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Research Article

Design and Analysis of Microstrip Line and Lumped Element Based 3dB Equal-Ripple Low Pass Filter for C- Band

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Abstract: This work presents design, study and comparable circuit modelling of an equal ripple Microstrip transmission line (MLIN) based low pass filter (LPF) for C-band. A 5th order LPF is considered for corner frequency of 4GHz with 3dB attenuation using ideal lumped elements and MLIN based structure with FR4 substrate. Advanced Design System (ADS) software tool is used for design and simulation of LPF.The comparison of results confirms that MLIN based designed filter has excellent stop and pass band characteristics around the intended break frequency of 4 GHz and can be utilized in extensive choice of C-band microwave implementations due to its simple design and easy manufacturing compared to lumped elements based filter.

Keywords: 3dB Equal Ripple, C-band, Low Pass Filter, Lumped Elements, Microstrip transmission line, Advanced Design System.

1. INTRODUCTION

Low pass filters (LPF) are normally used for frequency selection application in satellite, radar and wireless communication systems. The LPFs are critical to reject harmonic components which are not required for the system under observation [1]. High and low impedance Microstrip transmission line (MLINs) are utilized for the designing of LPFs [1, 2]. Typical MLIN are manufactured using printed circuit board (PCB) technology and are mainly used for the filter application with quasi-TEM propagation mode [3, 4]. MLIN based microwave circuit designs are preferred because of smaller size, lesser cost, lighter weight and compact structure comfort [1, 4, 5, 6]. MLIN based LPFs works as an important functional block in numerousRF and microwave systems for the passing of desired frequency signals to the connecting microwave blocks [3, 5, 6].

In this work, a5th order 3dB equal ripple microstrip-line LPF was designed for the 0 to 4 GHz frequency range. The designed filter can be used for wide range of application in C-band like in weather radar systems, cordless telephones and Wi-Fi device [1, 2, 4]. ADS software is used for filer design and simulation [7]. An equivalent lumped element-based filter is also designed; the results are compared with MLIN based filter which shows very good agreement. The LPF can be used for removal of high frequency noise from desired signal, it can also be used with the amplifier circuits for limitation of input frequency.

The rest of the paper is organized as follows: Section 2 demonstrates the filter design theory. Section 3 describes the specifications of the designed LPF. The comparison of the designed filter results for MLIN and lumped elements based structure isfocused in Section 4. Section 5 accomplishes the conclusion.

2. FILTER DESIGN THEORY

The common examples of MLIN are filter application based on planner transmission lines. Fig. 1 shows a simple typical structure of MLIN. The width *(W)*, length *(L)* and thickness *(t)* of the metal strip along with substrate properties controls

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the characteristics impedance of a MLIN. In Fig.1, the thickness of the FR4 substrate is represented by *'h'*. The relative permittivity of the used FR4 substrate is denoted by ε_r.

2.1 Procedure For Designing Low Pass Filter

The designed LPF used 3dB equal ripple estimation with maximally flat response in the pass band. The 1Ω is used for source impedance tonormalize LPF calculation method [1, 4]. Fig. 2 illustrate the variation in the attenuation characteristics of a nominal filter with various orders (N) with regard to normalized frequency.

The cut of frequency and stop band attenuation of the designed filter are 4 GHz and -35 dB respectively. The considered target attenuation is more than -35 dB at stop band frequency. The stop band reflecting the transition from cut off to stop band is at 6 GHz. The information of Fig. 2 is used for the determination of the order of the filter.

The design procedure for LPF has been well thought-out as a low pass model (i.e., 3dB equal ripple approximation) with a 5th order *(N=5)*. The LPF element values are x_i *i.e.,* x_0, x_1, x_2, x_3, x_4, x_5, and x_6. The normalized element values i.e., x_0,x_1, x_2, x_3, x_4, x_5, and $x_6$are then changed to lumped elements for the required corner frequency of f_c= 4 GHz. Normally 50Ω source impedance is used for MLIN-based filter [4].

