Performance Comparison of Microstrip Band-Pass Filters for Different Dielectric Materials

Vivek Singh Kushwah¹, Geetam S. Tomar², Hye-jin Kim³

Abstract

In this paper design of Microstrip band-pass filters has been presented for different dielectric materials for GSM Guardband applications. The various designs have been investigated for performance and optimal solution has been provided in the work. The filter has been simulated using IE3D 14.1 simulation tool where various parameters have been obtained and performance has been measured using scattering parameters; insertion loss and return loss of microstrip filter.

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

I. INTRODUCTION

The present communication systems are going wireless at faster pace and needs to have better quality of components, which are being used in wireless communication systems. Filters are one of the primary components used for selection of wanted signals to have communication with better performance. Microwave filters are commonly used for passing the desired band of frequencies and rejecting other frequencies for various modern microwave applications such as satellite-communication, Radar and mobile communication etc [1]. The work is focused on filter design, mathematical modeling of the filter designs along with the determining performance parameters like scattering parameters and losses. Almost every wireless communication systems have been brought in the microwave frequency range. In this 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. 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]. Filters are also applicable in Radio Frequency front-ends as pre-select filters where pre-select filters select the desired frequency band. It is also highly recommended to have good quality of band reject filters with high insertion loss at its center frequency to reject selected pass band, which may be communicated in common media along with required base band [3]. There is also need for having high quality low/high pass filters at this range of frequency as to give better options of selection for various required or not required band of frequencies. Most of the communication systems require an RF front end LNA and filters processing elements for analog signal at the input [4]. This stage is an important stage in any communication system and needs high quality of filtering devices. The microstrip filters are generally used in transmitters and receivers at frequency ranges beyond 800 MHz. There have been many designs, which are proposed by researchers for various types of filters [5-27]. 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 therefore for achieving parameters as desired. Various types of dielectric materials are proposed for the design of microstrip filters in GSM 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 band pass filter is presented for various dielectric materials.

II. FUNDAMENTAL DESIGN OF MICROSTRIP BAND-PASS FILTERS

Microstrip Band-pass filters may also be designed with a large number of stubs as illustrated in Figure 1. In this type of filter all the branches i.e. connecting lines and all stubs have different dimensions and it is quarter guided wavelength (\(\lambda_{g0}/4\)) long where \(\lambda_{g0}\) is the guided wavelength for the design. The filter characteristics based on the characteristic admittance of the stub lines represented as \(Y_i\) and the characteristic admittances of the linking lines represented as \(Y_L\). A microstrip line has become popular planar component for design of microstrip filter which has a single ground plane and thin strip conductor on a low loss dielectric substrate above the ground plane and input-output are drawn using one of the
popular coupling techniques by mounting on the surface of the component. The various shapes and dimensions are key component of filter type and operational range. The performance of filters is measured on the basis of Scattering Parameters.

![Figure 1: Basic design of microstrip filter with the stubs](image)

Dimensions of filter are calculated with the help of Characteristic admittance and Characteristic admittances can be derived by using design equations (1-8).

\[
\theta = \frac{\pi}{2} \left( 1 - \frac{FBW}{2} \right) 
\]

\[
\frac{l_{12}}{Y_0} = g_0 \frac{h g_1}{g_2}, \quad f_{n-1, n} = g_0 \sqrt{\frac{h g_1 g_{n-1}}{g_0 g_{n-1}}} 
\]

\[
\frac{l_{i,i+1}}{Y_0} = \frac{h g_0 g_1}{g_0 g_{i+1}} \quad \text{for } i = 2 \text{ to } n-2 
\]

\[
N_{i+1} = \sqrt{\frac{l_{i,i+1}}{Y_0}} + \left( \frac{h g_0 g_1 \tan \theta}{2} \right)^2 \quad \text{for } i = 1 \text{ to } n-1 
\]

\[
Y_1 = g_0 Y_0 \left( 1 - \frac{h}{2} \right) g_1 \tan \theta + Y_0 \left( N_{12} - \frac{h l_{12}}{Y_0} \right) 
\]

\[
Y_n = Y_0 \left( g_0 g_{n-1} - g_0 g_{12}^2 \right) \tan \theta + Y_0 \left( N_{n-1,n} - \frac{h l_{n-1,n}}{Y_0} \right) 
\]

