Performance Comparison of Microstrip High-Pass Filters for Different Dielectric Substrates

Vivek Singh Kushwah\textsuperscript{1)}, G.S. Tomar\textsuperscript{2)}, Sarita Singh Bhaduria\textsuperscript{3)}, Hye-jin Kim\textsuperscript{4)\\

Abstract

In this paper performance and design comparison of Microstrip high-pass filters are presented for different dielectric materials for L, S and C-band applications. IE3D 14.1 simulation tool is used for obtaining the Insertion loss and return loss performance of microstrip high pass filter.

Keywords- Microstrip high Pass Filters, Return Loss, IE3D EM Simulation, Scattering parameters, Insertion Loss

I. INTRODUCTION

In recent time the wireless market has been growing very fast due to advancement of technology. In microwave range of frequency various active and passive components need to be fabricated with greater care and efficiency to obtain expected performance for better and efficient communication. The filters need much care and consideration as it is vital component in the communication systems to select the actual band of frequencies needed or need to be rejected, depending on the position of the filter in the communication system. Microwave filters are commonly used for passing the desired band of frequencies and rejecting other frequencies for various modern microwave applications such as satellite, radar and mobile communication etc \cite{1}. The microstrip filters are generally used in transmitters and receivers at frequency ranges beyond 800 MHz. The basic design structure of the filters has been
investigated by revisiting primary characteristics of the material and their applications according to the required applications and requirements. The design is considered with standard patch and modifications thereon for achieving parameters as desired. This work is focused on filter design, mathematical modeling of the filter designs along with the determining performance parameters like scattering parameters and losses. Filters are an integral component of any microwave communication system. Filters are essential to perform task of separating, sorting of signals and impedance matching in communication systems [2]. There have been many designs, which are proposed by researchers for high pass filters. In [3] an ultra-wideband band pass filter is proposed which is realized by combining a high pass filter (HPF) and a low pass filter (LPF). In [4] a wideband bandpass filter is proposed which is based on the highpass or cutoff characteristic of the microstrip high pass filter and the lowpass nature of a microstrip low pass filter. In [5] cross coupling technique is applied for designing of the microstrip high pass filter with attenuation poles. The high pass filter consists of parallel plate and gap type capacitors and inductor lines. The one block of the high pass filter has two sections of a constant K filter in the bridge T configuration. Thus the one block high pass filter is first correctly designed and the performance is optimized by circuit simulator. With the gap capacitor adjusted the proposed high pass filter illustrates the sharp attenuation characteristics near the cut-off frequency made by cross-coupling between the inductor lines. Microstrip high pass filters can also be designed using neuro modelling techniques for obtaining the more accurate performance and fast processing [6]. In [7] microstrip band pass filter is designed using a defected ground structure resonators and inter-digital capacitors. Microstrip high pass filter and a microstrip low pass filter are cascaded together to form a band pass filter. The designed filter exhibits sharp cut-off frequency response at 5 GHz mid-band frequency and 2 GHz bandwidth. The microstrip filter also shows stop band performance with rejection nearly 20 dB from DC to 3.55GHz in lower stop band and 6.2 to 14 GHz in upper stop-band respectively. The authors have also observed that the response of filter needs to be improved and need more precision for improving return loss of the filter.

Research work is continuously going on in this field and there have been many designs proposed by researchers throughout the world for various types of microstrip filters [8-14]. The basic design structure of the filters has been investigated by revisiting primary characteristics of the material and their applications according to the required applications and requirements. The design is considered with standard patch and modifications thereon for achieving parameters as desired. Two types of dielectric materials are proposed for the design of microstrip high pass filters in L, S and C-band of frequencies on microstrip patch which have reduced filter size.
drastically and have given better option for various design considerations and options to have sharp cutoff, improved bandwidth and high performance filter design. In this work performance comparison of Microstrip high pass filter is presented for two different types of dielectric materials.

