Design and analysis of Stepped impedance lowpass filter using microstrip line

Aditi Singh¹, Pravesh Singh²

ECE Department, KIET, Ghaziabad, Uttar Pradesh
¹aditi8jian@gmail.com, ²pravesh_singh01@yahoo.co.in

Abstract— In this paper a lowpass filter has been designed. The filter has designed by using the method known as stepped impedance. This paper fulfills the demand of newer microwave and millimeter-wave systems to meet the various issues such as cost, performance and size in the field of telecommunication. This paper presents a low insertion loss and the low cost design S-lowpass filter(LPF) with the use of microstrip layout having the center frequency at 2.5GHz with the permittivity of value 4.4 and the height/thickness of the substrate is 1.27mm for the order n=6. The use of microstrip provides the advantages of simplicity and ease of fabrication. The design and simulation are performed by using the 3D full wave electromagnetic simulator IE3D.

Keywords – Lowpass filter, IE3D, Dielectric constant, microstrip filter, Impedance configuration.

I. INTRODUCTION

In today’s fast growing world, microwave communication systems are expanding rapidly to higher frequency such as S-band since it is quiet advantageous as compared to conventional wireless links in respect of size and the bandwidth. Hence microstrip technology play important role in many RF or microwave applications. A lowpass filter is defined as a filter that can pass low frequency signals and attenuates/cuts the amplitude of signals with frequencies higher than the cut-off frequency. It can be used as hiss filter for audio purpose, as digital filter for smoothing data, acoustic barrier ans as an anti-aliasing filter for conditioning signals.

The actual amount of attenuation for each frequency varies depending on specific filter design. It is sometimes called as high-cut filter or treble cut filter in audio applications. A lowpass filter is the opposite of the high pass filter. A bandpass fiis a combination of the lowpass and a highpass filter. The filters are one of the primamand necessary components of a microwave systems. We prefer microstrip line as it is advantageous because of various parameters, such as low cost, compact size, light weight, planar structure and easy integration eith other components on a single circuit board. Conventional structures of filters such as equal ripple and butterworth lowpass filters are some requirements of special fabrication methods. Thus microstrip technology is used for simplicity and ease of fabrication. The design and simulation are performed u3D full wave electromagnetic simulator IE3D.

this filter is widely used today in radarsatellite and terrestrial communication applications.

II. DESIGN AND ANALYSIS OF MICROSTRIP FILTER

In order to design low pass filter basically two steps to be followed- In the first step, an appropriate low pass prototype is selected. The choice of the type of the response, including pass band ripple and the number of reactive elements will depend on the specifications that are required. The element values of the low pass prototype filters which are usually normalized to make a source impedance \( g_0 = 1 \) and a cutoff frequency \( \Omega_c = 1.0 \), then transform to the L-C elements for the desired source impedance usually 50ohms for microstrip filters[1] is to find an appropriate microstrip realisation approximates the lumped element filter. The element values of the low pass prototype with chebyshev response at passband ripple factor \( L_{4dB} = 0.1 \) db, characterize impedance source/load \( Z_0 = 50\text{ohms} \), are taken from normalized values \( g_1, g_2, g_3, \ldots, g_n \). The filter is assumed to be fabricated on a substrate of dielectric constant \( \varepsilon_r \) and of thickness(or height) h mm for angular(normalized) cutoff frequency \( \Omega_c \), using the element transformation[2].

The filter design steps are mentioned below-

1) Determine the number of sections from specification characteristics for microstrip parameters:-
Filter Specification-

Relative Dielectric constant, \( \varepsilon_r = 4.4 \)

Height of substrate \( h = 1.27 \text{mm} \)

Cutoff frequency, \( f_c = 2.5 \text{ GHz} \)

The loss tangent \( \tan \delta = 0.02 \)

The filter impedance, \( Z_0 = 50 \Omega \)

The highest line impedance \( Z_H = Z_{OL} = 100 \Omega \)

The lowest line impedance \( Z_L = Z_{OC} = 25 \Omega \)

Normalized cut off frequency, \( \Omega_c = 1 \text{ rad/sec} \)

2) We have chosen the element values for the desired lowpass filter from table 3.2[1] for \( n = 6 \). The values of the prototype elements to realize the specifications is given by the formula written below-

\[
L_i = \frac{Q_i Z_0}{\omega C_0 g_0} g_i \quad \text{and} \quad C_i = \frac{Q_i g_0}{\omega Z_0} g_i
\]

