Design and Implementation of Microstrip Line Based Stepped Impedance Low Pass Filter

Mariya Neemuchwala
Student, Dept. of EXTC
DJSCE
Mumbai, India

Shreya Gupta
Student, Dept. of EXTC
DJSCE
Mumbai, India

Ameya Kadam
Dept. of EXTC
DJSCE
Mumbai, India

Abstract— **Filters are noteworthy RF and Microwave components in communication systems. Lumped element filters using capacitors and inductors are unrealistic for compact designs of wireless communications equipment, especially hand-held devices. Distributed element filter design offers a much smaller area and are low profile. With the initiation of advanced substrate materials offering high dielectric constants with low loss, the size reduction with preserved efficiency is greatly enhanced. Transmission line filters can be easy to fabricate, depending on the type of transmission line used. This paper proposes the microstrip line stepped impedance low pass filter. This paper presents about the design, testing and fabrication of microwave low pass filter by using micro strip layout. The development of the micro strip filter is simulated by using CST2019 software followed by practical measurements using R&S make Vector Network Analyzer. The higher cut-off frequency is 2.4GHz and has insertion loss is -23dB at 3.9GHz.**

Keywords—Stepped Impedance Filter, Low Pass Filter, Butterworth.

I. INTRODUCTION

Filters play vital role in communication systems and are used to pass or reject explicit frequency bands. Filters are classified according to their frequency response as low-pass (LP), high-pass (HP), band-pass (BP), and band-stop (BS). Low Pas Filter (LPF) is used at the output of a power amplifier to remove the harmonics generated by the nonlinearity of the power amplifier at the output of a mixer to pass only the intermediate frequency, at the input of a receiver to reject the unwanted higher frequencies and in conjunction with a HPF to realize a wideband band-pass filter. Microwave filters can be divided into two main different types, lumped or distributed. Lumped elements comprises of discrete elements, such as capacitors and inductors, while distributed elements use the transmission lines of various length and width to create their inductive or capacitive values [1].

Microstrip line is a good candidate for filter design due to its advantages of compact size, low cost,light weight, conformal structure and ease of integration with other components on a same board. The broadband wireless access (BWA) is a significant topic in recent advances of the modern wireless communication system. To meet this inclination, 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 superior to other implementations so often used to filter unnecessary out-of-band signals. In PCB designs, signals must be routed from one part to another with the minimal distortion and better linear phase response. 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 used for designing certain components, like filter, coupler, transformer or power divider.

Microstrip lines are fabricated as a planar strip of metal and the insulating material forms a dielectric between two parallel planes 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 dielectric constant 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 and also to minimize the cost of fabrication. The design is optimized using Ansoft Designer SV software using transmission line model followed by verification using CST2019 software which is based on FDTD method.

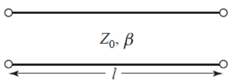
Low pass filter could either be realized using lumped components or distributed components. Lumped components consists of discrete elements like inductors, capacitors etc. Distributed elements consist of transmission line sections which simulate various inductance and capacitance values. It is difficult 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 also it is difficult to get the particular value of components [1]. However, transmission line filters are easy to implement and are compact at this frequency. By changing the length and width the desired reactive component can be realized.

II. DESIGN OF MICRO-STRIP STEPPED IMPEDANCE LOW PASS FILTER

A relatively easy way to implement low-pass filters in microstrip or stripline is to use alternating sections of very high and very low characteristic impedance (Z_0) lines. Such filters are usually referred to as stepped-impedance, or hi-Z, low-Z filters, and are widespread because they are easier to design and take up less space than a similar low-pass filter using stubs. Because of the approximations involved, however, their electrical performance is not as good, so the use of such filters is usually limited to applications where a sharp cutoff is not required for instance, in rejecting out-of-band mixer products.

