2.1. INTRODUCTION

The present chapter is dedicated to describe the effects of dielectric loading on the performance characteristics of the microstrip antennas. The concept of dielectric loading on microstrip lines dates back in year 1980, when I. J. Bahl & S. Stuchly proposed a variational method to describe the microstrip line covered with a lossy dielectric sheet. They found that characteristics of microstrip covered with a thick sheet of high dielectric constant are drastically affected. The effect of dielectric cover is more pronounced for small values of $w/h$ ratio, $w$ is width line and $h$ is height of dielectric substrate. This is because the fringing fields which interact with the covering sheet increases for smaller values of $w/h$ ratio. Their studies were focused on the variation of characteristic impedance, effective dielectric constant, and conductor as well as dielectric losses with $w/h$ ratio for different dielectric loaded materials. In addition it has been reported that above parameters also varies with $d/h$ ($d$- thickness of cover). In particular for $d/h = 0.02$, the values of effective dielectric constant decreases with increase in ratio $w/h$. However for larger values of $w/h$ ratio effective dielectric constant increases for smaller values of $d/h$. The effective dielectric constant decreases with the increase in $w/h$ values because in this case fringing field decreases with increasing $w/h$ values. For large $w/h$ ratio the structure behaves like a microstrip and the effective dielectric constant increases [1]. It is also found that conductor loss and dielectric loss increases with increases in $d/h$ values, whereas dielectric loss decreases with increasing $w/h$ ratio.

2.2. EFFECT OF DIELECTRIC LOADING ON RECTANGULAR MICROSTRIP PATCH ANTENNAS

In 1982 I. J. Bahl et al designed a microstrip antenna covered with dielectric layer and found that covered microstrip antenna alters its performances such as characteristics
impedance, phase velocity and dielectric losses. The basic geometry of a dielectric loaded rectangular microstrip antenna is shown in Figure 2.1.

Figure 2.1 Side view of a dielectric loaded rectangular microstrip antenna

In particular, due to dielectric cover the resonance frequency of antenna changes, and reason behind that effective dielectric constant changes due to dielectric layer. And corresponding fractional change in resonance frequency $\Delta f_r$ is calculated using [2].

$$\frac{\Delta f_r}{f_r} = \frac{1}{2} \frac{\Delta \varepsilon_e}{\varepsilon_{eo}} \frac{1}{1 + \frac{1}{2} \frac{\Delta \varepsilon_e}{\varepsilon_{eo}}}$$

(2.1)

Where,

$\varepsilon_e$ = effective dielectric constant with cover

$\varepsilon_{eo}$ = effective dielectric constant without cover

$\Delta \varepsilon_e$ = change in dielectric constant due to cover

$\Delta f_r$ = fractional change in resonant frequency

$f_r$ = resonance frequency

In particular, it had been found that, the fractional change of resonance frequency for optimum design at 10 GHz are 5.8%, 7.8%, and 16% for the dielectric cover of polystyrene, ice and beryllium oxide respectively (Figure 2.2).
Figure 2.2 The fractional resonant frequency of a microstrip antenna covered with a dielectric layer as a function of resonant frequency for plasma

Figure 2.3 The fractional resonant frequency of a microstrip antenna loaded with ice, as a function of frequency for various thicknesses of dielectric covers

It has also been noticed that if the dielectric cover thickness increases more than 2 cm, the effect of dielectric loading on resonance frequency of patch becomes smaller (Figure 2.3). In addition effect of dielectric thickness indicates that a return loss first increases with increasing the thickness of dielectric cover and then decreases. Whereas bandwidth increases with increasing cover thickness for low dielectric constant material and decreases for high dielectric material (Table 2.1).
Table 2.1 Experimental data for the effect of dielectric loading on the characteristics of microstrip antennas.

