CHAPTER-6

Design and Simulation of Dielectric Resonator Filter with Discontinuities in Microstrip Line

Waveguide filters are popular for their high quality factor, greater temperature stability and allowing a narrow bandwidth in the microwave frequency range. The disadvantage is that they are bulky and heavy in weight. Microstrip line filter design technology is used to overcome these drawbacks of waveguide filter in some of the microwave systems. A wide band filter can be realized by using microstrip line because of their low quality factor (Q). Due to low volume and ease of integration with microwave circuits, microstrip line has gained popularity, but high losses and temperature instability are the main disadvantages. A dielectric resonator filter is a compromise between the waveguide and the microstrip line filter. Dielectric resonators allow reduction in size, (depending on the dielectric constant of the material). The size of the resonator is inversely proportional to the square root of the dielectric constant of the material used. Due to advancement in the ceramic material technology, it is possible to design low dielectric loss resonators. These high dielectric constant resonators are capable to function as a waveguide and as good as in terms of miniaturization, weight and stability. Now a days, low loss dielectric resonators of low volume, light weight and greater temperature stability have been realized. In microwave filter design technology, dielectric resonators are preferred for their better quality factor, low loss and miniaturization attributes. Due to advancement in ceramic material technology and mass production at a reasonably low cost the demand for dielectric resonator filters has increased considerably. Further miniaturization is
possible in case of higher order mode filter [1]. Discontinuities in microstrip line like Defected Ground Structure (DGS), electromagnetic band gap (EBG) or defected microstrip structure (DMS) also play very important role in size reduction techniques [5]. During the course of this research, we have designed and simulated various types of dielectric resonator filters using discontinuities in microstrip line for further miniaturization. These high Q, low loss miniaturized filters are highly suitable for wireless applications. It is a great challenge to meet out the filter design specifications in the era of evolving communication systems. In wireless and satellite base station, they perform significant roles at various stages of the radio frequency (RF) front-end unit. Usually, low loss and high rejection of the signals are required at the pass band edges to get better selectivity and prevent cross-channel interference between the subscribers that share the same spectrum. Low loss, high dielectric constant DR filters are capable of high Qs. At the same operating frequency, high permittivity dielectric resonator filters are considerably smaller in size as compared to hollow cavity resonator filters. The most common shape of dielectric resonators are cylindrical disc. TE\textsubscript{01δ} mode is the dominant mode in this geometry. In this mode, 95% of electric energy and 60% of magnetic energy is stored within the puck and the remaining energy is distributed around surroundings [50]. Generally, ceramic materials used in constructing DRs have a dielectric constant in the range of 10 to 90. Therefore, dielectric resonator filter have gained huge popularity in the field of miniaturization (as compare to resonant cavity filters). In addition, although planar microstrip filters are easier to design and consequently, they can also replace bulky cavity resonator in the most of the microwave communication systems, but their low Q limits them in terms of their performance. Hence they cannot generally be used to fulfill the demand of challenging application of modern communication systems. Therefore,
dielectric resonator filters are used to bridge the gap between microstrip line filters and waveguide filters. They offer flexibility and are capable of being used in a variety of microwave circuits and subsystem. The major drawback of dielectric resonators is that even though their geometric shapes are very simple, it is difficult to find out the accurate solutions for Maxwell equations (as compared to cavity resonator). However, approximations are possible and simple equations may be derived.

