).

$$j\,X_L = jwL = j\,Z_o \tan\left(\frac{\pi}{4}\frac{f}{f_o}\right) = j\,Z_o \tan\left(\frac{\pi}{4}\,\Omega\right) = S\,Z_o \quad (1)$$

$$j\,B_c = jwC = j\,Y_o \tan\left(\frac{\pi}{4}\frac{f}{f_o}\right) = j\,Y_o \tan\left(\frac{\pi}{4}\,\Omega\right) = S\,Y_o \quad (2)$$

TABLE 2
KURODA'S IDENTITIES

<table>
<tr><th>Circuit to be converted</th><th>After Kuroda's identity</th></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
</table>

To achieve practical realizable filters, it is required that we separate the transmission line components spatially. This is done by inserting the Unite elements (UEs) with electrical length $\theta = \left(\frac{\pi}{4}\frac{f}{f_o}\right)$ and $Z_o = Z_{UE}$. Along with this, Kuroda's identities are used to convert the design to more suitable andeasier implementation. The complications of realizing a series stub is minimized by this identity. Table 2 shows the Kuroda's identities used in this paper to convert series inductance to shunt stub and vice versa.

All the inductance and capacitances are their equivalent Richardson's transforms in Table 2. The value of N in the table shown above is given as in equation (3).

$$N = 1 + \frac{Z_2}{Z_1} \quad (3)$$

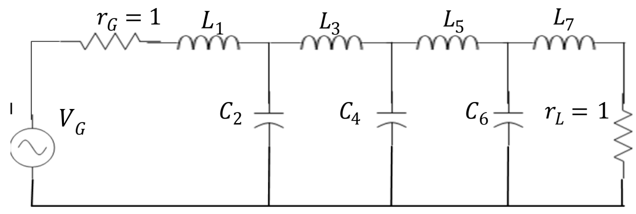
The final step in designing the filter is to de-normalize the low-pass design. There are two methods of de-normalization: Frequency and impedance transformation. In this paper, we use impedance transformation where we need to scale the filter coefficients by actual impedance of the circuit. [3]

## III. IMPLEMENTATION OF THE DESIGN

The prototype used for this paper is the second realization of fig.1. From the table showing the attenuation vs. normalized frequency, For the desired attenuation of greater than 100dB in X-band range and a cut off frequency of 10GHz, we select a low-pass filter of the order N=7. From the table showing the coefficient values, $g_m$ , we get the following values for N=7:

$g_1 = g_7 = 0.4450$,
$g_2 = g_6 = 1.2470$,
$g_3 = g_5 = 1.8019$,




$g_4 = 2.000$

Fig.3Normalized LPF of order N=7

The prototype circuit would look as shown in fig. 3 and the values of Ls and Cs are:
$Z_1 = Z_7 = 0.4450$,
$Y_2 = Y_6 = 1.2470$; $Z_2 = Z_6 = 1 / 1.2470 = 0.8019$,
$Z_3 = Z_5 = 1.8019$;
$Y_4 = 2.000$; $Z_4 = 1 / 2.000 = 0.5$

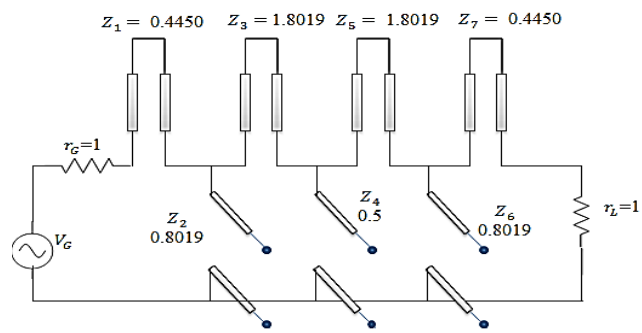



Fig. 4 Applying Richardson's Transformation

Using Richardson's transformation, the circuit becomes as shown in fig. 4. The lumped inductances are replaced by series stubs and the conductors are replaced by shunt stubs. The values of impedances are shown in the figure. To this transformed circuit with stubs, we insert unit elements in order to match the load and source and to make the filter realizable as in fig.5.

