CHAPTER 2

DESIGN AND IMPLEMENTATION OF A MICROSTRIP PATCH ANTENNA ARRAY

2.1 INTRODUCTION

The past two decades have witnessed the growing popularity of microstrip antenna arrays in wireless applications. The microstrip antenna array consists of a number of flat metallic radiating patches on a grounded dielectric material, that is cascaded together. The cascading of the radiating elements is achieved by the feed network. Therefore, in a microstrip antenna array configuration, the feed network is crucial. There are two types of feed methods used in a microstrip antenna array namely, the series feed and the corporate feed. In this research work, the microstrip antenna array elements are individually connected to the feed network, using the corporate feed method.

This chapter discusses three microstrip antenna array structures:

- Single frequency microstrip antenna array

The single frequency microstrip antenna array is designed using the corporate feed method. The radiating element in the microstrip antenna array is a rectangular patch, which is placed on the grounded dielectric substrate. This microstrip antenna array is designed to operate at 4.8 GHz, using single layer configuration.
• Dual band-dual polarised microstrip antenna array

The dual band-dual polarised microstrip antenna array is designed, using the corporate feed method. Similar to the single frequency microstrip antenna array in this design also the radiating element is a rectangular patch, which is placed on the grounded dielectric substrate. This microstrip antenna array is designed to operate at dual band of frequencies, viz., 3.12 GHz and 4.8 GHz, using a single layer configuration.

• Dual band aperture coupled microstrip antenna array

The dual band aperture coupled microstrip antenna array is designed, using the aperture coupled feed. The microstrip antenna array has a rectangular patch as its radiating element and the radiating patches are connected together using the corporate feed method. This aperture coupled feed microstrip antenna array is designed to operate at dual band of frequencies, viz., 3.12 GHz and 4.8 GHz. This antenna array is designed, using a multilayer configuration, in which the first dielectric material is sandwiched between the ground plane, and the aperture slot, and the second dielectric material is sandwiched between the aperture slot and the radiating patch.

The proposed microstrip antenna array simulations are carried out by CST microwave studio software, using the Finite Integration Technique (FIT) method. The designed microstrip antenna arrays are successfully fabricated using an FR-4 dielectric material, having a dielectric constant of 4.4 and a thickness of 1.6 mm. The performances of the designed microstrip antenna arrays are compared in simulation and measurement.
2.2 DESIGN OF A MICROSTRIP LINE

The microstrip line is a conductor of width $w$ printed on a thin grounded dielectric material of thickness $h$ and relative permittivity $\varepsilon_r$. The geometry of the microstrip line is shown in Figure 2.1 (Pozar 1992).

The effective dielectric constant $\varepsilon_{\text{reff}}$ of a microstrip line is given in Equation (2.1) (Pozar 1992).

$$\varepsilon_{\text{reff}} = \left( \frac{\varepsilon_r - 1}{2} \right) + \left[ \left( \frac{\varepsilon_r - 1}{2} \right) \left( 1 + \frac{12h}{w} \right)^{-1/2} \right]$$

(2.1)

![Figure 2.1 Geometry of the microstrip line](image)

**Figure 2.1 Geometry of the microstrip line**

The characteristic impedance $Z_0$ is calculated using Equation (2.2)

$$Z_0 = \begin{cases} \frac{60}{\sqrt{\varepsilon_{\text{reff}}}} \ln \left[ \frac{8h}{w} + \frac{w}{4h} \right] & \text{for } \frac{w}{h} \leq 1 \\ \frac{120\pi}{\sqrt{\varepsilon_{\text{reff}}}} \left[ \frac{w}{h} + 1.393 + 0.667 \ln \left( \frac{w}{h} + 1.444 \right) \right] & \text{for } \frac{w}{h} \geq 1 \end{cases}$$

(2.2)
For a given characteristic impedance $Z_0$, line length $\ell$, phase shift $\phi$ and dielectric constant $\varepsilon_r$, the w/h ratio is calculated using Equation (2.3).

$$\frac{w}{h} = \left\{ \begin{array}{ll}
\frac{8e^A}{e^{2A} - 2} & \text{for } \frac{w}{h} < 2 \\
\frac{2}{\pi} B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r} \left[ \ln(b - 1) + 0.39 \frac{0.61}{\varepsilon_r} \right] & \text{for } \frac{w}{h} > 2
\end{array} \right. $$

(2.3)

where,

$$A = \frac{Z_0}{60} \sqrt{\frac{\varepsilon_r + 1}{2}} \left( \frac{\varepsilon_r - 1}{\varepsilon_r + 1} \right) \left( 0.23 + \frac{0.11}{\varepsilon_r} \right) $$

(2.4)

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} $$

(2.5)

$$\phi = \frac{180^\circ}{\sqrt{\varepsilon_{\text{reff}}} K_0} $$

(2.6)

$$K_0 = \frac{2\pi f_o}{c} $$

(2.7)

where $f_o$ - operating frequency

c - velocity of light

The matching impedance $Z_0$ is obtained using the formula in (2.8)

$$Z_0 = \sqrt{Z_1 Z_2} $$

(2.8)

