

# DESIGN AND SIMULATION OF PRINTED MICRO STRIP LOW PASS FILTER BASED ON THE ELECTROMAGNETIC MODELS 18GHZ

## PRINTED MICROSTRIP LOWPASS FILTER USING X-MODELS

Arfiya Kouser<sup>1</sup>, Pramod K B<sup>2</sup>, Kumaraswamy H.V<sup>3</sup>, Jayaraj N<sup>4</sup>

<sup>1</sup>Department of Electronics and Communication Engineering, The Oxford College of Engineering, Bangalore, Karnataka, India

<sup>2</sup>Department of Electronics Engineering, Jain University, Bangalore, Karnataka, India

<sup>3</sup>Department of Telecommunication, R. V. College of Engineering, Bangalore, India

<sup>4</sup>Department of Electronics and Communication Engineering, The Oxford College of Engineering, Bangalore, India

### Abstract

This paper presents the Design, Simulation and characterization of Printed Micro strip Low Pass Filter based on 15 mil Alumina substrate. Simulations show a comparison between a pure EM simulation with EM Sight and a more efficient hybrid approach that combines EM analysis (using X-Models) with conventional circuit simulations and both approaches match the measured data. Furthermore, the proposed paper has four different low pass filter designs, lumped design; basic designs uses only micro strip lines; advanced design uses multiple edge coupled micro strip lines, EM sight design provides a very sharp cut-off frequency response with low insertion loss, results having great agreement with excellent correlation. Tuning and Optimization of the design is carried out using AWR Microwave office tool.

**Keywords**— EM sight, AWR, MMIC, X-Models, I-Filter

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## 1. INTRODUCTION

A low-pass filter (LPF) offers easy passage to low-frequency signals and difficult passage to high-frequency signals. It is highly demanded in modern microwave communication systems, especially in wireless and mobile communications in order to suppress harmonics and spurious signals [1]. The amount of insertion loss and phase shift encountered by a signal passing through the filter and the amount of rejection of an undesired signal is a function of the filter design. Filters are networks that process signals in a frequency-dependent manner and they can be explained by examining the frequency dependent nature of the impedance of capacitors and inductors. With the advent of printed-circuit board (PCB) technology, microwave system also develop a strip line components and system with a technique of integrated circuit, called MMIC. It is a type of Integrated circuit device that operates at microwave frequencies (300MHz - 300GHz). Inputs and outputs on MMIC devices are frequently matched to a characteristic impedance of 50 ohms. In advanced filter design, micro strip edge-coupled filters are used, they have advantages such as easy design procedures and simple integration into circuits. A general structure of parallel-coupled (or edge-coupled) micro strip filters that use half-wavelength line resonators. They are positioned so that adjacent resonators are parallel to each other along half of their length. This parallel arrangement gives relatively large coupling for a given spacing between resonators, therefore this

filter structure is particularly convenient for constructing filters having a wider bandwidth as compared to the structure for the end coupled microstrip filters. For the creation of EM waves we need specific structures with time-varying charges and currents. At high frequencies hollow waveguides are used to transmit energy because they do not radiate at any frequency. There are new design methodologies for EM analysis such as topological partitioning, functional partitioning, and tuning methodology. In this filter design topological partitioning method is applied since it has advantage of gain in speed and also one can make certain changes very quickly.

This paper deals with the designing and fabrication of microstrip low pass filters. The designing is done using AWR Microwave Office simulation program developed by Applied Wave Research USA. This is a user-friendly software with all of the capabilities necessary for the accurate modelling and design of microwave components. It contains a linear, harmonic-balance, time domain, EM simulation, physical layout and includes linear and nonlinear noise analysis and can model nonlinear behavior existing in microwave devices.

## 2. I-FILTER

I-Filter is specifically developed for synthesis of lumped element and distributed filters, it brings useful filter synthesis to the integrated desktop. The module plugs directly into the

Microwave Office design environment and is integrated as a wizard within the AWR Design Environment (AWRDE), it is completely integrated into AWRDE and easily accessible. Limits for minimum line width and minimum line spacing are specified in iFilter - which are typical dimensions for modern printed circuit board processes.

