Design & Optimization of Stepped Impedance Low Pass Filter using ADS Simulation tool at 5 GHz

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Abstract- **This paper presents a microstrip stepped impedance low pass filter with low insertion loss and wide pass band. Microstrip filters are used widely to fulfill demands for microwave systems and to solve the emerging telecommunication challenges in terms of performance, size and cost. Radio Frequency (RF) filters operating in the microwave frequency range which are needed for applications like radar and satellite communications while the C band is used for long-distance radio telecommunications. These applications demand high performance filters that can contribute as little as possible to a system's size and cost. In this paer stepped impedance filter is planned to design and optimize at a center frequency of 5 GHz and operating between 4 GHz to 6 GHz range of frequencies. This paper describes a common design technique for micro strip low pass filters that are used to attenuate microwave frequency signals beyond the cutoff frequency. Advanced Design System (ADS 2011_10) simulation tool is used to simulate a prototype of low pass filter using lumped and distributed component with different dielectric materials like FR4 and alumina for using at 5 GHz cut off frequency.**

Keyword- **LP, Stepped impedance, max flat response, Agilent ADS.**

I. INTRODUCTION

A low pass filter is defined as a filter that can passes low frequency signals and attenuates/ cut the amplitude of signals with frequencies higher than the cutoff frequency. It can be used as hiss filter for audio purpose, as anti-aliasing filter for conditioning signals and as digital filter for smoothing data, acoustic barriers. The actual amount of attenuation for each frequency varies depending on specific filter design. It is sometimes also known as high-cut filter, or treble cut filter in audio applications. A low-pass filter is the opposite of a high-pass filter. A band-pass filter is a combination of a low-pass and a high-pass. The rapid growth in commercial microwave communication systems had been developed. Hence microstrip technology play important role in many RF or Microwave applications. Emerging application such as wireless communication continue to challenge RF/Microwave filters with ever requirement higher performance, smaller size, lighter weight and lowest cost. The broadband wireless access (BWA) is an important issue in current developments of the modern wireless communication system. To meet this trend, the low pass filters with relatively wide bandwidth are frequently required. Stepped impedance is commonly called Hi-Z, Low-Z Filters. Its electrical performance is inferior to other implementations so often used to filter unnecessary out-of-band signals.

In high speed PCB designs, signals must be routed from one part to another with the characteristics of minimal distortion and better response so in this microstrip designs are used, thus tried to avoid high cross talk and radiation losses. Microstrip transmission line is the most used planar transmission line in Radio frequency (RF) applications. As other transmission line in RF applications, microstrip can also be exploited for designing certain components, like filter, coupler, transformer or power divider.

Microstrip lines are fabricated as a flat strip of metal and the insulating material forms a dielectric between two parallel plnes i.e. metal and ground plane. The characteristic impedance of the metal strip is calculated by the width of the strip, the thickness of the substrate and the permittivity of the substrate. The dielectric constant can affect the response of the filter designed with the dielectric material. Hence in this paper, an attempt is made to compare and find out the best response among the responses obtained using different materials.The design is performed in Advanced Design System software.

Low pass filter could either be realized using lumped components or distributed components. Lumped components consists of discrete elements like inductors, capacitors etc. Distributed elements consist of transmission line sections which simulate various inductance and capacitance values. It is hard to realize filters with lumped elements because at frequency above 1GHz, the dimensions of the electronic components are comparable with the wavelength of the signal as a result of which there could be distribute effects[1]. However transmission line filters are easy to implement and are compact at this frequency.

II. LOWPASS CONFIGURATION AND DESIGN PROCEDURE

In microwave filter, we can design and simulate Low pass lumped element filter circuit sections by way of coaxial lines, waveguides, microstrips lines or cavity resonator etc. [2]

The equivalent values of lumped elements can be derived in terms of frequency. [3]

In this paper, we use insertion loss method for designing lowpass filter. Basic design steps of lowpass filter operating at random frequency are designed with the prototype low pass filter by using following steps:

i): Impedance transform

ii): Frequency transformer

iii): Normalization and simulation of elements by steps of microstrip

iv): Designing prototype lowpass filter with specified frequency

v): Transformation of this low pass prototype filter to the desired filters (bandpass, bandstop, highpass or lowpass) with desired centre frequency and band-width.

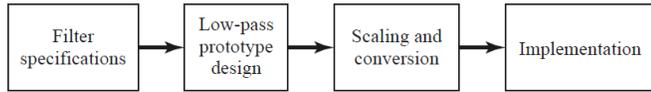vi): Realization of filter by using sections of microwave transmission lines.