The microstrip antenna length $L$ is obtained using Equation (2.9)

$$L = \frac{c}{2f_o\sqrt{\varepsilon_{\text{reff}}}} - 2\Delta L $$

(2.9)
where \( f_0 \) - Operating frequency

\( c \) - Velocity of light

\( \varepsilon_r \) - Permittivity of the dielectric substrate

\( \varepsilon_{\text{reff}} \) - Effective permittivity of the dielectric substrate

\( w \) - Width of the Patch

\( L \) - Length of the Patch

\( h \) - Thickness of the dielectric substrate

\( \Delta L \) - Extension of the length of patch

The patch width \( w \) is calculated using equation (2.12)

\[
w = \frac{c}{2f_0} \left[ \frac{2}{\varepsilon_r + 1} \right]^{1/2} \tag{2.12}
\]

The input admittance at the radiating edge is given by

\[
y_{\text{in}} = y_{\text{slot}} + y_o \frac{y_{\text{slot}} + jy_o \tan \beta (L + \Delta L)}{y_o + jy_{\text{slot}} \tan \beta (L + 2\Delta L)} \tag{2.13}
\]

At resonance, \( y_{\text{in}} = 2G \)
The conductance, \( G \) for the parallel radiator, is obtained using Equation (2.14)

\[
G = \frac{\pi w}{\eta \lambda_0} \left[ 1 - \frac{(kh)^2}{24} \right]
\]  

(2.14)

where,

\[
k = \frac{2\pi f_0}{c}
\]  

(2.15)

Intrinsic impedance \( \eta = 120\pi \)  

(2.16)

\( \lambda_0 \) - operating wavelength and

\( w \) - width of the patch

2.3 DESIGN OF A MICROSTRIP PATCH ANTENNA

2.3.1 Single Microstrip Patch Antenna

The microstrip patch antenna and its equivalent circuit transmission model is shown in Figure 2.2. The radiating patch is placed above the dielectric layer. From Figure 2.2, it is seen that the radiating patch has two radiating slots, namely, slot 1 and slot 2. The figure shows the flow of current through the patch and the ground plane (James et al 1989).
Figure 2.2 Microstrip patch antenna and its equivalent circuit

Figure 2.3 shows a microstrip patch antenna along with its patch dimensions. Using Equation (2.9) the radiating patch length $L$ is determined as 14.4 mm, and using Equation (2.12) the radiating patch width $W$ is determined as 19 mm. The microstrip feed line width is 0.672 mm, and the length is 16 mm. Using Equation (2.13) the feed point in the radiating patch $y_o$ is determined to be at a distance of 5.54 mm from the edge of the radiating patch.
2.3.2 Two Element Microstrip Patch Antenna Array

The microstrip patch antenna array of two elements with corporate feed is shown in Figure 2.4. The impedance matching of the inset feed microstrip line is 100 Ω for each of the microstrip patch antenna arrays, and they are matched to 50 Ω at the feed point. The feed point is connected to the coaxial probe of 50 Ω. This arrangement of the feed is easy to design and fabricate. The location of the inset feed point is determined, using Equation (2.13) for achieving the best impedance matching. The microstrip antenna array consists of two radiating patches having a width, W = 19 mm and length, L = 14.4 mm.

![Figure 2.4 Two element microstrip patch antenna array](image)

2.4 GEOMETRY OF THE MICROSTRIP PATCH ANTENNA

2.4.1 Single Frequency Microstrip Patch Antenna

The rectangular microstrip patch antenna is designed to operate at a frequency of 4.8 GHz. The schematic of the rectangular microstrip patch antenna for single frequency, on a ground plane, is illustrated in Figure 2.5. The ground plane lies at the bottom side of the substrate with a compact size of 30 mm x 30 mm. The radiating element of the proposed antenna consists
of a rectangular patch with a length (L) of 14.4 mm and a width (W) of 19 mm. The microstrip feed line of a width (w) of 3.6 mm and a length of 16 mm is designed for proper 50 Ω impedance matching. This design is etched on top of an FR-4 substrate, with a dielectric constant of 4.4 and thickness of 1.6 mm. The coaxial probe type Subversion Miniature A (SMA) connector is given at the end of the inset fed microstrip line. The feed location has been obtained for the inset feedline of the patch at 5.54 mm. The total thickness of the antenna is 1.67 mm.