\[
Y_i = Y_0 \left( N_{i-1,i} + N_{i,i+1} - \frac{l_{i-1,i}}{Y_0} - \frac{l_{i,i+1}}{Y_0} \right) \quad \text{for } i = 2 \text{ to } n-1 
\]

\[
Y_{i+1} = Y_0 \left( \frac{l_{i,i+1}}{Y_0} \right) \quad \text{for } i = 1 \text{ to } n-1 
\]
Here Y0 is the Characteristic admittances of the line. Characteristic admittances of inverters are denoted as $\Omega$, $\varepsilon$, $\delta$

$n$ is the constant which is unitless, the element values of prototype filter are $g0$, $g1$ and $gn$ such as a Chebyshev, given for a normalized cutoff $\Omega c = 1.0$, FBW is the fractional bandwidth of the filter which is used to decide the bandwidth of filter.

For five short circuited stubs, The prototype parameters of bandpass filter are in standard and fixed format.

$g0 = 1$, $g1 = 1.1468$, $g2 = 1.3712$, $g3 = 1.9750$, $g4 = 1.3712$, $g5 = 1.1468$, $g6 = 1.0$

The various design parameters of microstrip filter is calculated for 1.8 GHz frequency using standard design equations. The characteristic admittance of all the stubs and connecting microstrip line is listed in Table 1.

<table>
<thead>
<tr>
<th>Table 1: Characteristic admittance of microstrip line</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

III. PERFORMANCE COMPARISON OF MICROSTRIP BAND-PASS FILTERS

Three Dielectric materials are mostly used as a substrate for fabrication of Microstrip filters.

1. RT/Duroid 6010 LM which has Dielectric Constant ($\varepsilon_r$) of 10.2, Thickness(h)=0.635 mm, Loss tangent ($\tan \delta$) =0.0023

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

3. RT/Duroid 6006: Dielectric Constant ($\varepsilon_r$) = 6.18, Thickness(h)=1.27 mm, Loss tangent ($\tan \delta$) =0.027

For D.……. It has Dielectric Constant ($\varepsilon_r$) = 10.2, Thickness (h)=0.635 mm, Loss tangent ($\tan \delta$) =0.0023

The widths and guided wavelengths linked with the characteristic admittances of microstrip line can be derived with the help of designed equations and are summarized in Table 2.
### Table 2: Basic Design Parameters of first Microstrip Filter

<table>
<thead>
<tr>
<th>Stubs</th>
<th>Width of Microstrip stubs in mm</th>
<th>Quarter Guided Wavelength in mm</th>
<th>Width of Connecting lines</th>
<th>Length of Connecting lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.6</td>
<td>15</td>
<td>0.97</td>
<td>15.6</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>14.47</td>
<td>1.10</td>
<td>15.5</td>
</tr>
<tr>
<td>3</td>
<td>3.9</td>
<td>14.48</td>
<td>1.10</td>
<td>15.5</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>14.47</td>
<td>0.97</td>
<td>15.6</td>
</tr>
<tr>
<td>5</td>
<td>1.6</td>
<td>15</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The basic design of microstrip filter is shown in Figure 2 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 five 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 1152 mm² which is more compact as compared to existing designs [2-8]. Length of the proposed filter is 72 mm and width of the proposed filter is 16 mm. Fabricated design of proposed microstrip filter is shown in Figure 3.

![Figure 2. Fundamental Design of first Microstrip Filter for RT/Duriod 6010 LM](image-url)

Figure 2. Fundamental Design of first Microstrip Filter for RT/Duriod 6010 LM
(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 ($\tan\delta$) = 0.02

<table>
<thead>
<tr>
<th>Slab</th>
<th>Width of Microstrip stubs in mm</th>
<th>Quarter Guided Wavelength in mm</th>
<th>Width of Connecting lines</th>
<th>Length of Connecting lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.94</td>
<td>21.07</td>
<td>4.498</td>
<td>22.457</td>
</tr>
<tr>
<td>2</td>
<td>16.17</td>
<td>21.04</td>
<td>5.01367</td>
<td>22.0628</td>
</tr>
<tr>
<td>3</td>
<td>19.86</td>
<td>21.06</td>
<td>5.01367</td>
<td>22.0628</td>
</tr>
<tr>
<td>4</td>
<td>16.17</td>
<td>21.04</td>
<td>4.498</td>
<td>22.457</td>
</tr>
<tr>
<td>5</td>
<td>6.94</td>
<td>21.07</td>
<td>4.498</td>
<td>22.457</td>
</tr>
</tbody>
</table>