Fig 3: Stepped impedance implementation

Fig.1: Design flow diagram.

Fig 4: Microstrip layout of final filter

Filter realization: These stepped impedance low pass filters is realized in series combination of high pass and low pass impedance sections of microstrip lines. The prototype low pass stepped impedance filter is shown below.
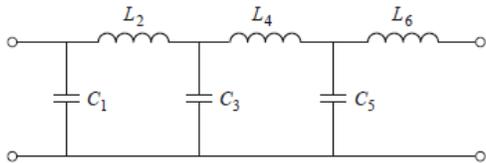

Fig.2: Realization of filter using LC components.

Fig.2 gives the circuit implementation of the filter by means of concentrated components like inductors (L) and capacitors (C). The component values can be calculated with the following rules-

Normalized frequency $= (\frac{1}{\Delta}(\frac{w}{wc} - \frac{wc}{w}))$ 1

Where w = 5.2 GHz
And wc= 5 GHz

$|\frac{w}{wc}| - 1 = 0.921538$ …....2

This low pass filter order is 6 for insertion loss >30 db at 5.2 GHz[1]. The normalized values are as follows:

g1 = 0.517=C1, g2 = 1.414=L2, g3 = 1.932=C3, g4 = 1.932= L4, g5 =1.414= C5, g6= 0.517 = L6

The value of Lumped elements is decided by normalized element values as shown above. The filter is realized by following the steps mentioned in fig.1. At the left the source is connected and the load is connected to the right. The filter could be reversed without affecting the response.
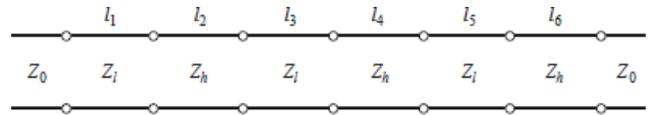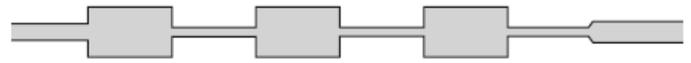
The series inductor can be replaced by high impedance line section Zo = Z_h and shunt capacitor can be replaced with low impedance line section Zo = Z_l. the ratio Z_h/Z_l should be as large as possible for the better response to be obtained. The range for Z_h and Z_l are beteween 100 to 150 Ω and 10 to 15Ω respectively. In this design, Z_h is 120Ω and Z_l is 20Ω.

$\beta l = \frac{LR_0}{Zh}$ (Inductor) ……………… (3)

$\beta l = \frac{CZ_l}{R_0}$ (Capacitor) …………….… (4)

Equation (3) and (4) are used to replace series inductors and shunt capacitors with sections of low and high impedance microstrip lines. The required physical lengths $\beta l \, (degree)$ and physical length Li and width Wi of microstrip lines are shown in table.

In this paper, we used material FR4 with two dielectric constant 4.2 and 4.34 and alumina with constant 9.9. Here 3 tables show material with electric lengths and widths of the required stepped impedance low pass filter. The length of each stage is chosen to be Li (Li is the guided wavelength), which corresponds to an electric length (Eeff) of 90^0. Using Line Calc tool in ADS, Li and Wi can be calculated. To match with the 50 ohm circuit, MLIN (Microstrip Line) components are added to both sides of the filter whose characteristic impedance is 50 ohms. The length and width of the transmission line sections are found using the Line Calc tool.

Section	Zi or Z_L or Z_H (Ω)	βl_l or βl_c	Wi	Li
1	20	11.84	11.2683930	1.04339310
2	120	33.8	0.43202524	3.34374700
3	20	44.3	11.2683930	3.90391100
4	120	46.1	0.43202524	4.56055560
5	20	32.4	11.2683930	2.85523110
6	120	12.3	0.43202524	1.21680760

Table 1: FR4 with dielectric constant 4.2 and its respective Wi & Li for filter

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Section	Z_i or Z_L or Z_H (Ω)	βl_l or βl_c	Wi	Li
1	20	11.8	1.9805633	1.1282850
2	120	33.8	0.0864338	3.5922790
3	20	44.3	1.9805633	4.2358499
4	120	46.1	0.0864338	4.8995295
5	20	32.4	1.9805633	3.0980031
6	120	12.3	0.0864338	1.3072497