**II. FUNDAMENTAL DESIGN OF MICROSTRIP HIGH-PASS FILTERS**

A high pass filter is a filter which passes signals above cutoff frequency and eliminates the signal below this. The elimination is not possible completely but the amplitude attenuation is by some specific range, which is considered to The common form of a high-pass filter consists of a series capacitor and shunt inductors. For more selective high pass filters, more elements are required. This type of high pass filter may be easily designed based on a lumped element low pass prototype such as one shown in Figure 1 and Figure 2, where \( g_i \) denote the element values normalized by a terminating impedance \( Z_0 \) and obtained at low pass cutoff frequency \( f_c \). High pass filters can also be constructed from equal electrical length transmission-line elements.

![Figure 1] A lowpass prototype filter

![Figure 2] Highpass filter transformed from the low-pass prototype

The concept of high pass filter based on the basic architecture has been used to design a filter for microwave communication range on microstrip line for cellular mobile band of 1.8 GHz. High pass filters may be constructed from distributed elements such as commensurate transmission line; these filters are having wide-band applications [14]. The Basic Transmission line structure of microstrip highpass filter is shown in Figure 3. The high pass filters consists of shunt short-circuited stubs of electrical length \( \pi f_c \) at some specified cut-off frequency \( f_c \).
separated by connecting lines of electrical length $2\pi c$. Basic transmission line characteristics of proposed microstrip filter are shown in Figure 4, where $f$ is the frequency variable and $\theta$ is the electrical length, which is proportional to $f$ and the electrical length can be calculated by:

$$\theta = \theta_c \frac{f}{f_c}$$

(1)

The filtering characteristics of the Transmission line network (Figure 3) can be described by equation 2.

$$|S_{21}(\theta)|^2 = \frac{1}{1 + \varepsilon^2 F_N^2(\theta)}$$

(2)

Where $\varepsilon$ is the pass band ripple constant, $\Theta$ is the electrical length as defined in equation 1, and $F_N$ is the filtering function given by

$$F_N(\theta) = \frac{(1 + \sqrt{1 - x_c^2})T_{2n-1} \left( \frac{x}{x_c} \right) - (1 - \sqrt{1 - x_c^2})T_{2n-1} \left( \frac{x}{x_c} \right)}{2 \cos \left( \frac{\pi}{2} - \theta \right)}$$

(3)

Where $n$ is the number of short-circuited stubs,

$$x = \sin \left( \frac{\pi}{2} - \theta \right), \quad x_c = \sin \left( \frac{\pi}{2} - \theta_c \right)$$

(4)

and $T_n(x) = \cos (n \cos^{-1}x)$ is the Chebyshev function of the first kind of degree $n$. Theoretically, this type high-pass filter can have an extremely wide primary pass-band as $\Theta c$ becomes very small, however, this may require unreasonably high impedance levels for short-circuited stubs.

![Figure 3] Basic Transmission line structure of microstrip highpass filter
The design of high-pass filters with 2-6 stubs and a pass band ripple of 0.1 dB for $\theta_c = 25^\circ, 30^\circ$ and $35^\circ$ has been planned as shown in Figure 3 and some standard element values of the network have been summarized in table 1. Note that the tabulated elements are the normalized characteristic admittances of transmission line elements, and for given terminating impedance $Z_0$ the linked characteristic line impedances are determined by equation (5).

$$Z_i = Z_0 / y_i \quad \text{or} \quad Z_{i+1} = Z_0 / y_{i+1}$$

For designing such type of microstrip high pass filter at cutoff frequency 1.8 GHz, pass-band has been considered upto 8 GHz for 0.1 dB ripple.

<table>
<thead>
<tr>
<th>n</th>
<th>l</th>
<th>y_1</th>
<th>y_2</th>
<th>y_3</th>
<th>y_4</th>
<th>y_5</th>
<th>y_6</th>
<th>y_7</th>
</tr>
</thead>
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<tr>
<td>10.2</td>
<td>11</td>
<td>23</td>
<td>14</td>
<td>14.141416</td>
<td>17.171718</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>24</td>
<td>16</td>
<td>12.722225</td>
<td>18.181818</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>25</td>
<td>16</td>
<td>20202020</td>
<td>22.222222</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>26</td>
<td>28</td>
<td>10101010</td>
<td>31.313131</td>
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</tr>
<tr>
<td>26</td>
<td>28</td>
<td>29</td>
<td>10101010</td>
<td>32.323232</td>
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<td>22.222222</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For designing such type of microstrip high pass filter at cutoff frequency 1.8 GHz, pass-band has been considered upto 8 GHz for 0.1 dB ripple.