<table>
<thead>
<tr>
<th>Dielectric Cover</th>
<th>( \varepsilon_r )</th>
<th>( d ) (cm)</th>
<th>( f_r ) (GHz)</th>
<th>Return Loss (dB)</th>
<th>Bandwidth(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>1.0</td>
<td>(=)</td>
<td>4.104</td>
<td>32</td>
<td>2.17</td>
</tr>
<tr>
<td>Duroid</td>
<td>2.32</td>
<td>0.08</td>
<td>4.008</td>
<td>35</td>
<td>2.18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.159</td>
<td>3.934</td>
<td>26</td>
<td>2.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.318</td>
<td>3.895</td>
<td>22</td>
<td>2.31</td>
</tr>
<tr>
<td>Plexiglass</td>
<td>2.6</td>
<td>0.112</td>
<td>3.952</td>
<td>33</td>
<td>2.18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.159</td>
<td>3.912</td>
<td>25</td>
<td>2.18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.318</td>
<td>3.874</td>
<td>22</td>
<td>2.20</td>
</tr>
<tr>
<td>Mylar</td>
<td>3.0</td>
<td>0.0064</td>
<td>4.070</td>
<td>37</td>
<td>2.18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0128</td>
<td>4.058</td>
<td>39</td>
<td>2.18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0384</td>
<td>4.010</td>
<td>40</td>
<td>2.20</td>
</tr>
<tr>
<td>Epsilam-10</td>
<td>10.2</td>
<td>0.0635</td>
<td>3.640</td>
<td>36</td>
<td>2.0</td>
</tr>
<tr>
<td>Custom High-k</td>
<td>10</td>
<td>0.154</td>
<td>3.482</td>
<td>24</td>
<td>1.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.132</td>
<td>3.26</td>
<td>18</td>
<td>1.90</td>
</tr>
</tbody>
</table>

In particular microstrip antenna designed on Duroid substrate for \( f = 4.1 \) GHz and loaded with a 0.318 cm thick dielectric cover exhibits bandwidth enhancement by 7%, whereas for dielectric loading of thickness less than 0.1 cm, the bandwidth is almost unaffected.

N.G. Alexopoulous using Greens function followed by Sommerfield method proposed that dielectric loaded microstrip antenna offers increased gain, radiation resistance and efficiency, provided covered material considered as desirable part of an antenna. They observed that by choosing proper thickness of cover, resonance condition may be created, whereby gain and radiation resistance are substantially improved over significant bandwidth. If thickness of the dielectric cover is about half of operating wavelength, 100% efficiency may be achieved [3].

H. Y. Yang and N. G. Alexopoulous in 1987 also analyzed multiple dielectric loaded printed circuit antennas using transmission line model. They considered a Hertzian electric dipole (HED) is embedded in the substrate with multi-dielectrics, and observed two resonance conditions. It was concluded that when the first resonance condition is satisfied and corresponding wave impedances are in high low-high-low sequence, extremely larger resonance gain can be obtained even with moderate values of \( \varepsilon \) and \( \mu \). The same conclusion is obtained for the second case of resonance condition except that wave
impedances are in the low-high sequence is satisfied. The proposed method reveals that extremely high gain (= 20 dB) is obtained which can be further increased by increasing the number of dielectric layers. But as the gain increases the bandwidth of antenna decreases and antenna becomes more bulky as well as sensitive to parameters [4].

Later A. Bhattacharya reported that dielectric loading minimizes the level of matching but it can be improved by shifting the feed location. All other parameters change usually due to loading of dielectric covers [5]. However -10 dB return loss bandwidth does not change significantly with the dielectric thickness. Experimental results obtained for rectangular microstrip antenna are tabulated in Table 2.2.

