Chapter 6

Development of Conformal Antenna Array for Cylindrical Surface

6.1 Introduction

The main objective is to develop and analyze the characteristics performance of different types of cylindrical conformal antennas and array. This work is divided into three categories which include the implementation of a microstrip array, single element conformal antenna and different type of four element conformal antenna array. The analysis of conformal antennas for single element, two elements conformal and four elements slotted conformal antennas are studied. Further, the meandered line included in feed line network with some modified structure is studied for conformal antenna. The simulation of four elements cylindrical conformal array and its fabrication is given in section 6.3 to 6.6. The technique used to analyze microstrip antenna for non planar surface conforming to the parent structure as cylinder has been explained [3,35,67,77,104,114].

The conformal mapping technique is used to transformation of a patch on cylindrical surface to an equivalent planar rectangular microstrip antenna. The performance for planar and conformal patch antenna on the cylindrical surface is studied. The mathematical relation for effect of curvature of the resonant frequency already is discussed in chapter 5.
6.2 Conformal Microstrip Patch Antenna

Conformal antenna having property of conformity for arbitrary surface due which conformal antenna become necessary for satellite or vehicular communications. Cylindrical, spherical and conical are the main structures so far. While dielectric constant play an important role in increasing edge field and its radiation power. Here, to conform the microstrip patch antenna on cylindrical surface at different curvature as shown in figure 6.2. The main interest of structure-1 is to analyze the characteristics and result of microstrip patch antenna for different curvature radius. The main parameters for choosing substrate are the thickness h and loss tangent. To conform the patch on substrate, it should be flexible or thin for bending purpose. Radiation power conductor loss and impedance depends on the thickness of substrate.

6.2.1 Transformation from Cylindrical to Planar

Cylindrical conformal patch antenna transformation from planar patch and conformal mapping has been discussed in chapter 5. The resonant frequency will be change for the conformal patch antenna due to change in curvature of the cylinder. The Cartesian equation of the cylindrical surface can be explained below. All the related equation to conformal mapping discussed in section 5.2.

\[ x^2 + y^2 = r^2 \]  \hspace{1cm} [6.1]

Width \( W = r_2 \left\{ (\varphi - \varphi_1) - \varphi_2 \right\} = r_2 \varphi \)  \hspace{1cm} [6.2]

Axial length = L, Edge of patch subtends angle \( \varphi \).
W = Transform width

For the planar transformation circumferential dimension will be change along the X axis. That become angle $\phi_i$ to $(\phi + \phi_i)$. It is clear from this analysis cylindrical surface and a planar surface are same using conformal mapping theorem and a rectangular patch on a cylindrical surface will be transformed into equivalent planar. Dimensions are given by the following equation 6.2.

Calculation of patch antenna for edge input impedance are as given by equation.

\[
Z_{in} = \frac{1}{2(G_i \pm G_{12})} \quad [6.3]
\]

\[
G_i = \frac{1}{90} \left( \frac{W}{\lambda_0} \right)^2 \quad \text{for} \quad \frac{W}{\lambda_0} << 1 \quad [6.4]
\]
\[
G_{t2} = \frac{1}{120\pi^2} \int_0^{\pi} \left[ \frac{\sin \left( \frac{K_0 W}{2 \cos \theta} \right)}{\cos \theta} \right]^2 J_0(K_0 L \sin \theta) \sin^3 \theta d\theta
\]  

[6.5]

\( J_0 = \text{Bessel function zero order first kind, } K_0 = \frac{2\pi}{\lambda_0} \) where, \( \lambda_0 \) is wavelength correspondence to resonant frequency \([1, 11, 72]\).