I-Filter also provides the ability to adjust secondary parameters in real time and see the results, in the case of hairpin filters, includes adjustment of the filter's nominal impedance. The short connecting lines between the resonators (in the U-turns), will have this impedance and the resonator lines will share this line width. If the area is assumed to be limited to 0.36 x 0.30 inches, the nominal impedance of the resonators can be adjusted to examine the effects of line width on performance and required area. Additionally, I-Filter performs accurate synthesis through electromagnetic verification with for instance, AWR's AXIEM 3D planar EM simulator. This is especially important when designing distributed filters.

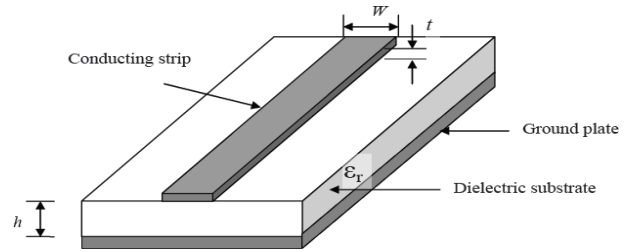


Fig 2: A basic Microstrip structure

The effective dielectric constant in terms of W (width of the Microstrip), h (height of the substrate) and ε<sub>r</sub> (relative dielectric constant) given by Hammerstad and Jensen [11] is:

$$\epsilon_{re} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left\{ \frac{1}{\sqrt{1 + \frac{12h}{W}}} \right\} \tag{1}$$

Characteristic impedance of the microstrip line is given by

$$Z_c = \frac{1}{c\sqrt{C_a C_d}} \tag{2}$$

Where c is the velocity of electromagnetic waves in free space c=2.99x10<sup>8</sup> m/s. The accuracy of Z<sub>c</sub>√ε<sub>re</sub> is better than 0.01 %.

4. INITIAL LUMPED DESIGN:

Insertion loss method is used in designing lumped element filter. It provides ways to shape pass band and stop band of the filter, although its design theory is much more complex. The order N of a filter can be found as follows:

$$N = \frac{\cosh^{-1} \sqrt{(10^{0.1 \times IL} - 1) / (10^{0.1 \times \alpha} - 1)}}{\cosh^{-1}(\omega / \omega_c)} \tag{3}$$

The filter design specification has cut-off frequency of 18GHz. From the above equation order of the filter is found to be 7. For this design prototype parameters are as follows:

- g<sub>0</sub> = g<sub>8</sub> = 1
- g<sub>1</sub> = g<sub>7</sub> = 1.3722
- g<sub>2</sub> = g<sub>6</sub> = 1.3781
- g<sub>3</sub> = g<sub>5</sub> = 2.2756
- g<sub>4</sub> = 1.5001

5. IMPLEMENTATION:

5.1 Basic Design:

Basic filter is designed using microstrip lines such as MLIN, MLEF and MTEE\$ microstrips which are available in AWR tool. Input/Output ports are matched to 50ohms, these are also available in AWR tool. Microstrip has relative dielectric constant, ε<sub>r</sub>=9.8, substrate thickness H=15mil, conductor

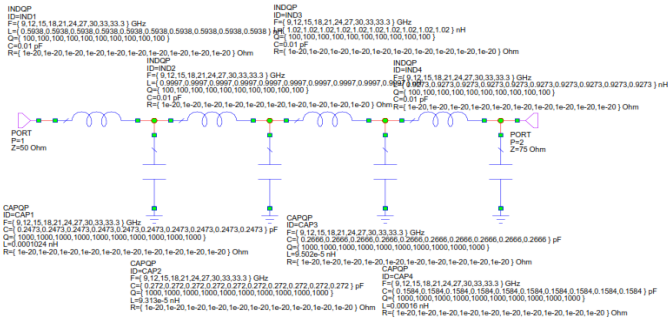


Fig 1: Schematic showing ifilter design

2.1 Features:

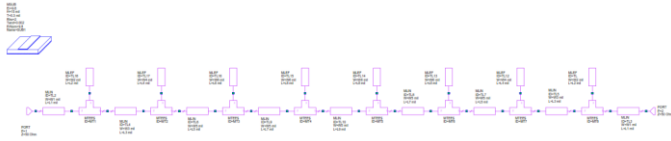
- Simplicity.
- Power – ideal or real, lumped or distributed, wide variety
- Ease-of-use.
- Integrated – works directly with AWR layout, EM, and optimization.
- Upgradeable – options for your design needs.