6.1 Design and Simulation of Dual Band Dielectric Resonator Filter with Defect at Ground Plane of Microstrip Line

In this research a multiband dielectric resonator with an array of defect in the ground plane is investigated. The filter is designed by placing high quality factor $\text{TE}_{01\delta}$ mode dielectric resonators on the microstrip line. The focus in the design process is on choosing the optimum geometry of the dielectric resonator so that high Q can be achieved. This is to be achieved without compromising miniaturization and efficiency. This filter is designed and simulated for low-pass filtering whose pass-band is 6.2 GHz and the bandwidth of band-pass filter is 1.3 GHz ranging from 9.9 GHz to 11.2 GHz. In this filter, three stair shaped cylindrical dielectric resonators were excited with a simple microstrip line in order to obtain the optimum coupling effect. Holes are created at the ground plane, which provides Defected Ground Structures (DGS) so that harmonics can be reduced. This reduces the volume too. This combination of DGS and DRs proficiently produces a low design profile. There is an inverse proportionality between size and dielectric constant.
A high dielectric constant is required to reduce the circuit size. Significant miniaturization has been achieved in our design because of the dielectric resonator. Geometry of the designed resonators is shown in the figure 6.3. As can be seen, they are stair cylindrical in shape. Total length of the microstrip line is 35mm. The centre position
of first resonator is 10mm down the line, while the second resonator is placed at 17.5mm and third is at 30.2mm (figure 6.1).

![Diagram of a dielectric resonator with dimensions H=3.5mm, D=5.2mm, h=1.9mm, d=1.1mm.]

**Figure 6.3 Geometry of dielectric resonator**

Dielectric constant of the resonator is 60. Seven holes, 1 mm in diameter each are created in the ground plane (figure 6.2). Each DR will resonate in same mode but at a different frequency, so that the combined response is an additional result of the individual responses, leading to an increased overall bandwidth. The choice of the coupling method depends upon the excitation mode of the resonator and the amount of coupling required. For cylindrical dielectric resonators excited in the fundamental TE_{01\delta} mode, magnetic coupling is the optimum solution as there are enough magnetic fields coming out of the resonator radially. Also, the size of the dielectric resonators and the distance between the resonators determine the internal coupling.

Transmission loss and insertion loss are shown in the figure 6.6. Figure 6.4 and 6.5 show the E-field and the H-field distribution. The amount of electrical and magnetic energy confined within the resonators can be easily seen.
Figure 6.4: E-field variations of dual band dielectric resonator filter

Figure 6.5: H-field variations of dual band dielectric resonator filter
Table 6.1: Different parameters of low-pass and band-pass filter

<table>
<thead>
<tr>
<th>Parameters/ Filter</th>
<th>Low-pass Filter</th>
<th>Band-pass Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Cut-off Frequency (-3 dB)</td>
<td>--------</td>
<td>9.9 GHz</td>
</tr>
<tr>
<td>Upper Cut-off Frequency (-3 dB)</td>
<td>6.2 GHz</td>
<td>11.2 GHz</td>
</tr>
<tr>
<td>Resonant Frequency $f_0$</td>
<td>3.1 GHz</td>
<td>10.55 GHz</td>
</tr>
<tr>
<td>Bandwidth (-3 dB)</td>
<td>6.2 GHz</td>
<td>1.3 GHz</td>
</tr>
<tr>
<td>Fractional Bandwidth</td>
<td>50 %</td>
<td>12.34%</td>
</tr>
</tbody>
</table>
6.2 A Novel Dielectric Resonator Band-Pass Filter (DRBF) with DGS

Further in this research, a tunable dielectric resonator band-pass filter has been successfully designed. Tunability is achieved by varying the thickness \( t \) of high impedance line which is coupled between two L-shaped ports as shown in the figure 6.7. Here, two types of coupling exist; first is between the L-shaped port and high impedance line and the second is between the port and the dielectric resonator. A matched combination of dielectric resonators and microstrip circuits generate an additional coupling effect. All these coupling effects are merged together to produce a wideband device. This also increases the quality factor of the whole circuit, increases the transmitting power and reduces the insertion loss. Holes are created in the ground plane as a Defected Ground Structures (DGS).