### 6.3 Effect of Curvature on Inset Feed Conformal Patch

To determine the basic dimension of the patch, section 3.3 reported all the related equations. The antenna is a 38mm×51mm patch printed on the grounded FR4 dielectric substrate having dielectric constant (\( \varepsilon_r \)) = 4.3 and substrate height (h) = 2.5 mm, \( f_r = 10\text{GHz} \), Radius \( r_1 = 35\text{mm} \). The length and width of the antenna can be calculated by transmission line method. The conductor thickness taken as chosen is 4.7\( \mu \text{m} \). To find the axial length \( L \) \([5.3]\), determine the angle subtended by measuring two axial lines of patch passing through centre of cylinder to the patch edge shown in figure. \( \varphi = \varphi = 48.4^0 - 45.8^0 = 2.6^0 \)

\[
L = \frac{\varphi}{180} \times \pi \times \text{radius} = \varphi \times 0.01746 \times \text{radius} \text{ in mm} \]  

[6.6]

\( W = r_2 \varphi = 56\text{mm} \)

The transmission line model is applicable to infinite ground planes only. But, for practical considerations, it is necessary to have a finite ground plane. The similar results for finite and infinite ground plane can be obtained if the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness all around the
periphery. $Z_m$ can be calculated by using equation 6.3 to achieve the matching for maximum power transfer.

**Figure 6.2: Conformal geometry -1 with inset feed microstrip patch antenna**

6.3.1 Simulation Result Analysis

A brief introduction and comparative study for the EM simulator has been discussed. In the field of microwave, antennas and wireless communication, vast variety of EM simulators is being used such as ADS, I3D, HFSS, SONET, CST etc. The CST studio allows the engineer to choose the best technique for each application using CST MWS and other application are Antennas, Circuits & Components, MW&RF, and Filters. Earlier ADS software used simulation of microstrip antenna but for the conformal application, CST studio is the best solution and it is used for whole conformal simulation.

6.3.2 Effect Of Different Curvature On $S_{11}$- parameter

The conformal antenna for different curvature radii was reported by change in radius of cylinder. This study includes the effect of curvature on antenna parameter on the bases of comparison of the simulation results from the conformal antennas analyzed. Scattering parameter Vs frequency plot are shown in below figure. Comparative result analysis in
terms of frequency, return loss of the antenna with different radius \( r = 35\text{mm}, 45\text{mm}, 50\text{mm} \) and \( 100\text{mm} \) are shown in table 6.1. It observed from this analysis that radiation characteristic degrades and with increase in radius, frequency and return loss decreases.

Figure 6.3: Return loss V/s frequency for cylinder radius (a) 35mm (b) 45mm (c) 55mm
6.3.3 Effect Of Different Curvature On Radiation parameter

3-D radiation pattern for gain and directivity

Figure 6.4: 3-D Radiation Pattern of antenna showing Gain for curvature

radius (a) 35mm (b) 44mm (c) 50mm

6.3.4 Summarized result to observe effect of curvature on antenna

<table>
<thead>
<tr>
<th>SN</th>
<th>Radius in mm</th>
<th>Frequency</th>
<th>Return loss dB</th>
<th>Gain dB</th>
<th>Directivity dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>35</td>
<td>9.28</td>
<td>-18.7</td>
<td>8.125</td>
<td>10.73</td>
</tr>
<tr>
<td>2</td>
<td>45</td>
<td>9.24</td>
<td>-20.5</td>
<td>7.408</td>
<td>9.996</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>9.182</td>
<td>-29.6</td>
<td>6.154</td>
<td>8.817</td>
</tr>
</tbody>
</table>

Table 6.1: Return loss, gain and directivity with different radius of cylinder
In this single patch, an efficient analysis of conformal microstrip patch antenna on different radius has been done. The gain start reducing with increase in radius and bandwidth decreases with increase in radius. A good agreement were made by Wang and other for < 30 cm diameter antenna for car on both rooftop and trunk at 2.4 GHZ [3,103].

6.4 Slotted Cylindrical Conformal Antenna

The miniaturization of antenna and improvement in bandwidth can be achieved by etching the slot in ground and patch of Microstrip antenna of proper length and width. The change in the resonance frequency is minimum for the longest slot length whereas it is maximum for the minimum slot length. Many literatures have been reported in the literature review for the slot antenna. Here, that slotted antenna applied for conformal application on cylinder. A comparative analysis has been made for the U and half U, π and half π designs are proposed by reducing area to50% and increasing the substrate thickness (air) [21,92]. This work presents the design of a microstrip patch antenna having E and U shape slot which is back to back connected to each other mounted on the finite cylindrical surface that can operate on a triple band 2.057 GHz, 3.6102 GHz, and 6.2624 GHz. This conformal structure with truncated corner used for circular polarization.