3. MICROSTRIP

Microstrip line consists of thin strip conductor suspended over ground plane by a low-loss dielectric material. Waves traveling in microstrip line not only travels in the dielectric medium they also travel in the air media above the microstrip line. Thus they don't support pure TEM waves, rather it supports quasi TEM approximation.

thickness  $T=0.3\text{mil}$ , metal bulk resistivity normalized to gold  $\rho=2$  and loss tangent dielectric,  $T_{\text{and}}=0.002$ . Basic filter design has insertion-loss of  $-1.0896\text{dB}$  and return loss of  $-42.441\text{dB}$  at  $18.95\text{GHz}$ .

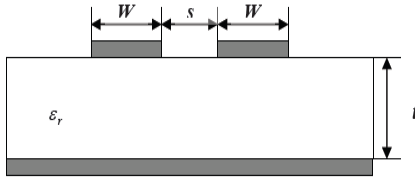
**FILTER BASIC SCHEMATIC**



**Fig 3:** Basic schematic of LPF

**5.2 Advanced Filter Design:**

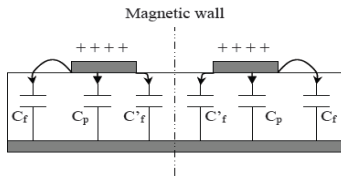
Advanced filter is designed using edge coupled microstrip line. The following figure shows the cross section of a coupled line. They support two modes of excitation, even and odd mode.



**Fig 4:** A Coupled Line Structure.

**5.3 Even Mode:**

In even mode excitation both the microstrip coupled lines have the same voltage potential resulting in a magnetic wall at the symmetry plane.



**Fig 5:** Quasi-TEM, Even Mode of a Pair of Coupled Microstrip Lines

The Odd mode Impedances can be calculated using the following formulae

$$(Z_{oe})_{j,j+1} = \frac{1}{Y_0} \left[ 1 + \frac{J_{01}}{Y_0} + \left( \frac{J_{01}}{Y_0} \right)^2 \right] \tag{4}$$

Where,

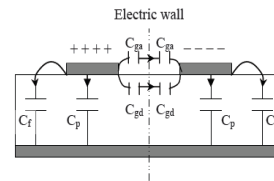
$$\frac{J_{01}}{Y_0} = \sqrt{\frac{\pi\Delta}{2g_0g_1}} \tag{5}$$

$$\frac{J_{j,j+1}}{Y_0} \Big|_{j=1 \text{ to } n-1} = \frac{\pi\Delta}{2\omega_1' \sqrt{2g_jg_{j+1}}} \tag{6}$$

$$\frac{J_{n,n+1}}{Y_0} = \sqrt{\frac{\pi\Delta}{2g_n g_{n+1}}} \tag{7}$$

**5.4 Odd Mode**

In odd mode the coupled microstrip line possess opposite potential. This results into an electric wall at the symmetry. The following cross section diagram shows the same.



**Fig 6:** Quasi-TEM, Odd Mode of a Pair of Coupled Microstrip Lines

The Odd mode impedances can be calculated as same as Even mode impedances using the following formulae.

$$(Z_{oo})_{j,j+1} = \frac{1}{Y_0} \left[ 1 - \frac{J_{01}}{Y_0} + \left( \frac{J_{01}}{Y_0} \right)^2 \right] \tag{8}$$

Where,

$$\frac{J_{01}}{Y_0} = \sqrt{\frac{\pi\Delta}{2g_0g_1}} \tag{9}$$

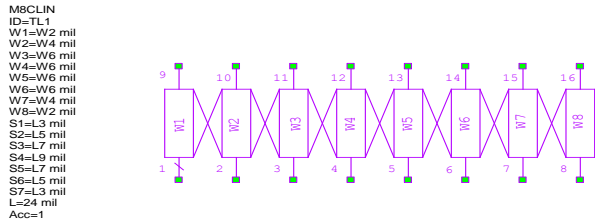
$$\frac{J_{j,j+1}}{Y_0} \Big|_{j=1 \text{ to } n-1} = \frac{\pi\Delta}{2\omega_1' \sqrt{2g_jg_{j+1}}} \tag{10}$$