The FR4 substrate is used with $\boldsymbol{\varepsilon}_r$ of 2.6 and thickness of 0.5 mm. The load and source impedances are considered as unity. A stepladder

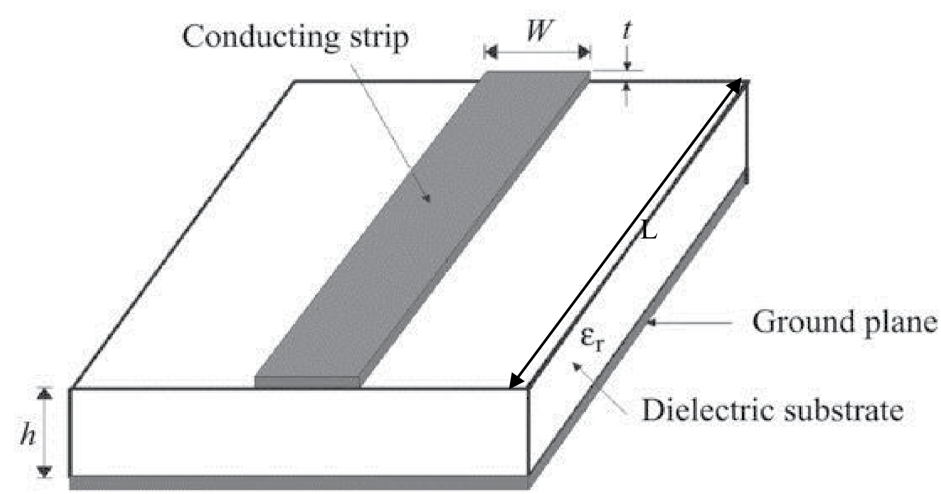

Fig. 1. Microstrip transmission line (MLIN)

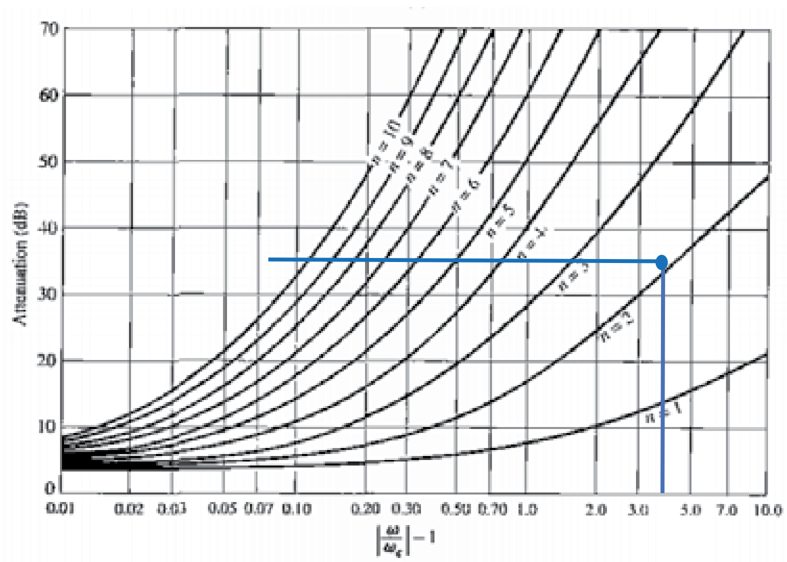

Fig. 2. Attenuation versus normalized frequency for 3dB equal-ripple filter prototypes [4]

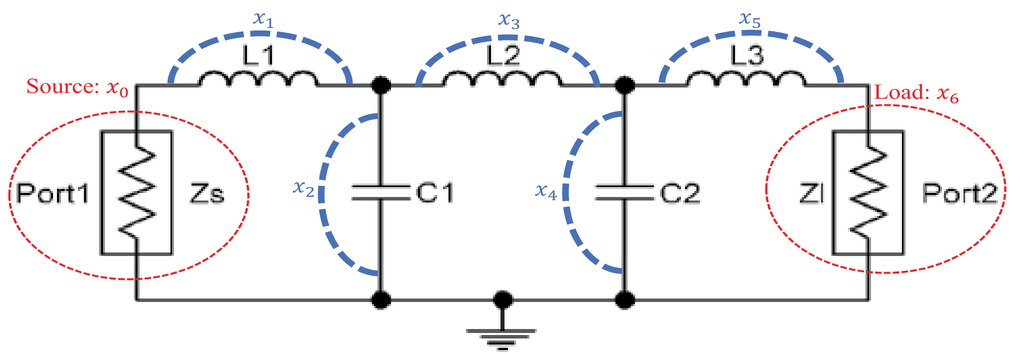

Fig. 3. Designed 5th order low pass filter based on lumped element (see Table 1 for component values)

circuit that initiated with cascaded elements of x_1, x_3 and x_5 are inductors and x_2, x_4 are capacitors as revealed in Fig.3