(3) For RT/Duroid 6006: Dielectric Constant ($\varepsilon_r = 6.15$), Thickness $h=1.27$ mm, Loss tangent ($\tan\delta$) = 0.0027
IV. IMPLEMENTATION AND RESULTS

Table 6: Basic Design Parameters of third Microstrip Filter

<table>
<thead>
<tr>
<th>Stubs</th>
<th>Width of Microstrip stubs in mm</th>
<th>Quarter Guided Wavelength in mm</th>
<th>Width of Connecting lines</th>
<th>Length of Connecting lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.48</td>
<td>19</td>
<td>2.94</td>
<td>19.5</td>
</tr>
<tr>
<td>2</td>
<td>10.6</td>
<td>18</td>
<td>8.18</td>
<td>19.32</td>
</tr>
<tr>
<td>3</td>
<td>10.4</td>
<td>18.1</td>
<td>8.18</td>
<td>19.32</td>
</tr>
<tr>
<td>4</td>
<td>10.6</td>
<td>18</td>
<td>2.94</td>
<td>19.5</td>
</tr>
<tr>
<td>5</td>
<td>4.48</td>
<td>19</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 6 illustrates the frequency response of microstrip band pass filter for the dielectric material RT/Duroid 6010 LM which shows the bandwidth of the filter ranges from 1.24 to 2.26 GHz for GSM guard-band applications. The filters on this band are very precise and miniature as to have better performance and quality parameters.
Performance of the filter is measured in terms of return loss and insertion loss which is measured in the form of S-parameters ($S_{11}$, $S_{21}$). Figure 7 shows the frequency response of microstrip bandpass filter for the dielectric material FR4 Substrate which shows the bandwidth of the filter ranges from 1.2 to 1.8 GHz for mobile communication. It has very low return loss and high insertion loss as compared to previous design.

![S-Parameters Display](image)

**Figure 7:** IE3D EM simulated performance of the second microstrip bandpass filter for Glass Epoxy FR4 dielectric substrate

Figure 8 illustrates the frequency versus return/insertion loss response of microstrip bandpass filter for the dielectric material RT/Duriod 6006 Substrate which shows the bandwidth of the filter ranges from 1.5 to 1.8 GHz for narrowband application. It also has very low return loss and high insertion loss as compared to previous design.

![S-Parameters Display](image)

**Figure 8:** IE3D EM simulated performance of the second microstrip bandpass filter for RT/Duriod 6006 dielectric substrate
Table 5 represents the performance comparison of microstrip filter in terms of return and insertion loss for various dielectric substrates.

Table 5: Performance Comparison of Microstrip Filter for different substrate

<table>
<thead>
<tr>
<th>Material/Substrate</th>
<th>Return loss in dB</th>
<th>Insertion Loss in dB</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT/Duroid 6010 LM</td>
<td>-37.1 dB</td>
<td>-0.52 dB</td>
<td>1.24 to 2.26 GHz</td>
</tr>
<tr>
<td>Glass Epoxy/FR4</td>
<td>-11.9 dB</td>
<td>-2 dB</td>
<td>1.2 to 1.8 GHz</td>
</tr>
<tr>
<td>RT/Duroid 6006</td>
<td>-5.8 dB</td>
<td>-2.2 dB</td>
<td>1.5 to 1.8 GHz</td>
</tr>
</tbody>
</table>

It is obvious from table 5 that most suitable substrate for the designing of microstrip band-pass filter is RT/Duroid 6010 LM which provides wide bandwidth and improved insertion and return loss with compact structure as compared to other substrates.

V. CONCLUSION

In this paper three types of dielectric substrates are used for the performance and design comparison of Microstrip band-pass filters which is used for GSM guard-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 6010 LM is the best dielectric substrate for obtaining good bandwidth, better performance and compact size as compared to other two substrates.

References