$$\frac{J_{n,n+1}}{Y_0} = \sqrt{\frac{\pi\Delta}{2g_n g_{n+1}}} \tag{11}$$

**Table 1:** Odd and Even Impedances values obtained from the admittance inverter parameters

J	Even – mode impedance (Zoe) <sub>j, j+1</sub>	Odd – mode impedance (Zoo) <sub>j, j+1</sub>	Characteristic Impedance Zo Zo <sup>2</sup> ≈ (Zoe)(Zoo)
0	78.777	37.9177	54.6514
1	59.7244	43.0544	50.7089
2	57.3072	44.3672	50.4238
3	56.9688	44.5688	50.3888

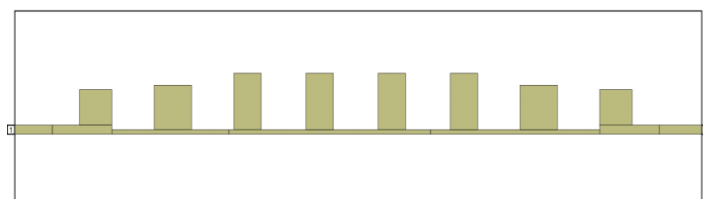
Applied Wave Research has developed accurate advanced numerical models for microstrip edge coupled lines, which are labelled MXCLIN elements. “X,” which can range from 3 to 16, represents the number of parallel edge-coupled microstrip lines. Figure.7 shows AWR MXCLIN with 8 coupled lines.



**Fig 7:** AWR MXCLIN advanced numerical element model where X=8.

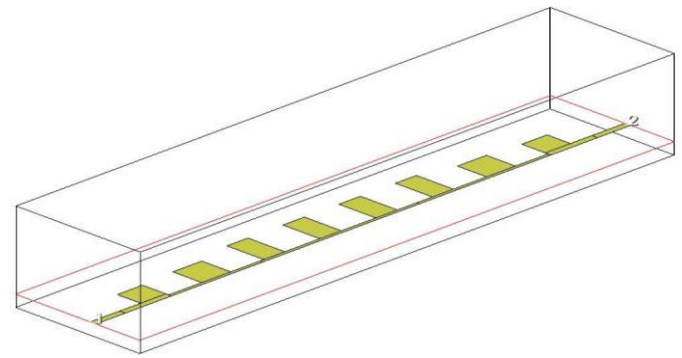
**5.5 Electromagnetic Model:**

At frequency greater than 3GHz it is compulsory for any microstrip design to undergo EM simulation. EM simulation considers all the dielectric effect so the response of the schematic will lose some of its characteristics and as the frequency goes higher and higher these responses may vary enormously. So at the higher frequency the EM Simulation is very necessary simultaneously it is difficulty to meet the specification. To increase the length of all resonators by connecting a multiple coupled line in between the two halves. The multiple coupled lines can come from a good circuit theory model, or it can be generated from an EM analysis. Increase the length of the added line to decrease the center frequency of the filter. To shorten all the resonators, connect a negative length line. While not physical, circuit theory and EM analysis programs both have no trouble doing this just connect a multiple coupled line in between the two halves. No need to repeat the entire EM analysis. Tune up your layout with circuit theory, do one more EM analysis to confirm the changes, and then fabricate. Design closure, quick and easy: a tunable EM analysis.



**Fig 8:** EM sight filter.

EM sight is designed using EM layer= 2, a perfect conductor material, drawing layer of top copper conductor, input port of impedance 50ohms and reference plane distance= 30mil, and output port of impedance 50ohms and reference plane distance= 34mil.