Table 2.2 Experimental observation for dielectric cover on rectangular patch antenna [5]

<table>
<thead>
<tr>
<th>S. No</th>
<th>Thickness of dielectric $h$ (cm)</th>
<th>Resonance Frequency(GHz)</th>
<th>Return loss(dB)</th>
<th>Frequency at -10 dB loss(GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>2.845</td>
<td>-43</td>
<td>2.765-2.925</td>
</tr>
<tr>
<td>2</td>
<td>0.318</td>
<td>2.749</td>
<td>-17.5</td>
<td>2.668-2.824</td>
</tr>
<tr>
<td>3</td>
<td>0.638</td>
<td>2.704</td>
<td>-13</td>
<td>2.641-2.743</td>
</tr>
<tr>
<td>4</td>
<td>0.95</td>
<td>2.682</td>
<td>-13</td>
<td>2.620-2.743</td>
</tr>
<tr>
<td>5</td>
<td>1.272</td>
<td>2.67</td>
<td>-12.5</td>
<td>2.610-2.734</td>
</tr>
</tbody>
</table>

R. Q. Lee and A. J. Zaman et al, studied two layer electromagnetic coupled microstrip antenna loaded with dielectric cover of various thicknesses (0-0.16cm). It was found that in high gain region resonant input impedance increases and the 3 dB beam width decreases with the dielectric thickness, while resonant frequency and bandwidth decreases (17.1 GHz to 7.6 GHz). In general impedance matching becomes poor with dielectric thickness [Table–1, 6]. Multiport network model [MNM] has been extended to analyze a rectangular dielectric covered microstrip antenna in [7]. The substrate thickness is chosen to be much smaller than the wavelength ($\lambda$), so the fields underneath the patch have no variations in the Z-direction. The conductance $G_r$ and $G_s$ of a radiating edge are related to voltage distribution as follows;

$$G_{r,s} = \frac{2P_{r,s}}{\frac{1}{b} \int_s V^2(s) ds} \quad (2.2)$$
Where the integration is along the patch edge of length $b$, $r$ is radiation conductance and $s$ is surface conductance and $V(s)$ is the voltage distribution along the edge, $P_{r,s}$ is the power radiated for the radiation and surface waves. Particularly for the substrate thickness $d = 0.25 \text{ mm}$, the percentage of the power radiated ($P / (P_r + P_s)$) is $\sim 61\%$. Whereas edge capacitance in presence of covered rectangular microstrip antenna is found to be

$$C(b) = \frac{b}{2} \left[ \varepsilon_{r_1}(a) \frac{1}{C_0 Z_0(\text{air})} - \varepsilon_0 \varepsilon_r \right]$$ (2.3)

Where all the parameters have their usual meaning. The radiating-edge capacitance of a rectangular patch antenna along with resonant frequency is tabulated in Table 2.3 [7].

Table 2.3 Radiating-edge capacitance of rectangular patch antenna with dielectric cover ($h = 0.396 \text{ mm}, d = 2.54 \text{ mm}, \varepsilon_{r_1} = \varepsilon_{r_2} = 2.2$)

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Length ($a$) (cm)</th>
<th>Width ($b$) (cm)</th>
<th>Resonance Frequency (GHz)</th>
<th>Edge capacitance (pF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.3372</td>
<td>2.017</td>
<td>7.13</td>
<td>0.06717</td>
</tr>
<tr>
<td>2</td>
<td>1.3359</td>
<td>4.008</td>
<td>7.0475</td>
<td>0.14141</td>
</tr>
<tr>
<td>3</td>
<td>1.3411</td>
<td>6.03</td>
<td>7.045</td>
<td>0.19320</td>
</tr>
<tr>
<td>4</td>
<td>1.3376</td>
<td>8.043</td>
<td>7.02</td>
<td>0.27115</td>
</tr>
</tbody>
</table>