Table 2: FR4 with dielectric constant 4.2 and its respective Wi & Li for filter

Section	Z_i or Z_L or Z_H (Ω)	βl_l or βl_c	Wi	Li
1	20	11.8	1.055982292	0.70779135
2	120	33.8	0.015411340	2.34556712
3	20	44.3	1.055983390	2.65721670
4	120	46.1	0.015411340	3.19913149
5	20	32.4	1.055983392	1.94342700
6	120	12.3	0.015413405	0.85356400

Table 3: Alumina with dielectric constant 9.9 and its respective Wi & Li for filter

III. FILTER SPECIFICATION

In this paper we use different materials like Al_2O_3 (A-493) Kyocera and FR4 with their different constant.

Response type	Butterworth (or) maximally flat	Butterworth (or) maximally flat	Butterworth (or) maximally flat
Dielectric Material	FR4	FR4	Al_2O_3 (A-493) kyocera
Centre Frequency	5 GHz	5GHz	5 GHz
Stop band attenuation	32dB	21dB	19dB
Source and load impedance	50 ohm	50 ohm	50 ohm
Substrate height	1.58mm	0.025mm	0.25mm
Dielectric constant	4.2	4.34	9.9
Dielectric Loss angle	0.02	0.025	0.0002

Table 4: Response and characteristics of filter respective to different materials

IV. SIMULATION AND OPTIMIZED RESULT

This schematic diagram of the LP using lumped element fig5 produces corresponding output waveform S(2,1) that is plotted with respect to frequency as shown in Fig.6. Graph shows that the signal attenuation at 5GHz. Beyond 500MHz, filters with discrete components are difficult to realize because the wavelength becomes comparable with the physical filter element dimensions, resulting in various losses severely degrading the circuit performance. Thus to achieve at practical filters, the lumped component filters must be converted into distribution element realizations using ADS simulation software tool.
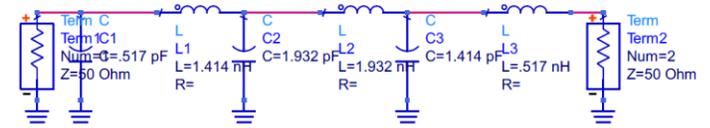
Fig 5: Lumped structure for stepped impedance filter
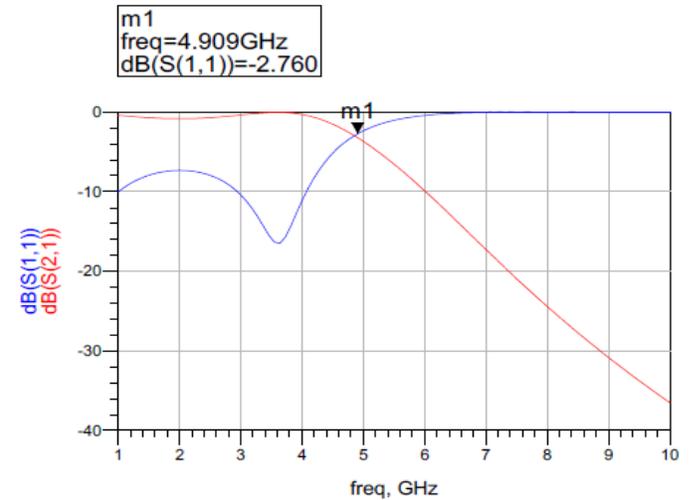
Fig 6: Simulation of lumped structure

Using material FR4 the schematic structure, S21 (Insertion loss) and S11(return loss) response without tuning operation and with tuned operation are shown below.
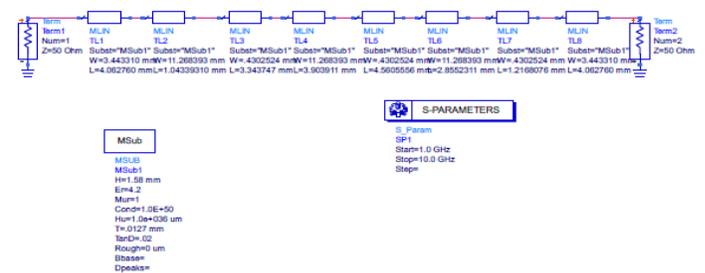
Fig 7: The schematic structure of the filter for the material FR4 with constant 4.2