![Figure 2.5 Microstrip patch antenna](image)

2.4.2 Two Element Microstrip Patch Antenna Array

The schematic of the two element microstrip patch antenna array is shown in Figure 2.6. The microstrip patch antenna array is designed for single frequency of 4.8 GHz. The ground plane lies at the bottom of the substrate of size of 60 mm x 60 mm. The antenna array consists of two rectangular patches, and it is printed on the top of an FR-4 substrate with a dielectric constant of 4.4 and thickness h of 1.6 mm. The total thickness of the antenna array is 1.67 mm.
The microstrip feed line width \(w\) is 0.672 mm and the length is 16 mm, printed along with the microstrip antenna on the same layer. The microstrip line and its feed position are calculated in such a way, that it has proper impedance matching with the radiating patch element. The optimal distance for the feed point in the patch element, obtained by the formulae (2.13), is 5.54 mm. The microstrip feedline is designed as a quarter wave transformer line for the best impedance matching. This feed point is very important in the designing of the antenna array, and is connected by an SMA connector.

![Figure 2.6 Two element microstrip patch antenna array](image)

2.4.3 Four Element Microstrip Patch Antenna Array

The schematic of the four element microstrip patch antenna array is shown in Figure 2.7. The microstrip patch antenna array is designed for single frequency of 4.8 GHz. The ground plane lies at the bottom of the substrate with a size of 100 mm x 100 mm. The antenna array consists of four rectangular patches, and it is etched on the top of an FR-4 substrate with a dielectric constant of 4.4 and thickness \(h\) of 1.6 mm. The total thickness of the antenna array is 1.67 mm.
The microstrip line width is 0.672 mm and the length is 16 mm, printed with the antennas on the same layer. The microstrip line and its feed position are designed in such a way, that it has proper impedance matching with the radiating patch. The optimal distance for the feed point in the radiating patch is calculated as 5.54 mm using the formulae (2.13). The microstrip line is designed as a quarter wave transformer line for the best impedance matching. This feed point is very important, while designing the microstrip patch antenna array, and the feed excitation is given by an SMA connector.

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**Figure 2.7 Four element microstrip patch antenna array**

**2.4.4 Dual Frequency-Dual Polarised Microstrip Patch Antenna Array**

**2.4.4.1 Dual frequency-dual polarised microstrip patch antenna array**

The schematic of the two element microstrip patch antenna array for dual frequency-dual polarisation is shown in Figure 2.8. The antenna array is designed to have dual polarisation by tilting the radiating patches at ±45°. The ground plane lies at the bottom side of the substrate of a size of 60 mm x 60 mm. The proposed antenna array consists of two radiating elements, and it is printed on the top of an FR-4 material having a dielectric constant 4.4
and thickness (h) of 1.6 mm. The total thickness of the antenna array is 1.67 mm.

The rectangular patch can be excited both in length and width, in order to produce dual resonances. This is done by using the equations in section 2.2 with the dielectric constant of 4.4 and thickness of 1.6 mm for the operating frequencies of 3.12 GHz and 4.8 GHz. Initially, the feedline is designed to match the impedance value of 100 Ω, and then, it is matched to the impedance value of 70 Ω for an appropriate power transfer of energy. The rectangular microstrip antenna array has the following dimensions of a length (L) = 14.4 mm and a width (W) = 19 mm for each patch. The position of the feed point is crucial in this design of the antenna array. Both the radiating patches are tilted by ± 45° for achieving dual polarisation. The tilted radiating elements are connected, using a quarter wave transformer line through a single feed. The excitation of the microstrip antenna array is given, using an SMA connector at the center of the feed line of the feed network. The two rectangular patches are connected, using the corporate feed network. The inset feed point from the bottom side of the radiating patch is at 5.67 mm and the inset feed length is 16 mm.

![Figure 2.8 Dual frequency-dual polarised microstrip patch antenna array](image)

Figure 2.8 Dual frequency-dual polarised microstrip patch antenna array
2.4.4.2 Dual frequency-dual polarised microstrip patch antenna array

The schematic of the two element microstrip patch antenna array for dual frequency-dual polarisation is shown in Figure 2.9. In the figure the radiating patches of the microstrip antenna array can be tilted at + 45° and -45° individually, for achieving dual polarisation. The ground plane lies at the bottom side of the substrate of a size of 60 mm x 60 mm. The proposed antenna array consists of two radiating elements, and it is printed on the top of an FR-4 dielectric material, having a dielectric constant of 4.4 and thickness h of 1.6 mm. The total thickness of the antenna array is 1.67 mm.

![Figure 2.9 Dual frequency-dual polarised microstrip patch antenna array](image)

2.4.5 Aperture Coupled Microstrip Patch Antenna Array

2.4.5.1 Aperture coupled microstrip patch antenna

Another popular feeding method is the electromagnetic coupled feed, in which the feed network and the radiating patch are coupled indirectly through a coupling slot. This antenna design is otherwise called as a superstrate antenna or multilayer antenna. The feedline is the bottommost layer. The coupling slot is kept in between the two dielectric substrates. The
A radiating patch is kept on top of the superstrate dielectric material. The advantages of this antenna design are a wide bandwidth, reduced feed network loss, and good efficiency. The disadvantages are, the difficulty in fabrication, and dielectric loss due to the increased substrate height. Figure 2.10 shows the schematic of the aperture coupled single microstrip antenna. The proposed antenna consists of a single radiating element, and it is etched on the top of an FR-4 material, having a dielectric constant of 4.4 and thickness (h) of 1.6 mm. The total thickness of the antenna is 3.305 mm.