We begin by finding the approximate equivalent circuits for a short length of transmission line having either a very large or a very small characteristic impedance. The ABCD parameters of a length of line having characteristic impedance Z_0 are given in Table 4.1;

TABLE I. ABCD PARAMETERS OF SOME USEFUL TWO-PORT CIRCUITS

Circuit	*ABCD* Parameters	
	$A = \cos\beta\ell$ $C = jY_0 \sin\beta\ell$	$B = jZ_0 \sin\beta\ell$ $D = \cos\beta\ell$

The ABCD parameters are converted to equivalent Z-parameters as

$$Z_{11} = Z_{22} = \frac{A}{C} = -jZ_0 \cot\beta\ell, \qquad (1a)$$

$$Z_{12} = Z_{21} = \frac{1}{C} = -jZ_0 \csc\beta\ell. \qquad (1b)$$

The series elements of the T-equivalent circuit are

$$Z_{11} - Z_{12} = -jZ_0\left(\frac{\cos\beta\ell - 1}{\sin\beta\ell}\right) = jZ_0 \tan\left(\frac{\beta\ell}{2}\right), \qquad (2)$$

while the shunt element of the T-equivalent is Z_{12}. If $\beta l < \pi/2$, the series elements have a positive reactance (inductors), while the shunt element has a negative reactance (capacitor). We thus have the equivalent circuit shown in Figure 1a, where

$$\frac{X}{2} = Z_0 \tan\left(\frac{\beta\ell}{2}\right), \qquad (3a)$$

$$B = \frac{1}{Z_0}\sin\beta\ell. \qquad (3b)$$

Now assume a short length of line (say $\beta l < \pi/4$) and a large characteristic impedance.

Then Eqs (3) approximately reduces to

$$X \simeq Z_0\beta\ell, \qquad (4a)$$

$$B \simeq 0, \qquad (4b)$$

which implies the equivalent circuit of Figure 1b (a series inductor). For a short length of line and a small characteristic impedance, Eqs (3) approximately reduces to

$$X \simeq 0, \qquad (5a)$$

$$B \simeq Y_0\beta\ell, \qquad (5b)$$

which implies the equivalent circuit of Figure 1c (a shunt capacitor). So the series inductors of a low-pass prototype can be replaced with high-impedance line sections ($Z_0 = Z_h$), and the shunt capacitors can be replaced with low-impedance line sections ($Z_0 = Z_l$).

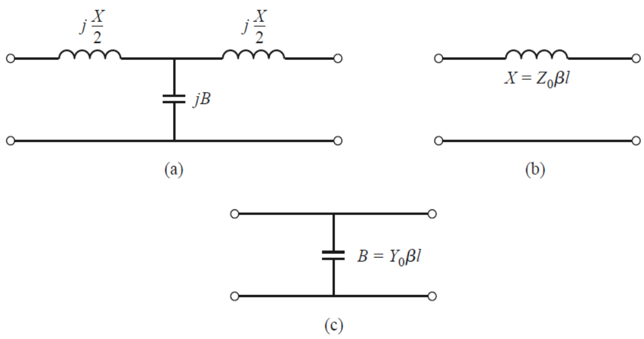


Fig. 1. Approximate equivalent circuits for short sections of transmission lines. (a) T equivalent circuit for a transmission line section having $\beta l << \pi/2$. (b) Equivalent circuit for small βl and large Z_0. (c) Equivalent circuit for small β and small Z_0

The ratio Z_h/Z should be as large as possible, so the actual values of Z_h and Z are usually set to the highest and lowest characteristic impedance that can be practically fabricated. The lengths of the lines can then be determined from Eqs (4) and Eqs (5); to get the best response near cutoff, these lengths should be evaluated at $\omega = \omega_c$. Combining the results of Eqs (4) and Eqs (5) with the scaling equations of Eqs (6) allows the electrical lengths of the inductor sections to be calculated as

$$\beta\ell = \frac{LR_0}{Z_h} \quad \text{(inductor)} \qquad (6a)$$

and the electrical length of the capacitor sections as

$$\beta\ell = \frac{CZ_\ell}{R_0} \quad \text{(capacitor)}, \qquad (6b)$$

where R_0 is the filter impedance and L and C are the normalized element values (the g_k) of the low-pass prototype.