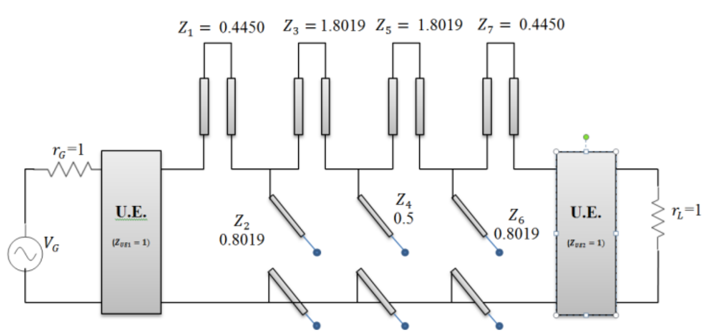



Fig.5Insertion of first set of Unit elements

Once the Unit Elements are inserted at the two ends of the filter, we apply Kuroda's identities to convert all the series stubs to shunt stubs to make the filter realizable. Till the entire circuit comprises of only shunt stubs, we keep inserting Unit Elements and then apply Kuroda's identity on both the sides of the filter. The circuit remains non-realizable if there are shunt stubs. At the end, we finally arrive at the circuit shown in fig.6.

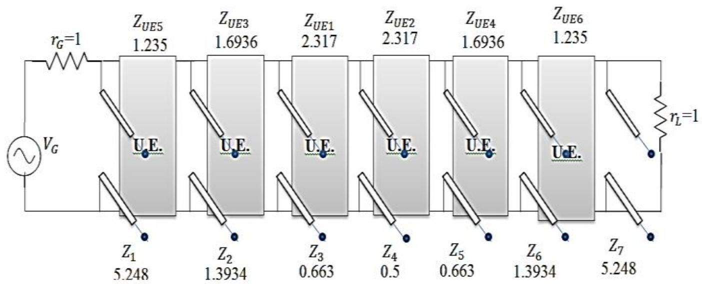



Fig.6Final Realizable LPF obtained after using Kuroda's identity

The last step is to de-normalize this obtained circuit using impedance transformation technique. This is done by scaling the elements to 50 Ω input and output impedances. The impedances obtained are shown in Table 3.

TABLE 3
IMPEDANCE VALUES OF STUBS

| **Impedance of stubs** | **Value in Ω** |
|---|---|
| $Z_1 = Z_7$ | 262.4 Ω |
| $Z_2 = Z_6$ | 69.67 Ω |
| $Z_3 = Z_5$ | 33.15 Ω |
| $Z_4$ | 25 Ω |

The design specification is for an electrical length of 230º and 90º. For 230º and 90º the widths and lengths obtained for the stubs are as shown in table 4.

TABLE 4
WIDTHS AND LENGTH VALUES FOR THE IMPEDANCES

| **Value in Ω** | **Θ=230º (in mil)** | **Θ=90º (in mm)** |
|---|---|---|
| 262.4 Ω | W=0.002023<br>L=342.717323 | W=0.000014<br>L=3.339080 |
| 69.67 Ω | W=0.475925<br>L=371.96063 | W=0.04207<br>L=3.61246 |
| 33.15 Ω | W=9.740079<br>L=349.06 | W=0.876824<br>L=3.125830 |
| 25 Ω | W=20.550315<br>L=322.992913 | W=1.589380<br>L=2.924100 |

In ADS simulation tool the above values are substituted and the substrate specifications are given in MSUB as shown in fig.7. Alumina substrate is chosen with permittivity 9.6 and thickness of substrate 1.6 mm. The S-Parameter component shows the start,stop and step frequency for the graph generated.

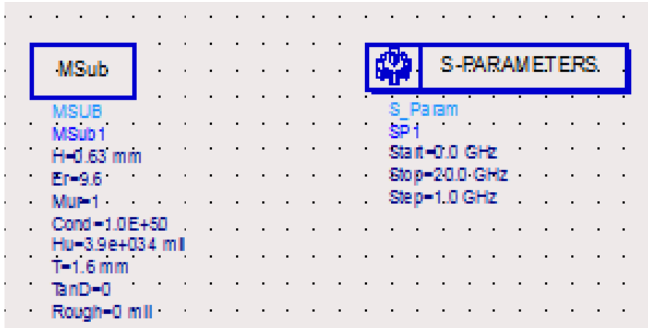



Fig. 7Substrate specifications

The final circuit for Θ=230º is shown in fig.8 where the widths and length values generated by linecalc tool is entered for the MLIN and MLOC components. The circuit is terminated to 50Ω impedance as shown.