![Figure 2.10 Aperture coupled microstrip patch antenna](image)

2.4.5.2 Two element aperture coupled microstrip patch antenna array

The schematic of the dual band two element aperture coupled microstrip patch antenna array is shown in Figure 2.11. The antenna array has a corporate feed network for the arrangement of the patches. The feed network is at the bottom most layer of the antenna design. The U-shaped aperture slot is designed to have electromagnetic coupling between the feed network and the radiating patches. A layer of dielectric material is sandwiched between the feed network layer and aperture coupled slot layer. The proposed antenna array consists of two radiating elements, which are printed on the topmost FR-4 material, having a dielectric constant 4.4 and thickness h of 1.6 mm. The total thickness of the antenna array is 3.305 mm.
The rectangular radiating patches have a length \((L) = 14.4\) mm, and width \((W) = 19\) mm each.

The U- shaped slot is designed in such a way that it gives dual band of operations at 3.12 GHz and 4.8 GHz. The feedline is designed to match the impedance value of 50 \(\Omega\), and then, it is matched to the impedance value of 70 \(\Omega\) for an appropriate power transfer of energy. The position of the feed point is crucial in this design of antenna array. The excitation is given by an SMA connector at the center of the feed line of the feed network.

![Radiating patches](image)

**Figure 2.11** Two element aperture coupled microstrip patch antenna array

### 2.4.5.3 Four element aperture coupled microstrip patch antenna array

The schematic of the four element aperture coupled patch microstrip antenna array for dual frequency is shown in Figure 2.12. The antenna array has a corporate feed network for cascading all the four patches. The feed network is at the bottom-most layer of the antenna design. The U-shaped aperture coupled slot is designed to achieve electromagnetic coupling between the feed network and the radiating patches. A layer of dielectric material is sandwiched between the feed network layer and the aperture
coupled slot layer. The proposed antenna array consists of four radiating elements, which are printed on the top of a second FR-4 material, having a dielectric constant of 4.4 and thickness $h$ of 1.6 mm. The total thickness of the antenna array is 3.305 mm. The rectangular radiating patches have a length $(L) = 14.4$ mm and width $(W) = 19$ mm each.

The U-shaped slot is designed in such a way that it gives dual band of operations at 3.12 GHz and 4.8 GHz. The feedline is designed to match the impedance value of $50 \, \Omega$, and then, it is matched to the impedance value of $70 \, \Omega$, for an appropriate power transfer of energy. The position of the feed point is important in the design of the antenna array. The excitation is given by a an SMA connector, at the center of the feed line of the feed network.

![Figure 2.12 Four element aperture coupled microstrip patch antenna array](image)

**Figure 2.12** Four element aperture coupled microstrip patch antenna array

### 2.5 RESULTS AND DISCUSSIONS

#### 2.5.1 Microstrip Patch Antenna

A prototype of the rectangular microstrip patch antenna was implemented and fabricated on a 1.6 mm thick FR-4 substrate ($\varepsilon_r = 4.4$, $\tan \delta = 0.019$). The radiating patch is placed on the grounded dielectric material.
The simulated and measured $S_{11}$ (dB) values of the single rectangular microstrip antenna are shown in Figure 2.13. It is clearly indicated that both resonant frequencies are around 4.8 GHz. The simulated result shows that the resonant frequency of the patch is located at approximately 4.72 GHz, with -10 dB impedance bandwidth of 110 MHz, obtained from the cut off frequencies of 4.69 GHz to 4.8 GHz, which represents the fractional bandwidth of 2.33 %. The measured result shows that the resonant frequency of the patch is located at approximately 4.82 GHz, with the -10 dB impedance bandwidth of 160 MHz obtained from the cut off frequencies of 4.71 GHz to 4.87 GHz, which represent the fractional bandwidth of 3.46 %. The measured directivity of the single microstrip antenna is 5.3 dBi. From the simulated results, it is observed that the directivity of the single antenna is about 6 dBi, and Table 2.1 gives the comparison of the simulated and measured results of the single microstrip patch antenna. Figure 2.14 shows the photograph of a single microstrip patch antenna. Appendix I gives the error analysis.