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m1
freq=4.909GHz
dB(S(1,1))=-3.427
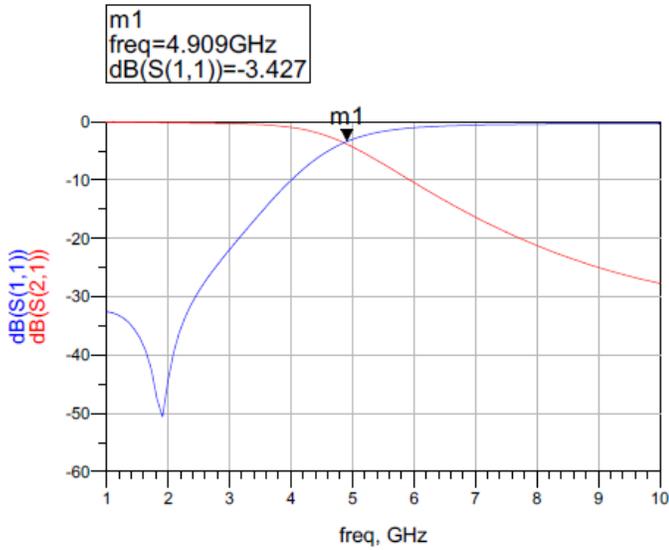
Fig 8: Output Wave form S parameters versus Frequency for filter with material FR4 (Constant 4.2)

Fig 10: Schematic structure of filter using FR4 with constant 4.34
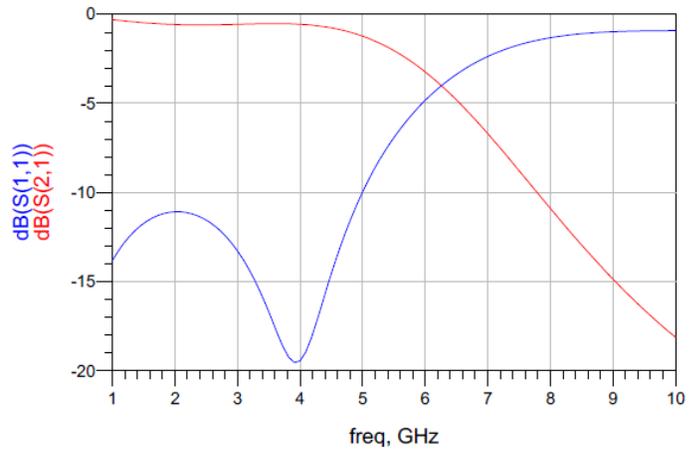
Fig11: Output Wave form S parameters versus Frequency for filter with material FR4 (Constant 4.34)

m1
freq=5.091GHz
dB(S(1,1))=-3.546

Fig 9: Tuned Simulation response of filter for FR4 (Constant 4.2)

Fig 12: Tuned simulation response of filter for FR4 (constant 4.34)

Stepped impedance filter with material FR4 with dielectric constant 4.2 are set up according to the values of W and L on ADS software tool and simulated. Output waveform of S parameter versus frequency has been observed and concluded that distributed circuit gives maximum attenuation of 31dB.

Fig13: Schematic of filter with Alumina material

Fig 14: Simulation response of filter with alumina
(Constant 9.9)

Fig 15: Tuned response of filter for alumina (constant 9.9)

The result of microstrip filter simulation is shown in the Fig. In the plot we find out that the centre frequency of the filter has deviated from the specified frequency 5GHz.To reach the optimal or specified request we adopt the tuning design owing by ADS numerical software based on method of moment. We use VAR component to set the tunable parameter such as microstrip length. The parameter in VAR component should set around the values which we have calculated with conventional method. The plot of amplitude versus frequency after optimization is shown in figure 9, 12 and 15 for different dielectric constant. In the plot we can see clearly that the center frequency of the filter has been adjusted to 5GHz and the corresponding loss is less than 0.5dB.The value of S11 in the pass band at 5GHz is 31 dB indicating that the request performance is well satisfied.