The analysis reveals that both the input reflection, the resonance frequency for one-port network, whereas input reflection, the resonance frequency as well as transmission coefficient for two-port, are in good agreement with experimental and theoretical results. In present case dielectric constant ($\varepsilon_r$) of substrate and dielectric are taken to equal. The measured resonance frequency is found to be 7.475 GHz, while the theoretical value is 7.485 GHz, which indicates that there is a discrepancy of about 0.134% (Figure 2.4 a). However the bandwidth of the one-port rectangular patch for (VSWR < 2) is 80 MHz or 1.06%. Figure 2.4 b shows a good agreement between theoretical and measured variations of input reflection coefficient $|S_{11}|$ with frequency. The measured resonance frequency is 7.485 GHz; the corresponding theoretical value is also 7.485 GHz with numerical values; -25.6 dB and -33.5 dB respectively. A good agreement between the theoretical and the measured variations of the transmission coefficient $|S_{21}|$ with frequency is also observed in
Figure 2.4 b. At the resonance frequency $f = 7.485$ GHz, the measured $|S_{21}|$ is -2.8 dB while theoretical value is -2.64 dB. It is also observed that in spite of changing resonant frequency, reflection coefficient and other parameters, dielectric loading also changes the shape of radiation pattern. Depending on the thickness of dielectric loading at higher frequency the radiation pattern is splitted into two and three lobes.

Experimental result obtained by R.N. Karekar, on a rectangular patch antenna designed on ($\varepsilon_r = 9.8$, $h = 0.635$m, $\tan\delta = 0.0001$), shows that angle of radiation pattern lobes varies between $\pm 60^0$ for dielectric relative thickness $(d/\lambda_m) = 0.58$ [Table 1, 8].

![Figure 2.4 (a) Comparison of experiment and theory for $|s_{11}|$ of a one port rectangular microstrip](image)

![Figure 2.4 (b) Comparison of experiment and theory for $|s_{11}|$ and $|s_{12}|$ of a two port RSMA](image)

Available results, on the covered patch indicate that calculation of radiation pattern has been paid less attention. In this view, Ghulam Qasim has made an attempt to calculate the
radiation pattern of covered rectangular MSA using spectral domain imittance (SDI) matrix approach after calculating the current distribution on the patch [9]. It is found that for $d = 0.8$ mm, $E$-plane pattern changes significantly at $\theta = \pm 90^\circ$ whereas for $d = 3.18$ mm, a small dip occurs and the field is maximum at $\theta = \pm 10^\circ$ (Figure 4, [9]). The effect of dielectric loading on the performance characteristics of slot-coupled microstrip antennas have also been studied, and it was found that dielectric loading decreases the resonant frequency and input impedance, however increases bandwidth. The radiation efficiency of antenna can be made optimum, provided the dielectric is made thicker than substrate of antenna. (Figures 3 & 4) [10].

A modified Wolf model (MWM) was proposed in year 1993 [11], to calculate the resonant frequency of dielectric loaded patch antenna as well as multilayer resonating structures and results obtained are found to be very close to experimental data than that of full wave analysis and almost in all cases, they are within 0.5% of published results for the fundamental mode and within 1.7% for other higher modes. It is basically cavity model, where the dynamic permittivity is calculated using variational method. The MWM has also been applied on triangular and hexagonal patches, and found very useful tool for microwave Computer Aided Design (CAD) on patch antenna. The resonant frequency is calculated by

$$f_f = f_{mn} = \frac{V_0}{2 \sqrt{\varepsilon_{dyn}}} \left[ \frac{m}{W_{eff} + L_{eff}} \right]$$

(2.4)

Where all the parameters are defined in [10]. However for rectangular microstrip antenna, complex resonant frequency varies more significantly, when the dielectric permittivity is greater than that of substrate [12]. P Lowes et al [13] described the effects of laminated glass dielectric along with a layer of resistive film on the outer layer of dielectric, on the radiation pattern as well as bandwidth of a microstrip patch antenna. The study indicates that antenna offers improvement in the impedance bandwidth of the antenna, $\approx 20\%$, as compared to 3% for a VSWR of 2, for an antenna with no cover. It is also found that, H-plane radiation pattern have nulls appearing at angles of $\pm 40^\circ$, while E-plane radiation pattern is unaffected with dielectric loading. The effects of dielectric loading on the circular polarization (CP) and cross polarization (XP) characteristics of a rectangular microstrip patch antenna has also been studied by W S Chen et al in year 1994 [14]. The effect of dielectric permittivity and thickness as well as substrate dielectric gap on
co-polarization and cross polarization of the patch antenna has also been analyzed. The optimal aspect ratio and centre operation frequency are then adjusted for producing C P radiation at the main-beam direction. In addition, the following condition must be satisfied at $\theta = 0^\circ$ i.e.