![Figure 2.13 $S_{11}$ (dB) of microstrip patch antenna](image)
Table 2.1 Simulated and measured results of the microstrip patch antenna

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Antenna parameters</th>
<th>Simulated</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Resonant frequency (GHz)</td>
<td>4.72</td>
<td>4.82</td>
</tr>
<tr>
<td>2.</td>
<td>Return loss(dB)</td>
<td>-20.80</td>
<td>-21.56</td>
</tr>
<tr>
<td>3.</td>
<td>Bandwidth (MHz)</td>
<td>110</td>
<td>160</td>
</tr>
<tr>
<td>4.</td>
<td>VSWR</td>
<td>1.1</td>
<td>1.18</td>
</tr>
<tr>
<td>5.</td>
<td>Directivity(dBi)</td>
<td>5.3</td>
<td>6</td>
</tr>
</tbody>
</table>

2.5.2 Two Element Microstrip Patch Antenna Array

The simulated and measured S\(_{11}\) (dB) vs frequency (GHz) graph of the two element microstrip patch antenna array is depicted in Figure 2.15. From the graph, it is clear that the antenna array has a single resonant frequency of around 4.8 GHz. The simulated return loss result shows that the resonant frequency of the microstrip antenna array is located at approximately at 4.67 GHz, with the -10 dB impedance bandwidth of 190 MHz, from the cut off frequencies of 4.63 GHz to 4.82 GHz, which represent the fractional
bandwidth of 4.025 %. The measured result shows that the resonant frequency of the antenna array is approximately at 4.71 GHz, with the -10 dB impedance bandwidth of 220 MHz from the cut off frequencies of 4.65 GHz to 4.87 GHz, which represent the fractional bandwidth of 4.67 %. The simulated directivity of the microstrip antenna array is 12.03 dBi. The measured directivity of the microstrip antenna array is 11.17 dBi. The photograph of the fabricated two element microstrip antenna array is shown in Figure 2.16, and Table 2.2 gives the comparison of the simulated and the measured results of the microstrip antenna array.

Figure 2.15 $S_{11}$ (dB) of two element microstrip patch antenna array

Figure 2.16 Photograph of the fabricated two element microstrip patch antenna array
Table 2.2 Simulated and measured results of the two element microstrip patch antenna array

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Antenna parameters</th>
<th>Simulated</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Resonant frequency (GHz)</td>
<td>4.67</td>
<td>4.71</td>
</tr>
<tr>
<td>2.</td>
<td>Return loss (dB)</td>
<td>-16.24</td>
<td>-14.55</td>
</tr>
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<td>3.</td>
<td>Bandwidth (MHz)</td>
<td>190</td>
<td>220</td>
</tr>
<tr>
<td>4.</td>
<td>VSWR</td>
<td>1.36</td>
<td>1.6</td>
</tr>
<tr>
<td>5.</td>
<td>Directivity (dBi)</td>
<td>12.03</td>
<td>11.17</td>
</tr>
</tbody>
</table>

From Tables 2.1 and 2.2 it can be understood, that the microstrip patch antenna array has improved directivity and also the other antenna parameters, compared to that of single microstrip patch antenna. This clearly justifies the application of the microstrip patch antenna array instead of the single microstrip patch antenna.

2.5.3 Four Element Microstrip Patch Antenna Array

Figure 2.17 depicts the simulated $S_{11}$ (dB) vs frequency (GHz) graph. From the graph, it is clear that the microstrip patch antenna array has been designed to operate at 4.8 GHz. The simulated return loss result shows that the resonant frequency of the microstrip patch antenna array is located at approximately at 4.7 GHz, with the -10 dB impedance bandwidth of 150 MHz obtained from the cut off frequency points of 4.66 GHz to 4.81 GHz, which represent the fractional bandwidth of 3.2 %. The simulated directivity is 16.4 dBi.
In this design, the simulated results of two different types of microstrip patch antenna arrays are presented. The first type is designed as a single feed two element microstrip patch antenna array, with the patches tilted +45° and -45° individually, for achieving dual polarisation. The second type is designed as a two element microstrip patch antenna array, with each radiating patch given a dual feed, in order to achieve dual polarisations, viz., linear and orthogonal polarisation, and tilted +45° and -45° individually.

2.5.4.1 Dual frequency-dual polarised microstrip patch antenna array

The simulated and measured return loss results of the dual frequency two element microstrip antenna array is shown in Figure 2.18. It is clearly indicated that the antenna array has dual band characteristics. The simulated result shows that the lower band resonant frequency $f_1$ is located at about 3.12 GHz, with the -10 dB impedance bandwidth of 70 MHz from the cut off frequencies of 3.08 GHz to 3.15 GHz, which represent the fractional
bandwidth of 2.24%. The simulated result shows the high band resonant frequency $f_2$ located at about 4.72 GHz, with -10 dB impedance bandwidth of 130 MHz from about 4.69 GHz to 4.82 GHz, which represents the fractional bandwidth of 2.75%. The measured result shows that the resonant frequencies $f_1$ and $f_2$ of the microstrip patch antenna array are 3.07 GHz and 4.66 GHz. For the resonant frequency $f_1$, the -10 dB impedance bandwidth is 90 MHz from the cut off frequencies of 3.21 GHz to 3.30 GHz, which represents the fractional bandwidth of 2.75%. For the resonant frequency $f_2$, the -10 dB impedance bandwidth is 100 MHz from the cut off frequencies and 4.62 GHz to 4.72 GHz, which represents the fractional bandwidth of 2.13%. The simulated maximum return losses at the centre frequencies $f_1$ and $f_2$ are -13.6 dB and -13.5 dB respectively. The measured maximum return losses at the centre frequencies $f_1$ and $f_2$ are -12.4 dB and -12.2 dB respectively. The simulated directivity at $f_1$ and $f_2$ are obtained as 8.6 dBi and 13 dBi. The measured directivity at both frequencies $f_1$ and $f_2$ is observed as 6 dBi and 9.8 dBi. The simulation results are validated by measurements. The photograph of the fabricated dual band two element microstrip patch antenna array is shown in Figure 2.19, and Table 2.3 gives the comparison of the simulation and the measured results of the dual band two element microstrip patch antenna array.