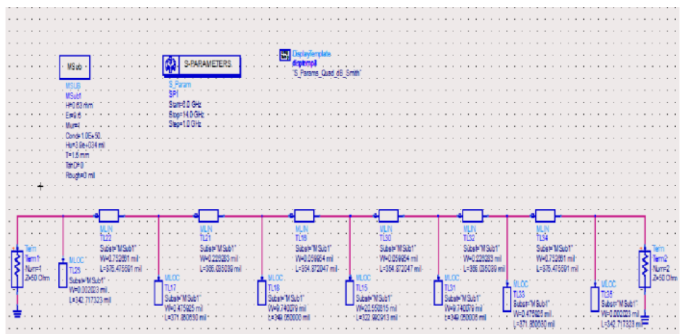



Fig. 8Final Circuit implementation in ADS for 230º

This implementation gives the output as in fig.9. It can be seen that the filter implemented passes the frequencies till the cut off frequency 10GHz and has a very sharp rejection after this frequency at about 12GHz of greater than 100dB as desired.

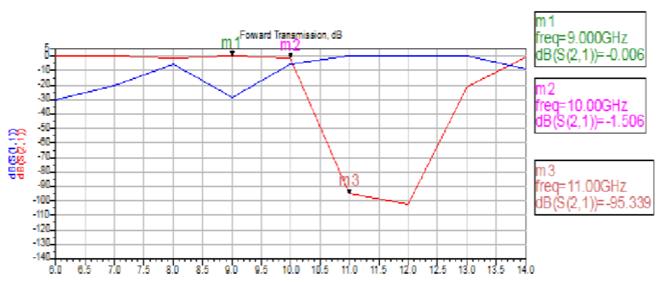



Fig. 9Output gain graph for the filter implementation

This implementation can as well be implemented using T component of ADS (MTEE) which connects the MLIN component to the shunt MLOC element. This is shown in fig. 10. This implementation shown above gives the output gain graph as shown in fig. 11. It can be seen that this implementation gives a very sharp rejection compared to the first implementation, i.e., of around 137.133dB at 13GHz. The filter passes frequencies till 10GHz cut-off frequency.

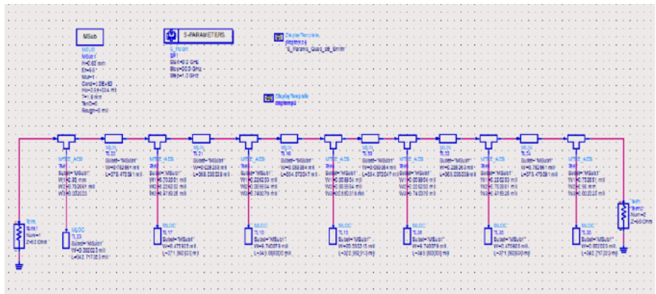


Fig. 10Implementation using MTEE element connector

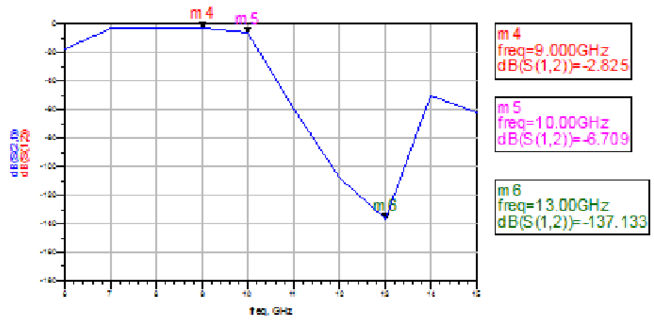



Fig. 11Output gain graph for the filter implementation with T connectors

It is seen from figure 12 that the amplitude response repeats which is the result of periodic nature of Richardson's transformation.