![Figure 4] Performance of the Microstrip High Pass filter
III. MATHEMATICAL MODELING FOR MICROSTRIP HIGH PASS FILTER DESIGN

In this section the mathematical calculations are performed for finding out the dimensions for the proposed high pass filter using standard equations used for microstrip filter designs. With reference to the design proposed in Figure 5, the electrical length \( \theta_c \) is calculated by equation (6).

\[
\left[ (x/ \sqrt{c}) - 1 \right] f_c = \theta
\]  

Which gives \( \theta_c = 0.577 \) radians or \( \theta_c = 33.08^\circ \). The microstrip high pass filter is designed with six short circuited stubs. The admittance values are selected for \( n=6 \) and \( \theta_c = 30^\circ \) from table 1, which provides a good bandwidth up to 8GHz, because the electrical length and the bandwidth are inversely proportional to each other. The admittance values for \( \theta_c = 33.08^\circ \) is calculated by interpolation from the admittance values shown in table 1.

For \( n=6 \) and \( \theta_c = 33.08^\circ \), the admittance value \( y_1 \) is calculated as follows:

\[
y_1 = 0.35346 + \frac{(0.48096 - 0.35346)}{5} \times 3.08 = 0.432
\]

In a similar way the rest of element values are found to be \( y_2 = 1.0403, y_3 = 0.6021, y_4 = 1.01149 \),

\( y_5 = 0.6797, y_6 = 1.00459 \).

50 \( \Omega \) port is provided at both the ends of microstrip high pass filter for giving the input
and obtaining the output response. The characteristic impedances for the microstrip line elements are calculated by using equation (5), which gives

\[ Z_0 = Z_M = 115.74 \ \Omega, \ Z_{a1} = Z_{a2} = 83.04 \ \Omega, \ Z_{d1} = Z_{d2} = 73.56 \ \Omega, \ Z_{a1} = Z_{d2} = 48.06 \ \Omega, \ Z_{a2} = Z_{d1} = 49.43 \ \Omega, \text{ and } \ Z_{d1} = 49.77 \ \Omega. \]

Here \( \Theta_c = 33.08^\circ \) for all the stubs and \( 2\Theta_c = 66.16^\circ \) for all the connecting microstrip lines. For terminating impedance, \( Z_0 = 50 \ \Omega. \)

If \[ \frac{W_0}{h} \geq 2, \]

Then

\[ \frac{W_0}{h} = \frac{2}{\pi} \left[ \frac{2\pi}{\varepsilon} \right] - \ln(2\pi - 1) + \frac{\varepsilon - 1}{2\pi} \left[ \ln(2\pi - 1) + 0.39 - \frac{0.61}{\varepsilon} \right] \]

(7)

Where \[ B = \frac{4.7157}{\varepsilon_0} = 5.25 \text{ mm}. \]

\[ w_0 = 4.8 \text{ mm}. \]

Guided wavelength \( \lambda_{g0} = \frac{2\pi}{\varepsilon_0} \sqrt{\varepsilon_{\text{eff}}}. \)

\[ \varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[ 1 + \frac{12}{h} \frac{h}{w} \right]^{-\frac{1}{2}} \]

(9)

\[ \varepsilon = \frac{2}{\pi} \quad \text{and} \quad \beta = \frac{2\pi}{\lambda_{g0}}. \]

(10)

Where \( \varepsilon_{\text{eff}} \) is the effective dielectric constant and \( \beta \) is the phase constant. These calculations are done for the design of microstrip high pass filters at various pass bands and cut-off frequencies depending on the requirements and applications.

IV. PERFORMANCE COMPARISON OF MICROSTRIP HIGH-PASS FILTERS

Two Dielectric materials are mostly used as a substrate for fabrication of Microstrip High Pass filters.