V. CONCLUSION

In this paper, stepped impedance micro strip low pass filter is designed with FR4 and alumina materials. This filter provides us to achieve better return loss with analysis of different dielectric constant. Designing of low pass filter with Butterworth approach in combination with concentrated components, i.e. inductors and capacitors and its computational verification in form of stepped impedance microstrip lines with Agilent ADS simulation tool gives very good filter characteristics at the center frequency 5 GHz. This filter is designed to use in C-band electromagnetic environments. The steps involved to design stepped impedance microstrip filter are also described in this paper. The special calculator, linecalc of ADS is used fo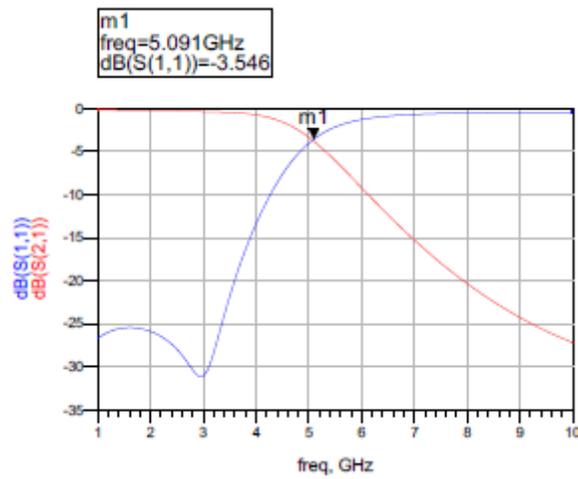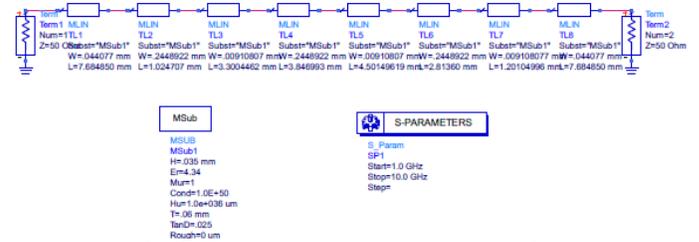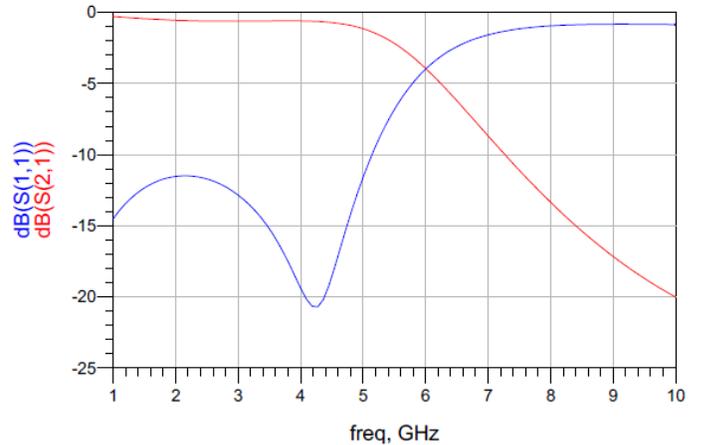r calculating length and width. The calculated filter parameters are applied to design a filter with different constant values. The insertion loss occurring in S(2,1) of about -1dB , primarily due to the tangent loss of the substrate. By analysis the designs and their responses, it is concluded that FR4 material with dielectric constant 4.2 is having better response rather designs with other constants values used in this paper. The layout of the designed stepped impedance micro strip filter is obtained using the software itself. Thus, finally a stepped impedance micro strip filter whose harmonic suppression is -31dB is obtained.

REFERENCES

[1] D. M. Pozar, "Microwave Engineering," 3nd ed New york, Wiley, 2012, pp. 367-368.

[2] George L.Matthaei, Leo Young, E. M. T. Jones. Microwaves Filters, Impedance- Matching Networks, and Coupling Structures. Reprint of the edition by McGraw-Hill. Dedham: Artech House, 1980.

[3] Bin Dong, Quanyuan Feng , Shuai Yang," Research and Design of X-band SIR Microstrip Filters",Natural Science. Foundation of China and China Academy of Engineering Physics under the grant No.10876029.

[4] Ralph Levy, Fellow IEEE,and Seymour B Cohn, Fellow," A History of Microwave Filter Research,Design, and Development", IEEE Transactions On Microwave Theory And Techniques, Vol. Mtt-32, No. 9, Septemrer1984.

[5] K.Rajasekaran, J.Jayalakshmi and T.Jayasankar,"Design and Analysis of Stepped Impedance Microstrip Low Pass Filter Using ADS Simulation Tool for Wireless Applications",International Journal of Scientific and Research Publications, Volume 3, Issue 8, August 2013 1 ISSN 2250-3153.

[6] I. Hunter, R. Ranson, A. Guyette, and A. Abunjaileh, "Microwave filter design from a systems perspective," *IEEE Microwave Magazine,* vol. 8, no. 5, p. 71, Oct.2007.