6.4.1 Back To Back E-And U Shape Microstrip Antenna

This configuration of the slotted Patch using two slots E and U which is back-to-back connected to each other and is printed on FR4 substrate having 1.6 mm thickness and relative dielectric constant of 4.3 and two side feed applied with 50 ohm ML, dimensions of patch are given in table 6.3. Two truncated corner designed for circular polarization in
which one is on the upper right hand side of the patch and another is on the lower left hand side of the patch of the proposed antenna [110]. The dimension of patch are as:

<table>
<thead>
<tr>
<th>Parameters L/W</th>
<th>Ws</th>
<th>Wp</th>
<th>Wg</th>
<th>Ls</th>
<th>Lp</th>
<th>Lg</th>
<th>h</th>
<th>Mt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension (mm)</td>
<td>80</td>
<td>35.11</td>
<td>80</td>
<td>80</td>
<td>27.13</td>
<td>80</td>
<td>1.6</td>
<td>0.17</td>
</tr>
</tbody>
</table>

*Table 6.2: Antenna Dimensions*

*Figure 6.5: Geometry -2, slotted dual port Microstrip Patch Antenna*

*Figure 6.6: Return loss for 1.7843 GHz, 3.5884GHz, 5.6582 at port 1 and port 2*

Return loss is a measure of how well antenna matching is done. The criterion for the determination of frequency band is value of return loss less than -10dB.
(a) Radiation pattern at $f_{r1} = 1.7843 \text{ GHz}$ for port 1 and port 2

(b) Radiation pattern at $f_{r2} = 3.5884 \text{ GHz}$ for port 1 and port 2

(c) Radiation pattern at $f_{r3} = 5.6582 \text{ GHz}$ for port 1 and port 2

Figure 6.7: Radiation pattern (a), (b), (c) at $1.7843 \text{ GHz}$, $3.5884 \text{ GHz}$, $5.6582 \text{ GHz}$ at port 1 and port 2 respectively
The antenna is resonating at three different resonant frequencies that show its triple band operation. Radiation pattern of microstrip patch antenna of planar patch given in figure 6.7 for frequencies 1.7843GHz, 3.5884GHz, 5.6582 at port 1 and port 2 respectively.

6.4.2 Back To Back E-And U Shape Cylindrical Conformal Patch Antenna

Furthermore, This Microstrip Patch Antenna Structure is conformed on a cylindrical sector substrate of 30 mm radius. The thickness and dielectric constant of the substrate are 1.6 mm and 4.3 respectively.

![Figure 6.8: Conformal geometry-2](image)

Simulation analysis provide return lose of -42 dB at 2GHz and -19.9 dB for second peak at 6.26GHz are shown in figure 6.9. The radiation plot for 2D and 3D are given figure6.10-6.11 for two port analysis. Weinschel H.D. [36] developed different geometry for application like aircrafts and rockets for curved surface.
(a) Radiation pattern at $f_{r1}=2.057$ GHz for port 1 and port 2

(b) 3 D-Radiation pattern at $f_{r2}=3.6102$ GHz for port 1 and port 2

(c) 3D-Radiation pattern at $f_{r3}=6.2624$ GHz for port 1 and port 2

Figure 6.10: 3D-Radiation pattern at frequencies 2.057 GHz, 3.6102 GHz and 6.2624 GHz for Port 1 and port2 respectively

<table>
<thead>
<tr>
<th>SN</th>
<th>Freq. GHz</th>
<th>S11dB</th>
<th>Gp1dB</th>
<th>Gp2dB</th>
<th>Dp1dBi</th>
<th>Dp2dBi</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.7843</td>
<td>-36.99</td>
<td>-5.001</td>
<td>-4.889</td>
<td>6.579</td>
<td>6.585</td>
</tr>
<tr>
<td>3</td>
<td>5.6582</td>
<td>-14.60</td>
<td>5.955</td>
<td>5.661</td>
<td>8.560</td>
<td>8.726</td>
</tr>
</tbody>
</table>

*Table 6.3: Gain and Directivity for Cylindrical Conformal Antenna port 1(1-8 GHz)*