(1) RT/Duroid 5880 Substrate which has Dielectric Constant \((\varepsilon)\) of 2.2 , Thickness\((b)\)=1.57 mm, Loss tangent \((\delta)\) =0.0009

(2) Dielectric Material FR4 Glass Epoxy Substrate which has the following properties :

Dielectric Constant \((\varepsilon)\)=4.4,Thickness\((b)\)=1.6mm, Loss tangent\((\delta)\)=0.02
(1) For Dielectric Material RT/Duroid 5880: It has Dielectric Constant ($\varepsilon_r$)=2.2, Thickness (h)=1.57mm, Loss tangent($\tan \delta$)=0.0009

The widths and physical length of the stubs linked with the characteristic admittances of microstrip line can be derived with the help of designed equations and are summarized in Table 2.

<table>
<thead>
<tr>
<th>Line Impedance(Ω)</th>
<th>Line width W(mm)</th>
<th>Physical length of Stubs l(mm)</th>
<th>$l_1/l_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z_1$=$Z_6$=115.74</td>
<td>$W_1$=$W_6$=0.8</td>
<td>$l_1$=$l_6$=11.3</td>
<td></td>
</tr>
<tr>
<td>$Z_2$=$Z_3$=83.04</td>
<td>$W_2$=$W_3$=1.8</td>
<td>$l_2$=$l_3$=11</td>
<td></td>
</tr>
<tr>
<td>$Z_3$=$Z_4$=73.56</td>
<td>$W_3$=$W_4$=2.4</td>
<td>$l_3$=$l_4$=10.8</td>
<td></td>
</tr>
<tr>
<td>$Z_{1,2}$=$Z_{5,6}$=48.06</td>
<td>$W_{1,2}$=$W_{5,6}$=4.9</td>
<td>$l_{1,2}$=$l_{5,6}$=18.8</td>
<td></td>
</tr>
<tr>
<td>$Z_5$=$Z_4$=49.43</td>
<td>$W_5$=$W_4$=4.84</td>
<td>$l_5$=$l_4$=18</td>
<td></td>
</tr>
<tr>
<td>$Z_{2,3}$=49.77</td>
<td>$W_{2,3}$=4.81</td>
<td>$l_{2,3}$=17.7</td>
<td></td>
</tr>
<tr>
<td>$Z_0$=50 Ω</td>
<td>$W_0$=4.8mm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The basic design of microstrip filter is shown in Figure 5 which is obtained by using some mathematical calculations with the help of design equations for microstrip filter and plotted by using IE3D electromagnetic simulation software. It consists of three stubs of quarter guided wavelength long linked with each other with the help of connecting microstrip lines. The 50 ohm terminating microstrip line is used for connecting the 50 ohm load/port so that input is provided to the microstrip filter through input port and output characteristics response is measured from the output port. The total area of the proposed design of microstrip filter is 2988.9 mm². Length of the proposed filter is 184.5mm and width of the proposed filter is 16.2mm.

![Figure 5: Fundamental Design of First Microstrip High Pass Filter for RT/Duroid 5880 Substrate](image)

(2) For Dielectric Material FR4 Substrate: This material has the following properties:
Dielectric Constant ($\varepsilon_r=4.4$), Thickness $h=1.6$ mm, Loss tangent ($\delta$) = 0.02

Table 3 represents the basic design parameters of microstrip band-reject filter for FR4 dielectric substrate.

<table>
<thead>
<tr>
<th>Line Impedance(Ω)</th>
<th>Line width W(mm)</th>
<th>Physical length of Stubs (mm)</th>
<th>$l=0/\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z_1=Z_6=115.74$</td>
<td>$W_1=W_6=0.45$</td>
<td>$l_1=l_6=8.9$</td>
<td></td>
</tr>
<tr>
<td>$Z_2=Z_5=83.04$</td>
<td>$W_2=W_5=1.14$</td>
<td>$l_2=l_5=8.7$</td>
<td></td>
</tr>
<tr>
<td>$Z_3=Z_4=73.56$</td>
<td>$W_3=W_4=1.49$</td>
<td>$l_3=l_4=8.6$</td>
<td></td>
</tr>
<tr>
<td>$Z_{1,2}=Z_{5,6}=48.06$</td>
<td>$W_{1,2}=W_{5,6}=3.27$</td>
<td>$l_{1,2}=l_{5,6}=8.4$</td>
<td></td>
</tr>
<tr>
<td>$Z_{2,3}=Z_{4,5}=49.43$</td>
<td>$W_{2,3}=W_{4,5}=3.11$</td>
<td>$l_{2,3}=l_{4,5}=8.38$</td>
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</tr>
<tr>
<td>$Z_3=49.77$</td>
<td>$W_3=3.08$</td>
<td>$l_3=8.39$</td>
<td></td>
</tr>
<tr>
<td>$Z_5=50$ Ω</td>
<td>$W_5=3mm$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 6 represents the design of microstrip high pass filter using Glass epoxy FR4 substrate. The total area of the proposed design of microstrip filter is 620.1 mm$^2$ which is more compact as compared to existing designs [3-6]. Length of the proposed filter is 52.11mm and width of the proposed filter is 11.9mm.