![Figure 6.7: Geometry of dielectric resonator filter with DGS](image)

L=50mm, w= 2.41mm, h= 9.53mm, b=13.4mm, a=25mm, \( t=0.75\)mm, D=7.5mm and height of DR is 3.48mm.
DGS reduces the harmonics and circuit size. Together the combination of DGS and DR produces a low design profile. In this band-pass filter, we achieved high-quality factor, reduced size and variable bandwidth. The DRs used in this filter are cylinder in shape. The dimensions of the microstrip line used in this filter are 50mm × 20mm × 0.8mm. The central distance between the resonators is 9mm. The dielectric constant of microstrip line is 3.2, while dielectric constant of dielectric resonator is 68. The shape and size of the dielectric resonator specify its fundamental mode. Among all, TE$\text{}_{01\delta}$ mode is the most interesting because this is the dominant mode and it is simple to excite. To achieve TE$\text{}_{01\delta}$ mode, the height of the DR must be about 40% of the diameter. The diameter and height of the resonators used in this filter are 7.5mm and 3.48mm respectively. Since dielectric permittivity is fixed, the physical dimensions of DR are used to obtain the operating frequency of the filter. The spacing between dielectric resonators on the microstrip line is used to tune the desired operating frequency band and/or to achieve good impedance matching within the frequency band of interest.

When a dielectric resonator is placed in the vicinity of a microstrip line (figure 6.7), and excited in the TE$\text{}_{01\delta}$ mode, the transmission characteristics are modified by the magnetic effect. The electric field in the high permittivity dielectric resonator is small because majority of the electric field is not only concentrated in the microstrip line but almost orthogonal to the dielectric resonator. The magnetic effect is the interaction between the magnetic fields of the dielectric resonator and the magnetic fields owing to the current in the microstrip structure. This interaction can be considered as a mutual inductance, and an electromotive force is caused in the microstrip structure [50]. We know that the resonance frequency $f_0$ of the filter depends on the physical dimensions of the DR. By
tuning and optimization a good band-pass filter has been realize. The high impedance line is terminated with broader thickness \( t_{\text{term}} > t_{\text{line}} \). The insertion loss and return loss at different values of “t” have been shown in the figure 6.8 and 6.9 respectively. It is clearly seen that, by varying the thickness of high impedance line, the bandwidth of the filter is also varied.

**Figure 6.8: Insertion loss at variable thickness “t”**

**Figure 6.9: Return loss at variable thickness “t”**
Table 6.2: Variation in parameters at different value of widths of impedance line “t”

<table>
<thead>
<tr>
<th>Width “t” (mm)</th>
<th>Insertion Loss (dB)</th>
<th>Return Loss (dB)</th>
<th>Center Frequency $f_0$ (GHz)</th>
<th>3-dB Bandwidth (GHz)</th>
<th>Fractional B.W</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>-0.3</td>
<td>-15</td>
<td>3.6</td>
<td>1.2</td>
<td>33%</td>
</tr>
<tr>
<td>0.4</td>
<td>-0.3</td>
<td>-13</td>
<td>3.61</td>
<td>1.27</td>
<td>35%</td>
</tr>
<tr>
<td>0.5</td>
<td>-0.3</td>
<td>-14</td>
<td>3.57</td>
<td>1.36</td>
<td>38%</td>
</tr>
<tr>
<td>0.6</td>
<td>-0.3</td>
<td>-13</td>
<td>3.54</td>
<td>1.49</td>
<td>42%</td>
</tr>
<tr>
<td>0.7</td>
<td>-0.3</td>
<td>-12.5</td>
<td>3.51</td>
<td>1.67</td>
<td>47.5%</td>
</tr>
<tr>
<td>0.8</td>
<td>-0.17</td>
<td>-14.5</td>
<td>3.47</td>
<td>1.9</td>
<td>54.5%</td>
</tr>
</tbody>
</table>

The thickness of the termination ($t_{term}$) plays a major role in increasing or decreasing the bandwidth of the filter. As can be seen from the table 6.2, the center frequency remains almost constant. Parameters like insertion loss, return loss, resonant frequency, bandwidth and fractional bandwidth at different value of “t” has been tabulated in the table 6.2. By fixing the thickness of high impedance line as 0.75mm, a model has been fabricated. The top and the bottom view of fabricated model of the filter are shown in the figure 6.10 and 6.11 respectively.
Figure 6.10: Top view of fabricated model of filter

Figure 6.11: Bottom view of fabricated model of filter
Figure 6.12: S-Parameters of simulated and measured result at $t = 0.75$ mm.