The physical impedances of the high and low impedance lines are given below-

\[
l_c = \frac{\lambda_{pc}}{2\pi} \sin^{-1} \left( \frac{\omega_c l_c}{\lambda_{pc}} \right)
\]

\[
l_e = \frac{\lambda_{pe}}{2\pi} \sin^{-1} \left( \omega_e C_i Z_{oc} \right)
\]

3) The formula used in order to calculate the width of the capacitor and inductor is given by[1],

For \( \frac{w}{h} < 2 \)

\[
w = \frac{8 \exp(6A)}{\exp(24) - 2}
\]

Where,

\[
A = \frac{Z_c}{60} \left[ \frac{\varepsilon_r + 1}{2} \right]^{0.5} + \left[ \frac{\varepsilon_r + 1}{\varepsilon_r - 1} \right] \left[ 0.23 + \frac{0.11}{\varepsilon_r} \right]
\]

And

\[
Z_c = \frac{\eta}{2\pi} \sqrt{\varepsilon_r} \ln \left( \frac{6h}{w} + 0.25 \right)
\]

Where \( \eta = 120\pi \) ohms is the wave impedance in free space.

4) The effective dielectric constant can be found by the following formula[1]

\[
\varepsilon_{re} = \left( \frac{\varepsilon_r + 1}{2} \right) \left[ 1 + \frac{12h}{w} \right]^{-0.5} + \left( 0.04 \right) \left( 1 - \frac{w}{h} \right)^2
\]

5) The effective wavelength can also be found as[1],

\[
\lambda_{ge} = \frac{300}{f(\text{GHz})\varepsilon_{re}} \text{ mm}
\]

### TABLE I

Dimensions for a stepped impedance lowpass filter (For \( n = 6 \)).

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microstrip line width (in mm)</td>
<td>( W_c = 8.38 )</td>
</tr>
<tr>
<td>Characteristic impedance (in ohms)</td>
<td>( Z_{OC} = 22 )</td>
</tr>
<tr>
<td>Effective Dielectric constant</td>
<td>( (\varepsilon_{re})_C = 5.843 )</td>
</tr>
</tbody>
</table>

### III. SIMULATION RESULT

The layout of a 6-pole, stepped impedance microstrip lowpass filter on substrate with \( \varepsilon_r = 4.4, h = 1.2 \text{mm} \) at 2.5GHz frequency, has been shown below.

![Fig.1: Layout of a 6-pole stepped impedance microstrip lowpass filter on substrate with \( \varepsilon_r = 4.4, h = 1.2 \text{mm} \) at 2.5GHz frequency.](image)
IV. RESULTS AND DISCUSSION

The simulated filter structure and response is shown in fig. 1 and fig. 3. The fabricated and measured response is shown in fig. 3. In the response graph gain (dB) is plotted on the Y-axis and frequency (GHz) on the X-axis. The simulated LPF achieved a 3dB bandwidth of about 24%. From the graph shown in fig. 4, it is clear that the simulated cut-off frequency is found to be 2.5GHz for stepped impedance low pass filter and from figure 3, it is clear that the measured value is 2.210580GHz at 8.0288dB. Hence the low pass filter is capable of passing the frequency less than 2.210580 GHz & rejects the frequency after 2.210580GHz. So this filter can be used for S-band applications i.e. above 2GHz. The response of the low pass filter with alternating sections of high and low impedance line is also plotted in fig 5 by developing program code in Matlab which shows the value of insertion loss(S21) of -4dB at cutoff frequency 2.5GHz.

V. APPLICATIONS

Microstrip lines circuits find extensively applications in radar systems, microwave communication links, satellite communication systems, wireless and mobile communication systems, medical equipment etc.

VI. CONCLUSION

A stepped impedance low pass microstrip filter has been simulated, designed, fabricated and tested by measurement with a vector network analyzer. The cutoff frequency achieved is lower than the design specification value(2.5GHz).

VII. ACKNOWLEDGEMENT

The authors would like to thank authorities of Krishna Institute of Engineering and Technology, Ghaziabad for all the support provided. The measurement facility provided by, Dr. Sanjay Sharma (H.O.D. of ECE deptt. KIET, Ghaziabad) is gratefully acknowledged.

References