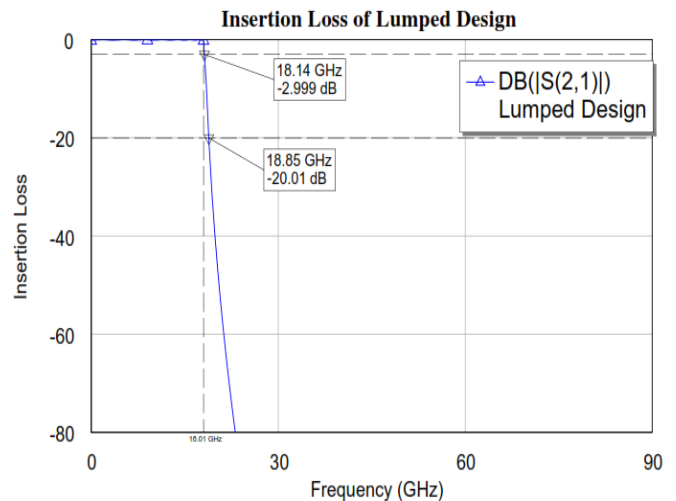


**Fig 9:** Three dimensional EM Structure design with enclosure box

An EM simulation is recommended to confirm the design accuracy fig 9 shows the simulation of planar 3D structures containing multiple metallization and dielectric layers. The structures can have interconnecting vias between layers or to ground. EMSight uses the Galerkin Method of Moments (MoM) in the spectral domain, an extremely accurate method for analyzing micro strip, this technique can provide accurate simulation results up to 100 GHz and beyond.

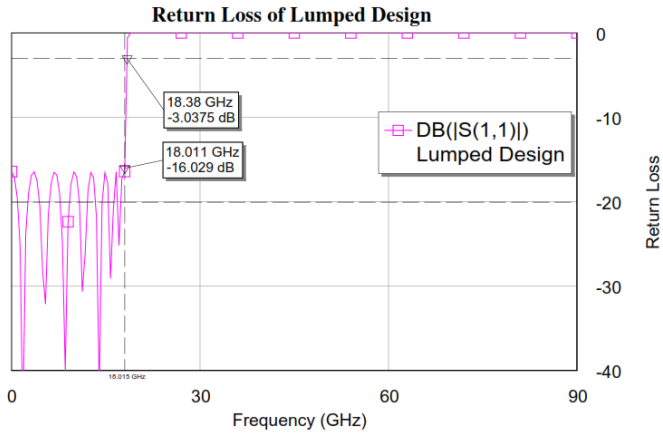
**6. RESULT AND ANALYSIS:**

Insertion loss plot of lumped element low pass filter is shown in figure 10. Here the insertion loss at 18.14GHz is -2.999dB.



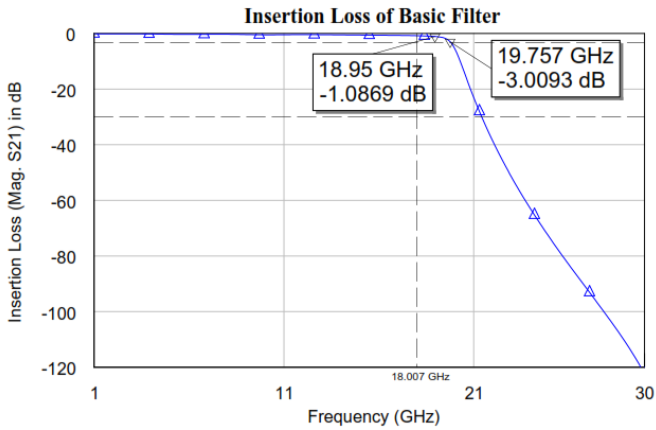
**Fig 10:** Insertion loss of Lumped design.

Return loss of lumped element low pass filter is shown in fig 11. Here the return loss at 18.011GHz is -16.029dB.



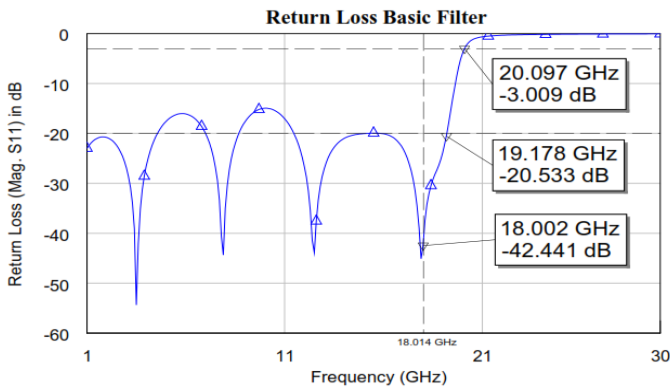
**Fig 11:** Return loss of Lumped design

Insertion loss of Basic low pass filter design is shown in fig 12. Here the insertion loss at 18.95GHz is -1.0869dB.