The comparisons of simulated and measured results are shown in the figure 6.12. The simulated bandwidth of this filter is 1.8 GHz ranging from 2.6 GHz to 4.4 GHz. In case of measured result, the bandwidth of the filter is 1.76 GHz and the lower and upper cut-off frequencies are 2.48 GHz and 4.24 GHz respectively. Values of various simulated and measured parameters are shown in table 6.3.

Table 6.3: Comparison of simulated and measured parameters at $t = 0.75$mm

<table>
<thead>
<tr>
<th>Parameters/ Result</th>
<th>Insertion Loss (dB)</th>
<th>Return Loss (dB)</th>
<th>Center Frequency $f_0$ (GHz)</th>
<th>3-dB Bandwidth (GHz)</th>
<th>Fractional Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulated</td>
<td>-0.17</td>
<td>-14</td>
<td>3.5</td>
<td>1.8</td>
<td>51%</td>
</tr>
<tr>
<td>Measured</td>
<td>-0.43</td>
<td>-12.5</td>
<td>3.36</td>
<td>1.76</td>
<td>52%</td>
</tr>
</tbody>
</table>

From the above data, we can say that the simulated and measured results are almost similar.
6.3 Design of Novel Dielectric Resonator Band-Pass Filter with DGS and DMS.

Here, we propose a dielectric resonator band-pass filter with Defected Ground Structures (DGS) and Defected Microstrip Structures (DMS). A z-shaped FR-4 microstrip line is used to design the filter. A square dumb-bell shaped DGS is etched out at the ground plane and two slots are cut on the strip of microstrip line which acts as a DMS. Two dielectric resonators are placed on the microstrip line separated by 14.5mm. The dielectric resonator is responsible of the high Q value, while Defected Ground Structure (DGS) and Defected Microstrip Structure (DMS) are used for further inductive and capacitive coupling as well as size reduction. The gap “w” on the strip of the mirostrip line helps in the maximum confinement of energy in the resonator.

Figure 6.13: Geometry of Band-pass filter with DGS and DMS

a= 30mm, h=20mm, L=13.7mm, b=10.85mm, p=4.05mm, x=5.5mm, w=0.8mm, t=0.3mm, r=14.5mm
The idea behind taking z-shape is to achieve maximum discontinuities in microstrip line. The detailed geometry and dimensions of the filter is shown in the figure 6.13. The resonator used in this filter is cylindrical in shape with radius and height of 3.75mm and 3.5mm respectively, and dielectric constant 68. Step by step simulated layout is shown in figure 6.14 (top view without DRs), figure 6.15 (top view with DRs) and 6.16 (bottom view with DGS). Figure 6.14 shows the discontinuities in the strip of microstrip line, while figure 6.15 shows the dielectric resonators loaded on microstrip line and figure 6.16 shows the layout of DGS. By tuning and optimization, a band-pass filter has been realized.

Figure6.14: Top view of HFSS model of filter (without DRs)
Figure 6.15: Top view of HFSS model of Band-pass filter (with DRs)

Figure 6.16: Bottom view of HFSS model of band-pass filter (with DGS)
This filter is designed and simulated on High Frequency Structure Simulator (HFSS). The simulated insertion loss and return loss of the filter is shown in figure 6.17. This filter is resonating at 1.875 GHz. The bandwidth of the filter is 950 MHz ranging from 1.4 GHz to 2.35 GHz. The field pattern (E-field and H-field) are shown in the figure 6.20 and 6.21 respectively.