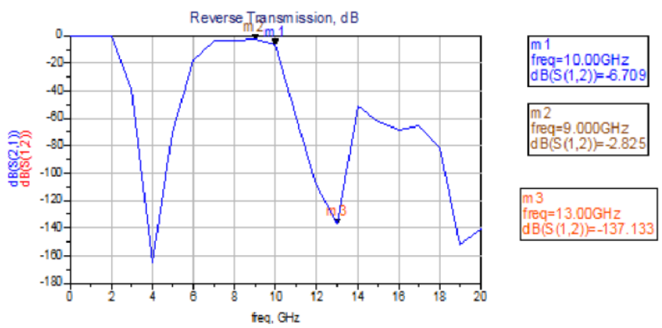



Fig. 12Output gain graph for the filter implementation with T connectors

Now we see the implementation using Θ=90º of electrical length. Fig. 13 shows the circuit output for this implementation with the widths and lengths as in Table 4. From the graph it is see that there is a very high rejection of

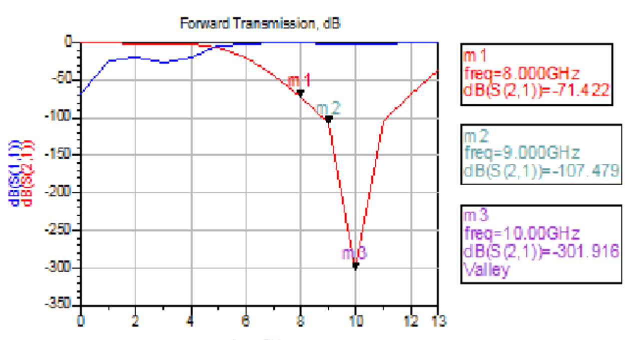



Fig. 13Output graph for the filter implementation with θ=90º

301.916 dB at 10GHz, which is the desired property shown by a low-pass filter. It rejects any frequency above 10GHz. And the return loss S11 graph I as desired for this filter.The layout the filter implementation is as shown in fig.14. The schematic without T element gives the layout as seen with the corresponding widths and lengths.

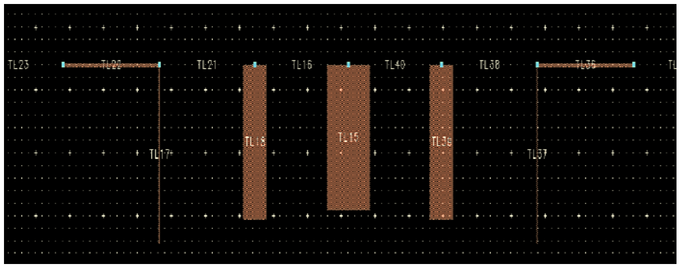


Fig. 14Layout of the LPF using Microstrip

## IV. RESULTS AND ANALYSIS

From the schematics and the corresponding graphs, it is seen that use of insertion loss method for the microstrip filter implementation gives a perfect property of low insertion loss in the passband and infinite attenuation in the stop band. Also, the use of distributed elements has given a sharper rejection at the cut off frequency for various specifications in this paper. The amplitude response for the filter in fig. 12 shows that the filter repeats itself, which is according to the periodic nature of the Richardson's transformation applied. There is a very sharp rejection of around 301.916 dB at the cut-off frequency for the schematic with a length of $\lambda/4$, 137.133 dB for the schematic of T network at 13GHz and a rejection of 101dB at 12GHz for the schematic of electrical length of 230º

## V. CONCLUSION

In this paper, a microstrip low-pass filter has been designed using insertion loss method with two electrical lengths of 230º and 90º ($\lambda/4$) transmission lines. The use of Richardson's transformation gave repeating characteristics of low-pass filter amplitude response. The rejection obtained at around the cut-off frequency of 10GHz was very sharp with highest for the schematic with electrical length of 90º. This analysis technique is very useful in suppressing harmonics and spurious frequencies in the stopbandand can be widely used for radar applications. The detailed steps for the microstrip filter implementation are explained. The software tool employed the simulation of the low-pass filter is Agilent's ADS tool, which gives the outputs of all the proposed schematics. The layout of the schematic is generated using the tool which can be fabricated and verified for the same results. This is the future scope of this paper.

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