![Fundamental Design of Second Microstrip High Pass Filter with stubs](image)

V. IMPLEMENTATION AND RESULTS

Figure 7 illustrates the frequency response of microstrip high pass filter for the dielectric material RT/ Duroid 5880 Substrate which shows the bandwidth of the filter ranges from 1.8 to 7 GHz for L, S and C-band applications.
Performance Comparison of Microstrip High-Pass Filters for Different Dielectric Substrates

![Graph showing S-parameters for high pass filter](image)

[Figure 7] IBID EM simulated Magnitude performance of the first microstrip high pass filter for RT/Duriod 5880 dielectric substrate

Performance of the filter is measured in terms of return loss and insertion loss which is measured in the form of S-parameters (S11,L21). It is clear from the given graph that insertion loss in pass band from 1.6 GHz to nearly 6.8 GHz is below 2 dB, which is considered to be good and below 1.8 GHz, it sharply increased to 30 dB, which gives good response of the high pass filter. It is also seen that return loss at cutoff frequency is also in high performance range and thus justifying the design of the proposed filter. In Figure 8, the phase response of proposed distributed microstrip high pass filter is plotted. The figure clearly shows the phases or angles of S-Parameters in degrees and gives smooth response for passband, which will produce output without any distortion.

![Graph showing phase performance for high pass filter](image)

[Figure 8] IBID EM simulated Phase performance of the first microstrip high pass filter for RT/Duriod 5880 dielectric substrate
Figure 9 shows the frequency response of microstrip high pass filter for the dielectric material FR4 Substrate which shows the bandwidth of the filter ranges from 2.6 to 6.4 GHz and it is used for for S-band radar and satellite communication down link and uplink applications. It has very low insertion loss, high return loss and very low pass-band as compared to previous design.

![S-Parameters Display](image)

[Figure 9] IE3D EM simulated magnitude performance of the second microstrip high-pass filter for Glass epoxy FR4 dielectric substrate

In Figure 10, the phase response of second microstrip high pass filter is plotted. The figure clearly shows the phases or angles of S-Parameters in degrees and gives less smooth response for passband, which will produce output with more distortion as compared to previous design.

![Phase Response](image)

[Figure 10] IE3D EM simulated Phase performance of the second microstrip high pass filter for Glass epoxy FR4 dielectric substrate
## Performance Comparison of Microstrip High Pass Filter for different Dielectric substrate

<table>
<thead>
<tr>
<th>Material/Substrate</th>
<th>Return loss in dB</th>
<th>Insertion Loss in dB</th>
<th>Pass-Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT/Duroid 5880 Substrate</td>
<td>-15.33 dB</td>
<td>-1.919 dB</td>
<td>1.8 to 7 GHz</td>
</tr>
<tr>
<td>Glass Epoxy FR4</td>
<td>-11.14 dB</td>
<td>-1.437 dB</td>
<td>2.6 to 6.4 GHz</td>
</tr>
</tbody>
</table>

It is obvious from table 4, that most suitable substrate for the design of microstrip high pass filter is RT/Duroid 5880 which provides wide bandwidth and improved insertion and return loss as compared to Glass Epoxy FR4 substrate.

### VI. CONCLUSION

In this paper, two types of dielectric substrates are used for the performance and design comparison of Microstrip high pass filter which is used for L, S and C-band applications. Scattering parameters are calculated from the simulated performance of the filter in terms of insertion and return loss. It is concluded that RT/Duroid 5880 is the best dielectric substrate for obtaining good bandwidth, better performance and compact size as compared to other substrate.

### References