![Figure 2.18 S11(dB) of dual frequency-dual polarised two element microstrip patch antenna array](image)

Figure 2.18 $S_{11}$(dB) of dual frequency-dual polarised two element microstrip patch antenna array
Figure 2.19  Photograph of the fabricated dual frequency-dual polarised two element microstrip patch antenna array

Table 2.3  Simulated and measured results of the dual frequency ($f_1$ and $f_2$)-dual polarised two element microstrip patch antenna array

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Antenna parameters</th>
<th>Simulated</th>
<th>Measured</th>
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<td></td>
<td></td>
<td>$f_1$</td>
<td>$f_2$</td>
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<tr>
<td>1.</td>
<td>Resonant frequency(GHz)</td>
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<tr>
<td>2.</td>
<td>Return loss(dB)</td>
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<td>VSWR</td>
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<td>Directivity(dBi)</td>
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<tr>
<td>5.</td>
<td>Bandwidth(MHz)</td>
<td>70</td>
<td>130</td>
</tr>
</tbody>
</table>

2.5.4.2  Dual frequency-dual polarised microstrip patch antenna array

The simulated return loss results of the two element microstrip antenna patch array with dual frequencies are shown in Figure 2.20. Two microstrip patch antenna arrays are designed, each with radiating patches tilted at $+45^\circ$ and $-45^\circ$ individually, and given dual feed in order to achieve
dual polarisation. The simulated result shows that the lower band resonant frequency $f_1$ is located at about 3.17 GHz, with the -10 dB impedance bandwidth of 60 MHz from the cut off frequencies of 3.13 GHz to 3.19 GHz, which represents the fractional bandwidth of 1.89 %. The simulated result shows that the high band resonant frequency $f_2$ is located at about 4.73 GHz, with the -10 dB impedance bandwidth, 70 MHz from about 4.71 GHz to 4.78 GHz, which represents the fractional bandwidth 1.5 %. The simulated maximum return losses at the centre frequencies are -13.3 dB and -13.1 dB respectively. The simulated directivity of the microstrip patch antenna array at frequencies $f_1$ and $f_2$ are 10.6 dBi and 12.3 dBi. Table 2.4 shows the comparison of the simulated values of the dual feed-dual frequency, two element microstrip patch antenna array.

![Simulated S11(dB) of dual frequency-dual polarised microstrip patch antenna array](image)

**Figure 2.20** Simulated $S_{11}\text{(dB)}$ of dual frequency-dual polarised microstrip patch antenna array
Table 2.4 Simulated results of dual frequency \((f_1\text{and}f_2)\)-dual polarised two element microstrip patch antenna array

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Antenna parameters</th>
<th>Simulated</th>
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<td></td>
<td>(f_1)</td>
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<tr>
<td>1.</td>
<td>Resonant frequency(GHz)</td>
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<td>Return loss(dB)</td>
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<td>VSWR</td>
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<td>5.</td>
<td>Bandwidth(MHz)</td>
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</table>

2.5.5 Aperture Coupled Microstrip Patch Antenna Array

2.5.5.1 Aperture coupled microstrip patch antenna

The simulated and measured return loss results of the aperture coupled microstrip patch antenna are shown in Figure 2.21. It is clearly indicated that the antenna has dual band characteristics. The simulated result shows that the lower band resonant frequency \(f_1\) is located at about 3.23 GHz, with the -10 dB impedance bandwidth of 90 MHz from the cut off frequencies of 3.18 GHz to 3.28 GHz, and the high band resonant frequency \(f_2\) is located at about 4.76 GHz, with the -10 dB impedance bandwidth of 100 MHz from about 4.70 GHz to 4.82 GHz, which represents the fractional bandwidth of 2.8 % and 2.1 % respectively. The measured result shows that the resonant frequencies \(f_1\) and \(f_2\) of the aperture coupled microstrip antenna are about 3.11 GHz and 4.68 GHz. The lower resonant frequency \(f_1\) with the -10 dB impedance bandwidth of 130 MHz, from about 3.09 GHz to 3.17 GHz, which represents the fractional bandwidth 4.06 %. The higher resonant frequency \(f_2\)
with the -10 dB impedance bandwidth of 140 MHz with the cut off frequencies of 4.62 GHz to 4.74 GHz, represents the fractional bandwidth of 2.91 %. The simulated maximum return losses at the centre frequencies \( f_1 \) and \( f_2 \) are -12.2 dB and -15.64 dB. The measured maximum return losses at the centre frequencies \( f_1 \) and \( f_2 \) are -13.7 dB and -13.4 dB. The simulated directivity is obtained as 6 dBi. The measured directivity is observed as 5.1 dBi. The simulation results are validated by the measurements. The photograph of the fabricated aperture coupled microstrip antenna is shown in Figure 2.22(a) and 2.22(b) and Table 2.5 gives the comparison of the simulation and the measured results of the dual band two element microstrip antenna array.