The problem statement is to design a stepped-impedance low-pass filter having a maximally flat response and a cutoff frequency of 2.5 GHz. It is desired to have more than 20 dB insertion loss at 4 GHz. The filter impedance is 50 Ω.

For the above specifications the order of the filter is calculated as

$$n = \frac{\log_{10}\left(10^{A/10} - 1\right)}{2\log_{10}(\omega_1/\omega_c)}$$

where A =20dB, ωc = cut-off frequency= $2*\pi*f_c$

$\omega_1 = 2*\pi*f_1$,

Here f_c = 2.5 GHz and f_1 = 4 GHz

So the order of the filter is n= 6.

The normalized component values are calculated are as follows

$$g_0 = g_{n+1} = 1$$

$$g_k = 2\sin\left[\frac{(2k-1)\pi}{2n}\right], \quad \text{where } k = 1,2,3\ldots n$$

The computed normalized values of the components are as follows:

$$g_1 = 0.517 = C_1,$$
$$g_2 = 1.414 = L_2,$$
$$g_3 = 1.932 = C_3,$$
$$g_4 = 1.932 = L_4,$$
$$g_5 = 1.414 = C_5,$$
$$g_6 = 0.517 = L_6$$

Fig.2 shows the circuit implementation of the filter by means of discrete components like inductors (L) and capacitors (C).

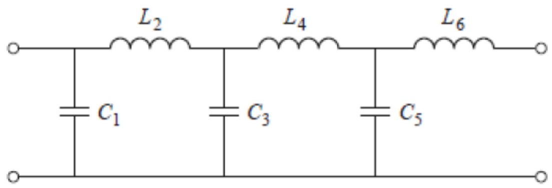


Fig. 2. Realization of filter using LC components.

Next, Eq (6a) and (6b) are used to replace the series inductors and shunt capacitors with sections of low-impedance and high-impedance lines. The required electrical line lengths, βi , along with the physical microstrip line widths, Wi , and lengths, i , are given in the table below.

TABLE II. PHYSICAL PARAMETERS OF THE MICROSTRIP LINE

Section	$Z_i = Z_\ell$ or $Z_h(\Omega)$	$\beta\ell_i$ (deg)	W_i (mm)	ℓ_i (mm)
1	20	11.8	11.3	2.05
2	120	33.8	0.428	6.63
3	20	44.3	11.3	7.69
4	120	46.1	0.428	9.04
5	20	32.4	11.3	5.63
6	120	12.3	0.428	2.41

The final filter circuit is shown in Figure 3, with Z = 20 Ω and Z_h = 120 Ω. Note that βl < 45◦ for all but one section.

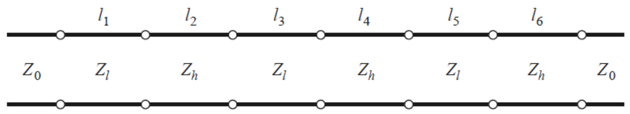


Fig. 3. Stepped impedance implementation.

For the realization of filter FR-4 Substrate has been used with thickness as h =1.6mm. The microstrip layout of the filter is shown in Figure 4.

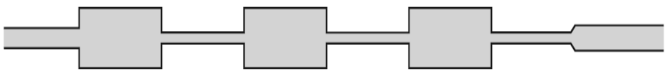


Fig. 4. Microstrip layout of final filter

III. SIMULATED AND MEASURED RESULTS

The stepped impedance low pass filter using microstrip line designed in the above section is implemented in Ansoft Designer SV software as shown in Figure 5.

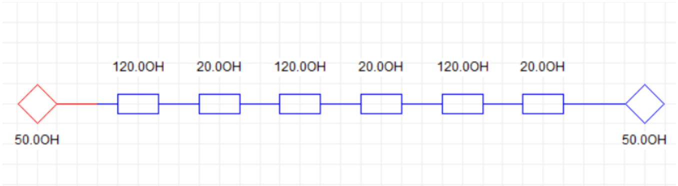


Fig. 5. Simulation Setup in Ansoft Designer SV

The above circuit is simulated over the frequency range 0 to 8GHz. The response is shown in Figure 6.