![Figure 6.17: Frequency response of simulated result](image)

Figure 6.17: Frequency response of simulated result

![Figure 6.18: E-field variation of band-pass filter](image)

Figure 6.18: E-field variation of band-pass filter
Figure 6.19: H-field variation of band-pass filter

A physical model of filter is fabricated on FR-4 epoxy (dielectric constant 4.4). The top and bottom view of the fabricated model (without DRs) are shown in the figure 6.20 (a) and (b) respectively. A complete model of the filter loaded with DRs is shown in the figure 6.21.

Figure 6.20: Fabricated model  (a) top view  (b) Bottom view of microstrip line without DR
Figure 6.21: Fabricated model of DR band-pass filter with DGS.

Figure 6.22: Frequency response curve of measured result
Figure 6.23: Comparison of S11 of simulated and measured results

Figure 6.24: Comparison of S21 of simulated and measured results
Figure 6.22, shows the frequency response curve (insertion loss and return loss) of the measured result. Both simulated and measured results are compared and some deviation is observed between the measured and the simulated results. This may be due to FR4-epoxy substrate used as a dielectric of microstrip line and losses in FR4-epoxy is greater as compared to RT Duriod. The comparison of return loss and insertion loss of simulated and measured results are shown in the figure 6.23 and 6.24 respectively. The values of various simulated and measure parameters are shown in table 6.4.

Table 6.4: Comparison of simulated and measured result

<table>
<thead>
<tr>
<th>Parameters/ Filter</th>
<th>Simulated</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Cut-off Frequency (-3 dB)</td>
<td>1.4 GHz</td>
<td>1.48 GHz</td>
</tr>
<tr>
<td>Upper Cut-off Frequency (-3 dB)</td>
<td>2.35 GHz</td>
<td>2.02 GHz</td>
</tr>
<tr>
<td>Resonant Frequency $f_0$</td>
<td>1.875 GHz</td>
<td>1.75 GHz</td>
</tr>
<tr>
<td>Bandwidth (-3 dB)</td>
<td>950 MHz</td>
<td>540 MHz</td>
</tr>
<tr>
<td>Fractional Bandwidth</td>
<td>50.66 %</td>
<td>30.87%</td>
</tr>
</tbody>
</table>

The simulated result is centered around 1.875 GHz, while resonant frequency of measured result is 1.75 GHz. Bandwidths of both the simulated and measured results are 950 MHz and 540 MHz respectively.
6.4. Design and Simulation of Dielectric Resonator Band-stop Filter using Ring type DGS

In this filter, single dielectric resonator loaded on ring type Defected Ground Structure microstrip line is used. This filter is designed in such a way that two open stubs are connected with the microstrip line. The detailed geometry and dimensions are shown in figure 6.25. A single DR (dielectric constant 68) is placed between two poles of the microstrips line. This resonator is placed on the substrate of microstrip line in the vicinity of stubs and the strip. Four, ring type DGS is created at the ground plane. All these DGS are at equidistance.

![Figure 6.25: Geometry of filter](image)

L = 25mm, b = 14mm, w = 1.2mm, r = 5mm, D = 7.95mm, d = 7.5mm, t = 0.8mm, s = 0.2mm, h = 8.3mm

The distance between the resonator and microstrip line plays a very important role in determining the coupling coefficient $\beta$. The coupling coefficient $\beta$ is the ratio of resonator
coupled resistance (R) at the resonant frequency to the resistance external to the resonator \((R_{\text{ext}})\)

\[
\beta = \frac{R}{R_{\text{ex}}} = \frac{R}{2Z_0} = \frac{S_{110}}{1-S_{110}} = \frac{1-S_{210}}{S_{210}} = \frac{S_{110}}{S_{210}}
\]

6.1

Where, \(Z_0\) is the characteristics impedance. \(S_{110}\) and \(S_{210}\) are the real values of reflection and transmission coefficient respectively.