The L and C of different components can be obtained from the equations (1) and (2) correspondingly from the regularized values [4].

$$L_{k+1} = \frac{Z_0 x_{k+1}}{2\pi f_c} \tag{1}$$

$$C_k = \frac{x_k}{Z_0 2\pi f_c} \tag{2}$$

In equations (1) and (2), L_{k+1} and C_k represents the inductances and capacitances of the MLIN respectively. Z_o is the source and load impedance, and f_c is the corner frequency [4]. The capacitor and inductor's width for low pass microwave filter are considered using the below mentioned formulations [1, 4]:

Below equation (5) is used for the calculation of the ε_e (effective dielectric constant).

$$\text{For } \frac{w}{h} \leq 2, \tag{3}$$

$$\frac{w}{h} = \frac{8e^A}{e^{2A-2}} \tag{4}$$

$$A = \frac{Z_0}{60}\sqrt{\frac{1+\varepsilon_r}{2}} + \left(\frac{-1+\varepsilon_r}{1+\varepsilon_r}\right)\left(0.23 + \left(\frac{0.11}{\varepsilon_r}\right)\right)$$

$$\varepsilon_e = \frac{1+\varepsilon_r}{2} + \frac{\left(\frac{-1+\varepsilon_r}{2}\right)}{\sqrt{1+12\left(\frac{h}{w}\right)}} \tag{5}$$

3. LOW PASS FILTER DESIGN SPECIFICATIONS

The designed LPF has 50 Ω characteristics impedance with 4 GHz cut off frequency. The highest and lowest designed impedances are 100 Ω and 25Ω respectively. The designed filter constitutes of capacitive and inductive transmission lines segments. Equations (6) and (7) are used for the determination of the electrical length (l) of those capacitive and inductive segments [4].

Where phase constantis β and l is representing the transmission line's physical length, Z_o is the source and load impedance which is 50 Ohm. The inductive and capacitive impedance of the transmission lines are represented by Z_{high} and Z_{low} respectively [3].

The designed LPF schematic illustration is shown in Fig. 4. In Fig. 4, the open stub length is most sensitive because it grounds the undesired signal and thus have an impact on the attenuation characteristics of the filter.

$$\beta l = \frac{Z_0 L}{Z_{high}} \tag{6}$$

$$\beta l = \frac{C Z_{low}}{Z_0} \tag{7}$$

Table 1. Lumped elementparameters for Fig. 3

Component	Values
Z_s (Ω)	50
Zl (Ω)	50
L1 (nH)	6.92
L2 (nH)	9.02
L3 (nH)	6.92
C1 (fF)	606
C2 (fF)	606

The width and length of the different sections of the designed filter of Fig. 4 are determined using the designed equations of (3), (6) and (7). A Matlab code for the calculations of the different parameters of the designed filter is written and is shown in Appendix.

The layout design is revealed in Fig. 5. The Fig. 5(a) displays the 2D layout and Fig. 5(b) depicts the 3D layout of designed filter.

4. COMPARISON OF LUMPED ELEMENT & MLIN BASED LOW PASS FILTER

This section presents the comparison between two types of designed LPFs i.e. one is MLIN based LPF and other one is lumped element based LPF. The scattering parameters are obtained using ADS software for comparison results. Fig. 6 shows the simulation results of designed low pass filters and Fig. 7 depicts the comparison between both filter types.

The S-parameter simulation results clearly depict that S_{11} is -3.730 dB at 4GHz in case of MLIN based structure and S_{11} is -3.094 dB in case of lumped element based structure, so it is clear from the comparison that results are similar and MLIN is preferable because of its simple design and real time fabrication. Also S_{21} for MLIN filter is -3.041dB and -2.928 dB for the lumped element based filter. The flat response after 4GHz is also similar for both cases however the response of MLIN based LPF is sharper compared with lumped elements based LPF. In Fig. 7. The stopband ripples are less in lumped elements based LPF as compared to MLIN based LPF, but it does not affect the performance of filter and this is not required because of out of intended band of frequency.