$$\angle E_\theta - \angle E_\varphi = \pm 90^\circ$$

$$|E_\theta| = |E_\varphi|$$

The obtained results indicate that, when the dielectric layer is spaced away from the patch, the loading effects on the antenna are considerably reduced. However the centre frequency for the C P radiation is slightly varied, on the other hand the 3 dB bandwidth and optimal feed position are almost unaffected. From the loading for higher air gap thicknesses, the main-beam polarization property is also better. However, XP characteristics under dielectric loading, indicate that, for the patch antenna excited at TM$_{01}$ mode, the ratio of co-polarized to cross polarized fields at $\theta = 0^\circ$ decreases with increasing dielectric permittivity and shows a minimum value when the dielectric thickness is a quarter wavelength or its odd multiples (Figure 2.5).

![Figure 2.5 Variations of the ratio of co polarized to cross polarized fields at $\theta = 0^\circ$ with dielectric thickness. Three cases of $\varepsilon_r = 2.32, 4.0$ and 5.6 are shown for $s = 0$](image)

From Figure 2.5, it is clear that ratio $|E_{01}|$ to $|\sum E_{m0}|$ at $\theta = 0$ is about 20.7 dB for $t = 0$. The ratio of $|E_{01}|_{\text{max}}$ to $|\sum E_{m0}|_{\text{max}}$ drastically decreases from 20.7 dB (no loading) to about 13.9 dB, 9.7 dB, and 8 dB, respectively, for loading the patch antenna with a $(\lambda/4)$
dielectric layer, for \( \varepsilon_r = 2.32, 4.0 \) and 5.6 respectively. Therefore, effect of dielectric loading on the ratio of \( |E_{01}|_{\text{max}} \) to \( \sum E_{m0}|_{\text{max}} \) could be minimized by choosing its thickness not equal to \((\lambda/4)\) or its odd multiple. In order to improve the gain of printed antennas, L. Zhang \textit{et al} [15] have used Photonic Band Gap (PBG) like structure in cavity backed microstrip antennas. In general gain enhancement is noticed, due to strong excitation of leaky wave’s modes in the PBG layer. To obtain PBG effects, the unit cell size should be comparable to the operating wavelength. In their study, they considered two types of PBG-Like substrate of (4x4) unit cells, and PBG substrate (5x5) unit cells. And they found that plane cavity backed antenna shows 5 dB of gain at two resonances, however maximum gains of 7.5 dB and 9.0 dB were found for respective resonance for PBG substrate. Effects of PBG dielectric on patch antenna reveals that maximum gain over 10 dB is seen for both E and H Plane radiation patterns. Later Jennifer T. Bernhard \textit{et al} developed a model that predict the resonant frequencies of rectangular microstrip antennas in terms of antenna dimensions, material parameter and antenna resonance with both flush and spaced dielectric. The desired parameter are calculated using expression (9-13) given in [16]. It was concluded that model is suitable for CAD and is directly applicable for the integration of microstrip antennas with protective layers in wireless equipment. The obtained results are in good agreement (less than 1% errors) for \( \varepsilon_r < 3 \), and slightly higher for \( \varepsilon_r > 3 \).