<table>
<thead>
<tr>
<th>SN</th>
<th>Freq. GHz</th>
<th>S11dB</th>
<th>Gp1dB</th>
<th>Gp2dB</th>
<th>Dp1dBi</th>
<th>Dp2dBi</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.057</td>
<td>-42.69</td>
<td>2.057</td>
<td>-6.84</td>
<td>3.744</td>
<td>3.828</td>
</tr>
<tr>
<td>2</td>
<td>3.6102</td>
<td>-10.06</td>
<td>3.6102</td>
<td>1.112</td>
<td>5.921</td>
<td>5.812</td>
</tr>
</tbody>
</table>

*Table 6.4: Gain and Directivity for Cylindrical Conformal Antenna port 2(1-8 GHz)*

### 6.4.3 Result Discussion

The above result analysis state that the conformal antenna frequencies shifted from the planar antenna frequencies shown in table 6.4 and 6.5 for example, planar frequency 5.6582GHz shifted to 6.2624GHz in conformal antenna and radiation parameter gain and directivity degrade slightly. Conformal antenna offering -10 dB bandwidth is 850 MHz by using back to back E and U slot. All the result are comprises in table 2. This antenna meets the requirement of DCS, PCS and C-band application.
6.5 Proposed Cylindrical Conformal Antenna Array

The flow charts give the overview of work plan to achieve the thesis problem as conformal antenna array for X-band and Ku band application.

*Figure 6.11: Flow charts for conformal antenna array*
6.5.1 Single Element Patch Antenna For Planner Surface

In this section a simple single element microstrip patch antenna is introduce printed on a FR4 substrate (\( \varepsilon_r = 4.3 \)) with height \( h = 1.66\) mm and patch is design for the operating frequency 9.2GHz. Calculation has been done based on previous study and shown in table 6.10. The antenna resonate at 9.2 GHz with return loss -21.1 dB and 3-D radiation pattern are shown in fig. 6.12 from which we can observe that obtained gain is 3.6 dB.

<table>
<thead>
<tr>
<th>Length (L)</th>
<th>0.68 cm</th>
<th>Length (Lg)</th>
<th>3.06 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width (W)</td>
<td>0.99cm</td>
<td>Width (Wg)</td>
<td>5.70cm</td>
</tr>
</tbody>
</table>

*Table 6.5: Patch dimensions L,W and Ground Plane dimensions Lg, Wg*

*Figure 6.12: Design of single element antenna and its S-parameter*

*Figure 6.13: 3-D radiation pattern at 9.2GHz*
Lot of modification has been done to obtain desired result. Now, a guard line is attached to the side of patch to reduce surface current for planner surface and observe the effect of guard line due to which it resonate at two frequency 8.7GHz and 11.9GHz. The guard line dimension \(L_{g1} = L_{g2} = 0.84, \ L_{g3} = 0.62 \text{ cm}, \ W_{gL} = 0.12 \text{ cm}\) shown in figure 6.14.

![Geometry 3, Guard line patch antenna and its scattering parameter](image)

**Figure 6.14: Geometry 3, Guard line patch antenna and its scattering parameter**

### 6.5.2 Four Elements Patch Antenna Array for Planner Surface.

In continuation of work, develop 4 element array with quarter wave transformer feed and improvement of array could be obtained by incorporating guard line. Table 6.11 present the calculated dimension of corporate feed network.

<table>
<thead>
<tr>
<th>Transmission line of feed network</th>
<th>Length</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 line (L50)&amp; 50 line (W50)</td>
<td>0.41 cm</td>
<td>0.31 cm</td>
</tr>
<tr>
<td>70 line (L70) Width of 70 (W70)</td>
<td>0.41 cm</td>
<td>0.16 cm</td>
</tr>
<tr>
<td>100 line (L100)&amp; 100 line (W100)</td>
<td>0.83 cm</td>
<td>0.07 cm</td>
</tr>
<tr>
<td>Coupler(CL)&amp;(CW)</td>
<td>0.31 cm</td>
<td>0.31 cm</td>
</tr>
<tr>
<td>Quarter wave transformer (Lq)&amp; (Wq)</td>
<td>0.41 cm</td>
<td>0.05 cm</td>
</tr>
</tbody>
</table>