The dielectric resonator coupled with microstrip line is equivalent to a parallel resonant circuit placed in series with the line (figure 6.26). The normalized induced impedance \(Z\) can be represent as [71],

\[
Z = \frac{1+2\beta+2JQ_u\delta}{1+2JQ_u\delta}
\]

6.2

Where \(Q_u\) is unloaded quality factor of resonator and \(\delta = (f - f_0)/f_0\). This circuit can be represented in terms of scattering parameters (reflection coefficient) as follows:

\[
S_{11} = (Z - 1)/(Z + 1)
\]

6.3
For ideal condition, it can be assumed that,

$$S_{11} + S_{21} = 1$$  \hspace{1cm} 6.4

Where, $S_{21}$ is the transmission coefficient. And it can be written as,

$$S_{21} = \frac{2}{2+1}$$  \hspace{1cm} 6.5

Therefore S parameters coupled to microstrip line with resonator can be written as

$$S = \begin{bmatrix} \beta & 1+j2Q_{u}\delta \\ 1+\beta+j2Q_{u}\delta & 1+\beta+j2Q_{u}\delta \end{bmatrix} \begin{bmatrix} 1+\beta+j2Q_{u}\delta \\ 1+\beta+j2Q_{u}\delta \end{bmatrix}$$  \hspace{1cm} 6.6

At resonance $\delta = 0$ and scattering matrix reduce to

$$S_0 = \begin{bmatrix} \beta & 1 \\ 1+\beta & 1+\beta \\ 1 & \beta \\ 1+\beta & 1+\beta \end{bmatrix}$$  \hspace{1cm} 6.7

The top and bottom view of HFSS schematic model of dielectric resonator band-stop filter with ring type DGS is shown in the figure 6.27 and figure 6.28 respectively. This filter is simulated on FR-4 epoxy (dielectric constant 4.4) substrate. The simulated frequency response curve is shown in the figure 6.29. The stop-bandwidth of this filter is 2.7 GHz (from 4.5 GHz to 7.2 GHz). The E-field and H-field patterns are shown in the figure 6.30 and 6.31 respectively.
Figure 6.27: Top view of dielectric resonator band-stop filter with ring type DGS.

Figure 6.28: Bottom view of DR band-stop filter with ring type DGS.
Figure 6.29: Simulated frequency response curve of band-stop filter

Figure 6.30: E-Field Pattern of band-stop filter
By using FR-4 epoxy (dielectric constant 4.4), a model has been fabricated. The top view and the bottom view of dielectric resonator band-stop filter are shown in the figure 6.32 (a) and (b) respectively. A DR (dielectric constant 68) is fixed using adhesive Loctite 409.
Figure 6.33: Simulated frequency response curve of band-stop filter

Figure 6.34: Comparison of S11 of simulated and measured results
The frequency response curve of the measured result is shown in the figure 6.33. The measured stop-bandwidth of this filter is 2.6 GHz (from 3.6 GHz to 6.2 GHz). The resonating frequency of the measured result is 4.9 GHz. The comparison between simulated and measured results of insertion loss and transmission loss are shown in figure 6.34 and 6.35.

Values of various simulated and measured parameters are shown in table 6.5. Here, some deviation is observed between the simulated and measured results. This may have been caused due to lack of fabrication expertise (difference between the designed and the actually fabricated dimensions).
Table 6.5: Simulated and measured parameters of band-stop filter

<table>
<thead>
<tr>
<th>Parameters/ Filter</th>
<th>Simulated</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Cut-off Frequency of stop-band (-3 dB)</td>
<td>4.5 GHz</td>
<td>3.6 GHz</td>
</tr>
<tr>
<td>Upper Cut-off Frequency of stop-band (-3 dB)</td>
<td>7.2 GHz</td>
<td>6.2 GHz</td>
</tr>
<tr>
<td>Resonant Frequency ( f_0 )</td>
<td>5.85 GHz</td>
<td>4.9 GHz</td>
</tr>
<tr>
<td>Stop-bandwidth (-3 dB)</td>
<td>2.7 GHz</td>
<td>2.6 GHz</td>
</tr>
<tr>
<td>Fractional Stop-bandwidth</td>
<td>46.15 %</td>
<td>53.06 %</td>
</tr>
</tbody>
</table>