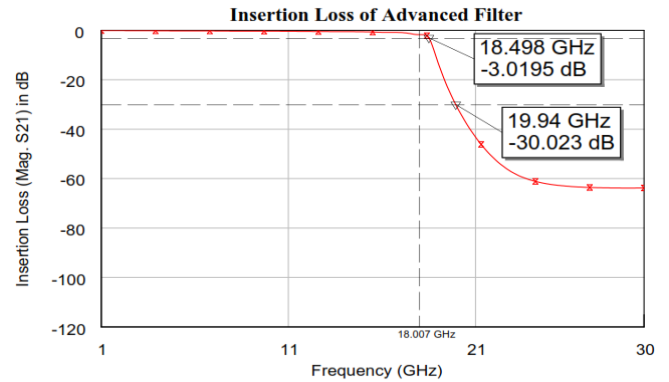
**Fig 12:** Insertion loss of Basic low pass filter.

Return loss of basic low pass filter is shown in fig 13. Here the return loss at 18GHz is -42.441dB.



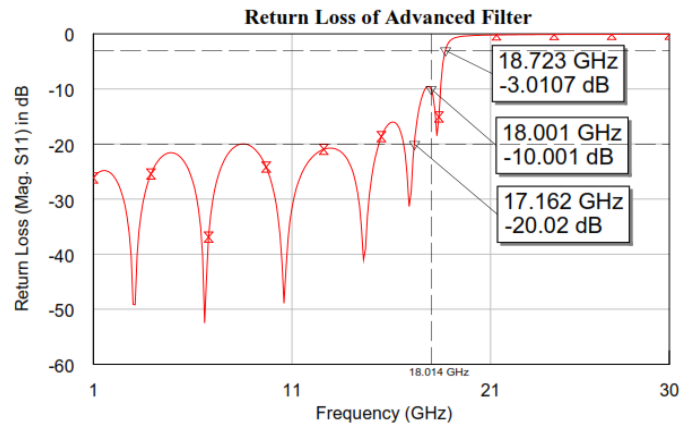
**Fig 13:** Return loss of basic low pass filter.

Insertion loss of advanced low pass filter is shown in fig 14. Here the insertion loss at 18.498GHz is -3.019dB.



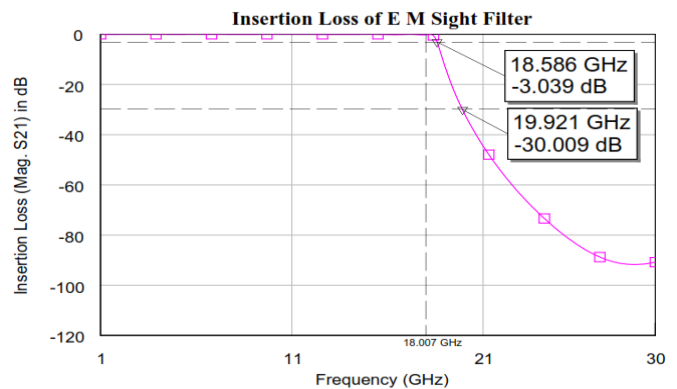
**Fig 14:** Insertion loss of advanced low pass filter.

Return loss of advanced low pass filter is shown in fig 15. Here the return loss at 18GHz is -10.001dB.



**Fig 15:** Return loss of advanced low pass filter.

Insertion loss of EM sight low pass filter is shown in fig 16. Here the insertion loss at 18.586GHz is -3.039dB.



**Fig 16:** Insertion loss of EM sight low pass filter.

Return loss of EM sight low pass filter is shown in fig 17. Here the return loss at 18.124GHz is -20dB.