![Figure 2.21](image)

**Figure 2.21** \( S_{11}(\text{dB}) \) of aperture coupled microstrip patch antenna

![Figure 2.22](image)

**Figure 2.22** (a) Photograph of the radiating patch of the aperture coupled microstrip patch antenna (b) Photograph of the feedline of the aperture coupled microstrip patch antenna
Table 2.5  Simulated and measured results of the aperture coupled microstrip patch antenna at frequencies \( f_1 \) and \( f_2 \) (3.12 GHz and 4.8 GHz)

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Antenna parameters</th>
<th>Simulation ( f_1 )</th>
<th>Simulation ( f_2 )</th>
<th>Measurement ( f_1 )</th>
<th>Measurement ( f_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Resonant frequency(GHz)</td>
<td>3.23</td>
<td>4.76</td>
<td>3.11</td>
<td>4.68</td>
</tr>
<tr>
<td>2.</td>
<td>Return loss(dB)</td>
<td>-12.2</td>
<td>-15.64</td>
<td>-13.7</td>
<td>-13.4</td>
</tr>
<tr>
<td>3.</td>
<td>VSWR</td>
<td>1.8</td>
<td>1.6</td>
<td>1.8</td>
<td>1.8</td>
</tr>
<tr>
<td>4.</td>
<td>Directivity(dB)</td>
<td>6</td>
<td>8</td>
<td>5.1</td>
<td>6</td>
</tr>
<tr>
<td>5.</td>
<td>Bandwidth(MHz)</td>
<td>90</td>
<td>100</td>
<td>130</td>
<td>140</td>
</tr>
</tbody>
</table>

2.5.5.2  Two element aperture coupled microstrip patch antenna array

The simulated and measured \( S_{11} \)(dB) results of the two element aperture coupled microstrip patch antenna array are shown in Figure 2.23. It is clearly indicated that the microstrip patch antenna array has dual band characteristics. The simulated result shows that the lower band resonant frequency \( f_1 \) is located at about 3.28 GHz, with the -10 dB impedance bandwidth of 90 MHz, obtained from the cut off frequencies 3.24 GHz to 3.5 GHz, and high band resonant frequency \( f_2 \) is located at about 4.71 GHz, with the -10 dB impedance bandwidth of 150 MHz, obtained from the cut off frequencies 4.67 GHz to 4.82 GHz, which represents the fractional bandwidth of 2.8 % and 3.12 % respectively. The measured result shows that the resonant frequency of the aperture coupled microstrip antenna is about 3.24 GHz and 4.78 GHz, with the -10 dB impedance bandwidth of 80 MHz and 120 MHz from about 3.17 GHz to 3.29 GHz and 4.60 GHz to 4.72 GHz, which represents the fractional bandwidth of 2.5 % and 2.6 % respectively. The simulated maximum return losses at the centre frequencies \( f_1 \) and \( f_2 \) are -14.26 dB and -12.32 dB. The measured maximum return losses at the centre
frequencies $f_1$ and $f_2$ are -13.1 dB and -14.34 dB. The simulated directivity obtained at both the frequencies $f_1$ and $f_2$ are 8 dBi and 11 dBi. The measured directivity obtained at both the frequencies $f_1$ and $f_2$ are 5.3 dBi and 7.2 dBi. The simulation results are validated by the measurements. The photograph of the fabricated aperture coupled microstrip antenna is shown in Figure 2.24(a) and 2.24(b), and Table 2.6 gives the comparison of the simulation and the measured results of the dual band two element microstrip patch antenna array.

![Graph](image)

**Figure 2.23** $S_{11}(dB)$ of the two element aperture coupled microstrip patch antenna array

![Photographs](image)

**Figure 2.24** (a) Photograph of the radiating patches of the two element aperture coupled microstrip patch antenna array (b) Photograph of the corporate feed network of the two element aperture coupled microstrip patch antenna array
Table 2.6 Simulated and measured results of the two element aperture coupled microstrip patch antenna array at frequencies $f_1$ and $f_2$ (3.12 GHz and 4.8 GHz)