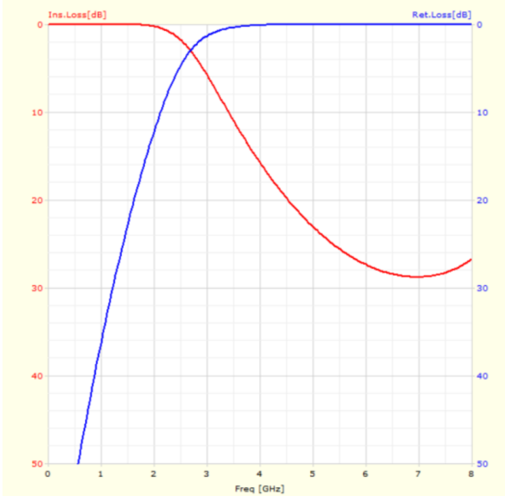


Fig. 6. Simulation Setup in Ansoft Designer SV

Further the design of stepped impedance low pass filter is implemented in CST2019 software as shown in Figure 7.

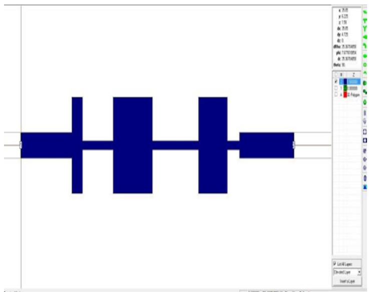


Fig. 7. Simulated magnitude response of the filter using Ansoft Designer SV

The circuit is simulated over the frequency range 0.6-4GHz. The simulated response of the filter is shown in the Figure 8.

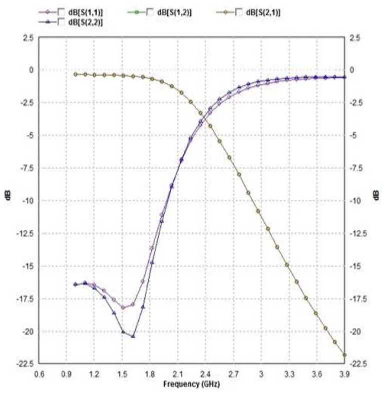


Fig. 8. Simulated magnitude response of the filter.

It is seen from the S_{21} response of the filter that the cut-off frequency is 2.504 GHz and the insertion loss at 3.9 GHz is less than 20dB. The filter is fabricated on the low-cost FR-4 substrate. Th prototype of the filter is shown below

Fig. 9. Fabricated protype of stepped Imedanace Low Pass Filter.

The response of the filter is measured using Rhode and Schwartz make Vector Network Analyzer ZVH-8 available in the laboratory. The measurement process is shown below.

Fig. 10. Measurement of Response of the filter using VNA ZVH-8.

The measured magnitude response of the filter is shown below:

Fig. 11. Measured Magnitude Response of the filter using VNA ZVH-8.

The two markers in the diagram indicates that the cut-off frequency is almost 2.4GHz while the insertion loss is around 23 dB at 3.96 GHz. The phase response of the filer is also measured and is shown in Figure

Fig. 12. Measured Phase Response of the filter using VNA ZVH-8.

CONCLUSIONS

In this paper, a stepped impedance low pass using micro strip line is presented. The filter has been designed, simulated using Ansoft Designer SV and CST 2019 software, fabricated and successfully tested on VNA ZVH-8. Simulated and measured results are in good agreement. The cut-off frequency observed closer to the design specification value of 2.5GHz. The observed could be differing from the expected value due to human error during fabrication and connection of the probes. The filter is compact in nature. The insertion loss at 4GHz is more than 22dB.

REFERENCES

[1] D. M. Pozar, “Microwave Engineering,” 3rd 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] 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.
[4] Ludwig, Reinhold and Bretchko, Pavel (2000). “RF Circuit Design - Theory and Application” New Jersey, USA: Prentice- Hall, Inc.