Although results of both designs are similar but the lumped element based design is not preferred for real time applications due to the non-ideal characteristics of the actual lumped elements which can have adverse impact on the performance of the filter and hence can deteriorate the desired performance of the microwave system.

Table 2. MLIN dimensions for Fig. 4

	Tee Section	
	W_1=W_2(mm)	**W_3(mm)**
Tee1	1.2	13.3
Tee2	1.2	13.3
	TL Section	
	W(mm)	**L(mm)**
TL1	1.2	16.4576
TL2	1.2	18.1160
TL3	1.2	16.4576
TL4	13.3	3.0676
TL5	13.3	3.0676

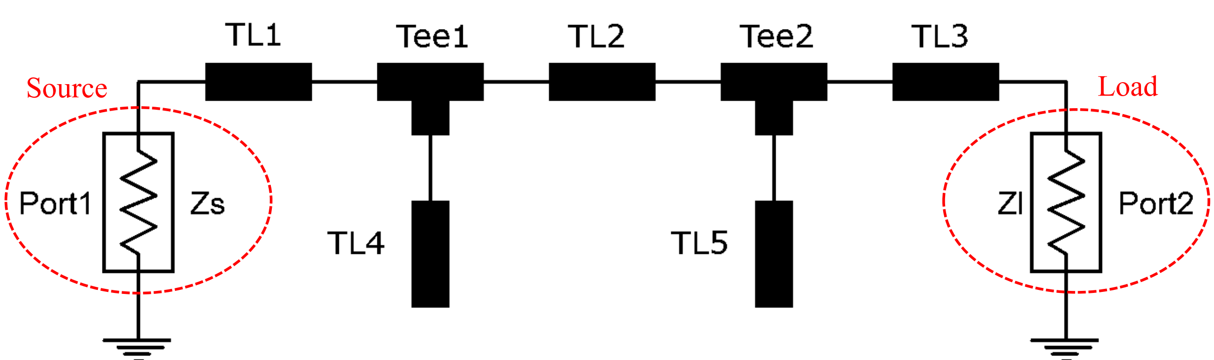

Fig. 4. Designed low pass filter based on MLIN (see Table 2 for transmission lines dimensions)