*Table 6.6: Corporate feed line dimensions*
6.5.3 Four Element Conformal Patch Antenna Array for cylindrical surface

The proposed antenna consist of FR4 substrate having thickness 1.56 mm, but it has to reduce for conformal fabrication purpose to 0.8mm and dielectric constant of material having $\varepsilon_r$ is 4.4 which is conformal to the cylindrical grounded metal surface. and The geometry of single element, two element and four element antenna array conformal to the cylindrical surface shown in Fig. 6.18. The elements of array are excited by using corporate feed network. Coupler is used to connect 50Ω line. The 70Ω matching transformer is used to connect the 100Ω microstrip line and 50Ω microstrip line. The centre distance between array elements is considered such that the side lobe level is low.
and radiated power increase in free space here $D=0.856 \lambda_0$, where $\lambda_0$ is the free space wavelength. Table 6.10 an 6.11 contain the dimension for proposed antenna. Radius of cylinder($R$) = 3.00 cm and distance between element =2.79cm. Resonating frequency for single element conformal antenna is measured as 15.385GHz while bandwidth is 343 MHz and 2-element array resonating at 7.9685 GHz, 8.927 GHz, and 12.933 GHz.

Figure 6.17: 2 elements guard line conformal antenna array with $S_{11}$ parameter
Figure 6.18: 2-D and 3-D radiation pattern for two element microstrip conformal array
Figure 6.19: Four elements guard line conformal antenna array of geometry-3

Figure 6.20: $S_{11}$-parameter for 4 elements GL conformal antenna

- Farfield Directivity $\Phi \geq 90$
  - Frequency = 8.766
  - Main lobe magnitude = 4.52 dB
  - Main lobe direction = 75.9 deg.
  - Angular width (1 dB) = 56.7 deg.
  - Side lobe level = -2.6 dB

- Farfield $\Phi \geq 90$
  - Frequency = 11.553
  - Main lobe magnitude = 1.96 dB
  - Main lobe direction = 68.0 deg.
  - Angular width (1 dB) = 53.3 deg.
  - Side lobe level = -3.6 dB
Figure 6.21: 2D and 3-D radiation pattern for 4 element GL conformal array
6.5.4 Comparative Analysis of 1, 2 and 4 element conformal array

The 2-D radiation pattern of two and four element array are simulated and gain, directivity, and side lobe level are measured at their resonating frequency as shown in figure (6.18-6.22). When we compared the gain we will observed that gain for 4 array element is less than 2 element array this is may be due to higher side lobes.

<table>
<thead>
<tr>
<th>Antenna</th>
<th>Frequency (GHz)</th>
<th>Gain (dB)</th>
<th>Directivity(dBi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-element</td>
<td>15.38</td>
<td>3.60</td>
<td>5.80</td>
</tr>
<tr>
<td>2-element array</td>
<td>7.9</td>
<td>3.40</td>
<td>5.09</td>
</tr>
<tr>
<td></td>
<td>8.9</td>
<td>4.66</td>
<td>5.21</td>
</tr>
<tr>
<td></td>
<td>11.9</td>
<td>4.72</td>
<td>5.9</td>
</tr>
<tr>
<td>4-element array</td>
<td>8.9</td>
<td>4.31</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>12.09</td>
<td>6.15</td>
<td>7.4</td>
</tr>
<tr>
<td></td>
<td>13.731</td>
<td>6.74</td>
<td>5.27</td>
</tr>
</tbody>
</table>

*Table 6.7: Gain and Directivity for 1, 2 and 4 element conformal array*

From the above discussion, it is conclude that by using meandered line as guard line 1, 2, 3 to reduce surface current for operating multiband application at frequency 6.9, 8.7, 11.5 and 13.731GHz. This antenna array makes a tradeoff between gain and resonating frequencies. Above analysis about the radiation pattern provide good angular width at middle two frequencies. By increasing the no. of element, gain can be increased as conforming the surface gain get reduces. Furthermore, the geometry of figure 6.18 conformal array modified in structure and reduces the height of the substrate because practicability and availability of dielectric sheet to conforms the geometry. Samir Dev Gupta developed 2&4 element conformable antenna for cylindrical surface with gain and directivity of 6.9dB and 7.9dbi respectively [90]. This modified conformal array discuses in next section.
6.5.5 Center slot Patch for Planner and conformal antenna array