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Antenna parameters</th>
<th>Simulation</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Resonant frequency(GHz)</td>
<td>3.28</td>
<td>4.71</td>
</tr>
<tr>
<td>2.</td>
<td>Return loss(dB)</td>
<td>-14.26</td>
<td>-12.32</td>
</tr>
<tr>
<td>3.</td>
<td>VSWR</td>
<td>1.7</td>
<td>1.8</td>
</tr>
<tr>
<td>4.</td>
<td>Directivity(dBi)</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>5.</td>
<td>Bandwidth(MHz)</td>
<td>90</td>
<td>150</td>
</tr>
</tbody>
</table>

### 2.5.5.3 Four element aperture coupled microstrip patch antenna array

The simulated and measured return loss results of the four element aperture coupled microstrip patch antenna array are shown in Figure 2.25. It is clearly indicated that the aperture coupled microstrip patch antenna array has dual band characteristics. The simulated result shows that the lower band resonant frequency $f_1$ is located at about 3.14 GHz, with the -10 dB impedance bandwidth of 90 MHz, from the cut off frequencies 3.11 GHz to 3.2 GHz which represents the fractional bandwidth of 2.86%. The simulated result shows the high band resonant frequency $f_2$ is located at about 4.71 GHz, with the -10 dB impedance bandwidth of 100 MHz, from the cut off frequencies 4.68 GHz to 4.78 GHz, which represents the fractional bandwidth of 2.12% respectively. The measured result shows that the resonant frequency of the aperture coupled microstrip antenna is about 3.17 GHz and 4.76 GHz, with the -10 dB impedance bandwidth of 120 MHz, from the cut off frequencies of 3.10 GHz to 3.22 GHz, and 190 MHz from the cut off frequencies of 4.71 GHz to 4.9 GHz, which represents the fractional bandwidth of 3.78% and 4% respectively. The simulated maximum return
losses at the centre frequencies are -14.5 dB and -15 dB. The measured maximum return losses at the centre frequencies are -14.01 dB and -14.1 dB. The simulated directivity at frequencies $f_1$ and $f_2$ is obtained as 13.4 dBi and 16 dBi. The measured directivity at frequencies $f_1$ and $f_2$ is obtained as 10.2 dBi and 13 dBi. The simulation results are validated by the measurements. The photograph of the fabricated aperture coupled microstrip antenna is shown in Figure 2.26(a) and 2.26(b), and Table 2.7 gives the comparison of the simulation and the measured results of the dual band four element microstrip antenna array.

![Plot of $S_{11}$ (dB) vs Frequency in GHz](image)

**Figure 2.25** $S_{11}$(dB) of the four element aperture coupled microstrip patch antenna array

![Photographs](image)

**Figure 2.26** (a) Photograph of the radiating patches of the four element aperture coupled microstrip patch antenna array  
(b) Photograph of the corporate feed network of the four element aperture coupled microstrip patch antenna array
Table 2.7 Simulated and measured results of the four element aperture coupled microstrip patch antenna array at frequencies $f_1$ and $f_2$ (3.12 GHz and 4.8 GHz)

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Antenna parameters</th>
<th>Simulated</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$f_1$</td>
<td>$f_2$</td>
</tr>
<tr>
<td>1.</td>
<td>Resonant frequency(GHz)</td>
<td>3.14</td>
<td>4.71</td>
</tr>
<tr>
<td>2.</td>
<td>Return loss(dB)</td>
<td>-14.4</td>
<td>-15.7</td>
</tr>
<tr>
<td>3.</td>
<td>VSWR</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>4.</td>
<td>Directivity(dBi)</td>
<td>13.4</td>
<td>16</td>
</tr>
<tr>
<td>5.</td>
<td>Bandwidth(MHz)</td>
<td>90</td>
<td>100</td>
</tr>
</tbody>
</table>

2.6 SUMMARY

The performance of several antenna arrays, like the two element and four element microstrip antenna arrays, dual frequency-dual polarised two element and four element microstrip antenna arrays, and aperture coupled microstrip antenna array of two elements and four elements, are analyzed with the necessary antenna parameters. The single frequency microstrip antenna array operates at 4.8 GHz, the dual frequency-dual polarised microstrip antenna array and aperture coupled antenna array operate dual frequencies at 3.12 GHz and 4.8 GHz. The radiating patches of the above mentioned antenna arrays are in a rectangular shape. It is important in many applications for the antenna arrays to be compact in size, and be low profile. To improve the performance of the microstrip antenna array, Electromagnetic Bandgap (EBG) structures and the FSS are used, the performance enhancement is described in the following chapters. The EBG structures are placed at the inset feedline of the microstrip antenna and antenna array. This is compared with the performance of the antenna array with traditional placing of EBG
structures. The proposed three types of EBG structures are, mushroom-like EBG, fork-like EBG and compact dual band EBG. The EBGs are fine tuned to exhibit their resonant frequencies, and are placed above the grounded dielectric substrate. The next chapter describes the concept, principles of operation, geometries and development of the various EBG structures. The FSS is placed as a superstrate layer in the aperture coupled antenna arrays. The characterisation of the FSS is studied by parametric studies.