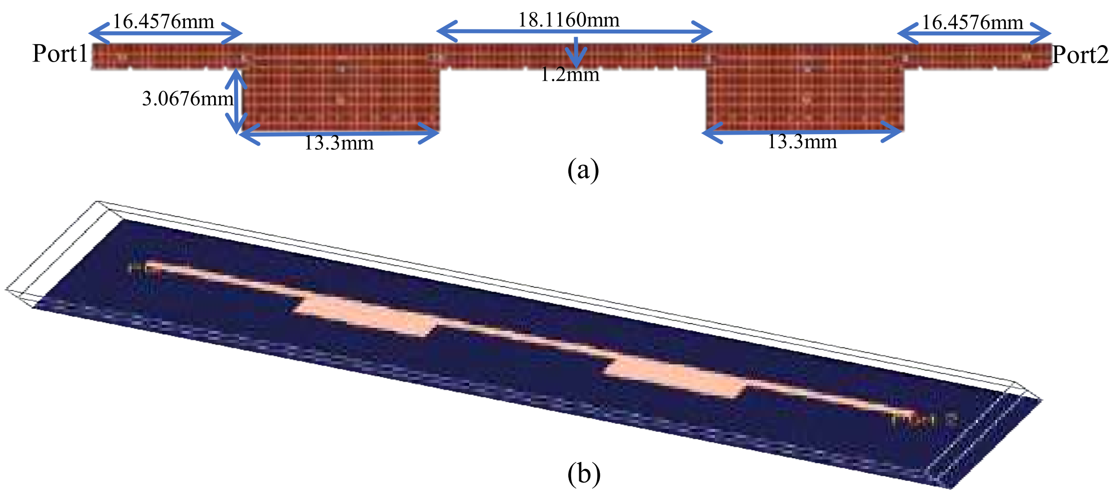

Fig. 5. (a) Microstrip LPF layout (b) 3D view of microstrip LPF layout

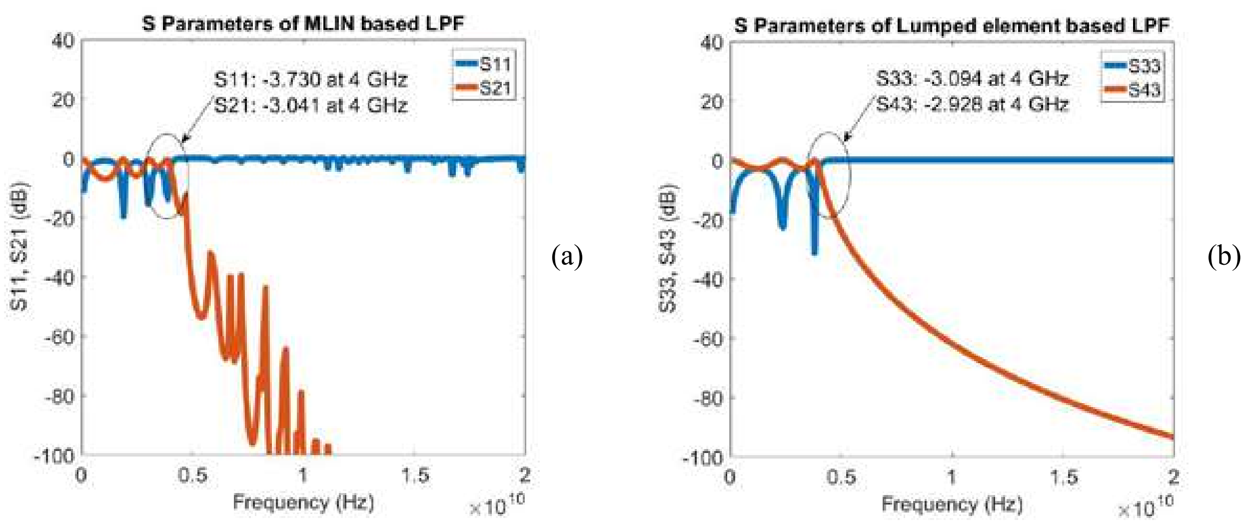

Fig. 6. S-parameters: (a) MLIN based S_{11} and S_{21} (b) Lumped element based S_{11} and S_{21}

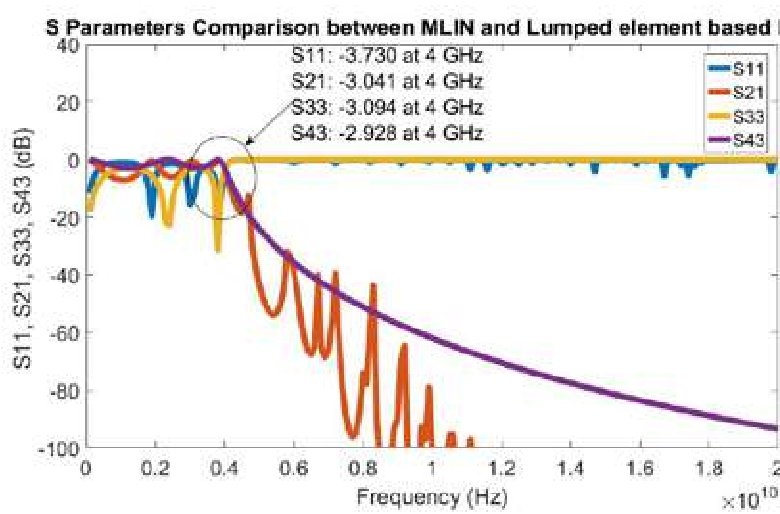

Fig. 7. Comparison between MLIN based (solid) and lumped element based (dashed) S_{11} and S_{21} (Port 1 and 2 are for MLIN filter and port 3 and 4 are for lumped element-based filter)

5. CONCLUSION

This study presents a comparison between MLIN and lumped element based low pass filters for C-band. The comparison shows that MLIN based LPF shows similar performance as ideal lumped elements based filter but the first one is more compact, simple and smaller. There is no need of surface mount elements and circuit is compressed in MLIN based LPF which add advantage for its easy manufacturing in real time applications.

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