It is known that the factors affecting the bandwidth of a MSA are primarily the shape of the radiator, the feeding scheme, the substrate and the arrangements of radiating and parasitic elements. Essentially, the broad bandwidth of a MSA can be attributed to its low Q value and simultaneously well excited multiple resonances. Bandwidth enhancement using slot loading technique, a quarter wave lengths with width of 0.12mm slot is created on the radiating patch of antenna which leads to wide bandwidth due to double resonant effect while keeping the size small. The slot in the patch increases the current path length and thus increases bandwidth. A slotted array for above structure resonating at 10.297GHz frequency are given in figure 6.22.

![Figure 6.22: Geometry- 4, with centre slot four element planar array](image)

![Figure 6.23: Conformed array of Geometry - 4 and return loss](image)
Figure 6.24: 2-D&3D radiation plots for Conformed array of geometry- 4
6.5.6 Meandered line feed phased conformal antenna array (Geometry-5)

Four elements guard line conformal array already explain in above section. This structure is reduced by thickness of 0.8mm for the fabrication reason and availability of substrate thickness for conformal structure. Two modification has been done in patch guard line-3 and feed line network by enhancing the width of $W_{gL3}=0.23$ and meandered line is placed in between the patch feed line to correct the phase or radiation pattern as planar array. The line length, $l$, \[ \phi = \beta l = \sqrt{\varepsilon_c} (k_o l) \]

for a $20^\circ$ phase shift; at 10GHz with $\varepsilon_r=3.82$, $l=0.39cm$

All the patch dimension and placing between the elements are shown in figure 6.25.

*Figure 6.25: Geometry-5, Conformal MLA array layout, Modal and $S_{11}$ parameter*
Figure 6.26: Simulated & measured $S_{11}$ parameter of conformal MLA array

Figure 6.27: 2D & 3D radiation pattern for proposed conformal MLA at 6.8 GHz
Figure 6.28: 2D & 3 D radiation pattern for proposed conformal MLA at 8.6GHz

Effect of substrate height-It is an important factor, which effect the antenna performance as bandwidth while radiation patterns are slightly affected for h= 1.3-1.6mm [fig.6.23]. The thickness of dielectric substrate is critical to choose for the conformal antenna manufacture because the flexibility of the material is typical for thick substrates and easy to bend for very thin materials.
6.5.7 Effect of substrate height

Simulation result shows by changing height of substrate from 1.0mm to 1.6mm affect slightly on resonating frequency.
Figure 6.31: 2D & 3D radiation pattern for modified proposed conformal MLA at 8.3GHz
In order to analyze the simulation of above all conformal antenna array on the bases of scattering parameter, VSWR, resonating frequencies, radiation patterns in figure 6.13-6.32. The comparative analysis of slotted and MLA array given in table 6.8 shows the value of directivity and angle covered with the value on the hemisphere of radiation. Carmen [13] investigated hemispherical coverage about $120^0$ in parallel position of patch. The slotted conformal array has large bandwidth of 1.1GHz (-10 dB) and conformal MLA
has a larger coverage for integrating to the parallel position.

6.5.8 Comparative Analysis of proposed slotted and conformal cylindrical antenna array

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conformal array</th>
<th>Slotted GL Array</th>
<th>Antenna 1</th>
<th>Conformal ML Array</th>
<th>Antenna 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (GHz)</td>
<td>S11</td>
<td>Directivity(dBi)</td>
<td>Main lobe direction in degree</td>
<td>Angular Width 3dB</td>
<td>Side lobe level</td>
</tr>
<tr>
<td>8.02</td>
<td>-31.2</td>
<td>10.14</td>
<td>14</td>
<td>53.8</td>
<td>-4.7</td>
</tr>
<tr>
<td>9.2</td>
<td>-12</td>
<td>9.8</td>
<td>51</td>
<td>60.8</td>
<td>-3.3</td>
</tr>
<tr>
<td>10.4</td>
<td>-51</td>
<td>10.08</td>
<td>5</td>
<td>59.1</td>
<td>-19.1</td>
</tr>
<tr>
<td>14.3</td>
<td>-17.5</td>
<td>5.7</td>
<td>65</td>
<td>45.7</td>
<td>-3.8</td>
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<tr>
<td>8.3</td>
<td>-38.9</td>
<td>10.73</td>
<td>31</td>
<td>51</td>
<td>-9.7</td>
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<tr>
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<td>13.1</td>
<td>-19.7</td>
<td>9.1</td>
<td>42</td>
<td>48</td>
<td>-10.4</td>
</tr>
</tbody>
</table>