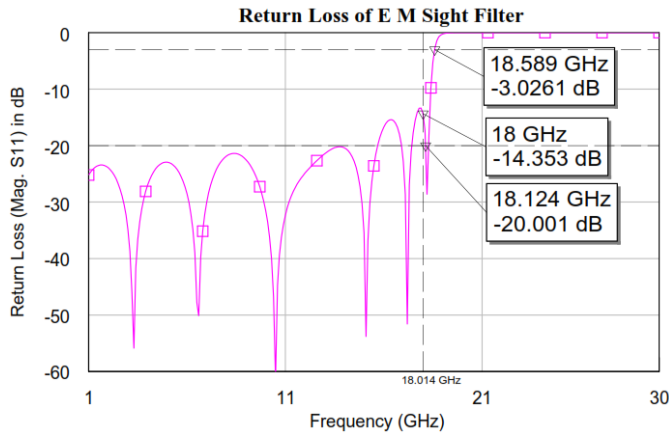


Fig 17: Return loss of EM sight low pass filter.

VSWR comparison between iFilter, basic LPF, advanced LPF and EM sight design is shown in fig 18. The advanced design and EM sight design having very good VSWR value. Variation of VSWR curve is crazy in Lumped design which is shown in fig 19.

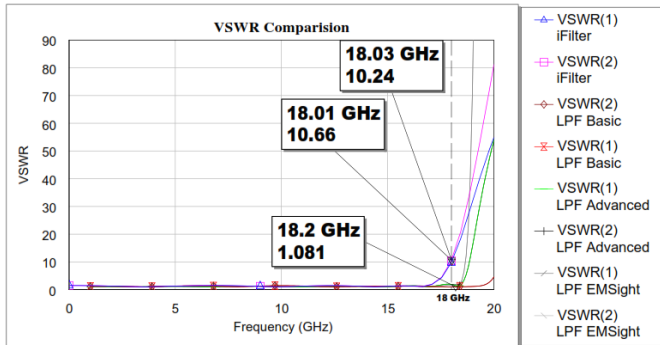


Fig 18: VSWR comparison.

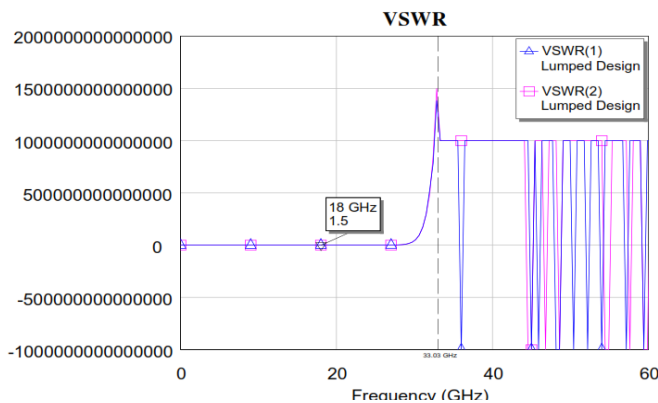


Fig 19: Variation of VSWR in lumped design.

7. SUMMARY

Table 2: Characteristics Comparison of all design types

Design	Frequency	Insertion loss	Return loss	VSWR
Lumped design	18.14GHz	-2.996dB	-16.067dB	1.5
Measured filter	18.659GHz	3.0573dB	18.458dB	10.24
Basic design	18.95GHz	1.0869dB	42.441dB	1.029
Advanced design	18.498GHz	3.0195dB	10.001dB	1.826
EM sight design	18.586GHz	-3.039dB	20.001dB	1.081

Table 3: Parameters Comparison with previous designs

References	[2]	[7]	[10]	This work
Order of the filter	5	4	3	7
Cut-off frequency	2 & 3GHz	7.7GHz	1990MHz	18.95GHz
Insertion-loss	-0.6dB	18dB	<0.6dB	1.0869dB

8. CONCLUSIONS

This paper shows the design of 18GHz printed micro strip low pass filter on 15 mil Alumina substrate and simulation shows the comparison between lumped , basic , advanced and EM sight design successfully. The "LPF EMSight" shows the filter in the EMSight 2.5D electromagnetic simulator, which is viewed in three dimensions. This compares very closely to measured data. The "LPF Advanced" schematic makes use of advanced X-Models (EM-based models), coupled lines and other linear schematic elements, including a substrate definition. This too gives excellent correlation. The "LPF Basic" indicates potential errors in schematic entry with the associated errors in results. A good comparison is achieved among all four designs and validated through circuits and EM sight in AWR MWO Environment, furthermore particular design can be chosen based on tradeoffs.

The design will be useful for Satellite and PTP Communications Links, Marine and Pleasure Craft Radar, Port Vessel Traffic Services etc...



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