6.5 Design and Simulation of Novel Dual-Band Dielectric Resonator with Defect on Microstrip Structure

This filter is a dual band dielectric resonator with defected microstrip structure (DMS). The geometry and dimensions of the filter is shown in figure 6.36. The DMS is created by etching some portion of the top of the z-shaped Rogers RO4350 microstrip line. The dielectric constant of microstrip line is 3.66. Two dielectric resonators are placed above the DMS portion of the strip line. The dielectric constant of the resonator used in this filter is 60 and the radius and height of the dielectric resonators are 7mm and height is 3.4mm respectively. Here, by tuning and optimization, a dual band band-pass filter has been realized. This dual band characteristic is achieved due to the coupling between the microstrip line and the coupling between the two resonators themselves. Step by step simulated design layout is shown in the figure 6.37 and 6.38. Figure 6.37 shows the discontinuities in the strip of microstrip line and figure 6.38 shows the dielectric resonators filter loaded on microstrip line.
Figure 6.36: Geometry of dual-band DR filter with defect on microstrip structure

\[ a = 30\text{mm}, \; h=20\text{mm}, \; L=13.7\text{mm}, \; b=10.85\text{mm}, \; p=5.7\text{mm}, \; w=0.4\text{mm}, \; t=0.13\text{mm}, \; r=14.5\text{mm} \]

Figure 6.37: Top view of HFSS model of dual band-pass filter (without DRs)
Figure 6.38: Top view of HFSS model of dual band-pass filter (with DRs)

Figure 6.39: E-Field variation of filter
Figure 6.40: H-Field Variation of filter

The E-field and the H-field of the filter is shown in the figure 6.39 and 6.40 respectively. In both the simulation results (figure 6.39 and figure 6.40), the resonators place on the left side possess more energy than that on the right side. The maximum energy is confined at the gaps (figure 6.37) on the microstrip line. The reflection and the transmission coefficient are shown in figure 6.41.

Figure 6.41: Frequency response curve of dual band dielectric resonator filter
The resonant frequency of the first band of filter is 6.82 GHz while the resonance of second band is 8.02 GHz with a stop-band between the two pass-bands is 540 MHz as can seen in figure 6.41.

Bandwidth of the first band of the filter is 980 MHz (from 6.33 GHz to 7.31 GHz), while the bandwidth of second band is 400 MHz (from 7.85 GHz to 8.25 GHz). The detailed parameters of the filter are tabulated in table 5.6.

Table 5.6: Simulated parameters of dual-band dielectric resonator filter

<table>
<thead>
<tr>
<th>Parameters/ Filter</th>
<th>First Band-pass Filter</th>
<th>Second Band-pass Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Cut-off Frequency (-3 dB)</td>
<td>6.33 GHz</td>
<td>7.85 GHz</td>
</tr>
<tr>
<td>Upper Cut-off Frequency (-3 dB)</td>
<td>7.31 GHz</td>
<td>8.25 GHz</td>
</tr>
<tr>
<td>Resonant Frequency ( f_0 )</td>
<td>6.82 GHz</td>
<td>8.02 GHz</td>
</tr>
<tr>
<td>Bandwidth (-3 dB)</td>
<td>980 MHz</td>
<td>400 MHz</td>
</tr>
<tr>
<td>Fractional Bandwidth</td>
<td>14.36 %</td>
<td>4.98 %</td>
</tr>
<tr>
<td>Stop-bandwidth between two pass-band</td>
<td></td>
<td>540 MHz</td>
</tr>
</tbody>
</table>