*Table 6.8: Comparison of slotted and Meandered Line conformal cylindrical Array*

6.5.9 Result Discussion and Performance Analysis contributions

This chapter provides a detailed analysis of results are obtained from the simulations carried out using CST Studio. Comparisons will be made with tabular form that shows good result agreement among all performed simulations. Theoretical aspects linking to the results will be discussed and commented.

Basic rectangular configurations calculation equations and radiation mechanism theory given in chapter 3. Analysis of a line feed microstrip patch antenna and arrays for optimum frequency range has been described in chapter 4. It has been shown that for any planar array configuration can be obtained by proper desirable antenna designing equations and characteristics, depending upon material and parameter used. The antennas provides single, double or triple frequency close to the designed operating frequency with
an acceptable directivity and gain range up to 4-9 dBi for substrate RT duriode and FR4. It has been shown that the impedance bandwidth of microstrip patch antennas can be significantly improved by using slow wave structure configuration. The gain bandwidth product is a constant, therefore an effort has been made to improve the bandwidth of the patch antenna while ensuring desired radiation pattern. Next, the effect of cover layer on impedance matching, Q factor hence bandwidth and frequency correction is discussed. The Method of Moments and Finite Difference Time Domain approach have been used for computation of the results presented in the chapter. A triple band antenna is analyzed for satellite communication with gain of 6.3dB. When antenna structure is closely spaced, the return loss improves in the E plane. It has been shown that with the increasing array spacing the gain of the antenna gets reduced significantly.

Further, conformal theory is used for cylindrical conformal application for single, double and four elements. The effects of surface waves and mutual coupling can be minimized by optimizing elements spacing in both the planes and by incorporating guard lines in length & width. The proposed designs, developed in Chapter 6, which described the effect of curvature and improved the effects of low band width, gain, inaccuracies occurred in radiation patterns. The process has been successfully analyzed on both thin and thick dielectric substrates having low permittivity. The antenna designed for given resonant frequency has been observed to be in correspondence to the patch dimension with high accuracy. The empirical relations derived for curvature can be used to predict the antenna designing parameters including resonant frequency, return loss, power radiated, directivity and gain for a microstrip antenna subjected to the limits for the thickness of substrate layer (0.58mm-2.54mm). The antenna parameters including resonant frequency, return
loss, power radiated, directivity and gain for a multilayer microstrip antenna can be predicted by using empirical relations. Chapter 5 addresses to the design of antenna of aircraft systems. To overcome the threat under conformality, airborne antenna systems may need to be reconfigurable and functional to overcome intentional and unintentional electromagnetic disturbances. A novel design of X-band frequency cylindrical conformal microstrip patch antenna with a cover layer placed directly on the surface of the aircraft has therefore been presented in this chapter. Such an antenna can be used for specific high-performance airborne applications and suitably be utilized for realization of frequency hopping. By selecting the desired cover layer parameters appropriately a significant increase in gain and antenna efficiency is achieved, enabling the cover to act as the part of antenna.

The proposed two designs achieves frequency agility ranging from 15.5% to 24% with centre frequency set at 8.357 GHz. Antennas mounted on singly curved cylindrical surfaces are an important class of conformal arrays for applications in which a large (azimuthally) angular coverage is required. These types of antennas can be used in radar and communication systems. The singly curved surface can also be used as an approximation of the shape of an aircraft wing, cockpit, fuselage or external pods etc. The focus is on the effect of mutual coupling and its influence on the radiation. A low profile conformal microstrip antenna on a cylindrical surface has distinct advantage for applications related to fighter aircraft and spacecraft. Microstrip antenna and arrays conformed to curved surfaces viz. aerodynamic surfaces like supersonic aircraft or missiles, can be modeled approximately in the shape of a cylinder.