Table 2.4 Measured maximum gain increment frequencies \( f_{\text{max gi}} \) and maximum gain increments \( G_{i_{\text{max}}} \) of the probe-fed rectangular patch antenna with the dielectric at different distances \( t_2 \)

<table>
<thead>
<tr>
<th>S.No</th>
<th>( t_2 ) (mm)</th>
<th>( f_{\text{max gi}} ) (GHz)</th>
<th>( G_{i_{\text{max}}} ) (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14.0</td>
<td>9.9220</td>
<td>6.553</td>
</tr>
<tr>
<td>2</td>
<td>15.0</td>
<td>9.5170</td>
<td>8.832</td>
</tr>
<tr>
<td>3</td>
<td>16.0</td>
<td>8.9170</td>
<td>9.137</td>
</tr>
<tr>
<td>4</td>
<td>17.0</td>
<td>8.5350</td>
<td>10.060</td>
</tr>
<tr>
<td>5</td>
<td>18.0</td>
<td>8.2270</td>
<td>9.577</td>
</tr>
<tr>
<td>6</td>
<td>19.0</td>
<td>7.8820</td>
<td>9.486</td>
</tr>
</tbody>
</table>

Later X. H. Shen \textit{et al} [17] have made an attempt to enhance gain of a microstrip patch antenna with one substrate dielectric structure between frequency 7.5 GHz to 10.5 GHz
for different distances between patch and dielectric. It was found that the highest maximum gain is found as 16.3770 dB at $f = 8.9170$ GHz with distance 16.0 mm. However the highest maximum gain increment is observed at distance 17.0 mm of 10.060 dB at $f = 8.335$ GHz with $\varepsilon_r = 10.5$.

It has been also concluded that maximum gain can be controlled by adjusting the distance between patch and dielectric [17].

Raj Kumar and P. Malathi [18] proposed a modified formula to calculate the resonant frequency of multilayered dielectric loaded RSMA and it is given by

$$f_r = \frac{c}{2(L + 2\Delta L)(\varepsilon_{eff})^{1/2}} \quad (2.5)$$

Where

$$\varepsilon_e(f) = \frac{\varepsilon_r' - \varepsilon_{eff(o)}}{1 + P(f)} \quad (2.6)$$

$\varepsilon_{eff(o)}$=effective dielectric constant

$\varepsilon_r'$ = equivalent relative permittivity of single layer patch antenna

$P(f)$ = frequency dependent factor

Analysis indicates that, as the dielectric thickness increases from 0.5 mm to 12.72 mm, the resonance frequency decreases from 2.759 GHz to 2.670 GHz, and maximum change in $f_r$ is around 4% when external loading thickness chosen between 1 to 5 mm. The resonant frequency is shifted to the higher frequency side as the air gap increases. The % variation in resonant frequency is around 21.8% as $h_1/h_2$ ratio of air-gap to substrate next to the ground plane is varying from 0.065 to 1.94. Effects of dielectric cover on a rectangular MSA operating in $TM_{10}$ mode have also been analyzed using Genetic Algorithm (GA).
The Genetic Algorithm program for this purpose is developed using C++ language. Two addition parameters: $\varepsilon_r$ and $h$ of the dielectric is also taken as input in the optimization. The obtained results reveal that there is usual variation of properties of antenna; resonance frequency and gain, with $\varepsilon_r$ and $h$ of the dielectric, as shown in Figures 2.6 & 2.7 [19].

The shift in resonant frequency of a rectangular microstrip antenna covered with a dielectric layer has also been analyzed by S. Chakraborty et al, using a neural network model. The model proposed is faster and accurate than conventional methods, and results
are found to be in good agreement with that of electromagnetic simulation based on method of moments [20].

L. Siu and K.M. Luk [21] proposed a unidirectional antenna with loaded dielectric substrate and composed with two shorted-circuited rectangular patches operating at 2.5 GHz. The measured SWR and gain of the antenna with/without the presence of a metallic wall, indicates that impedance bandwidth and average gain are 46.3% from 1.98 to 3.17 GHz and 7.9 dBi, respectively. Besides, the measured impedance bandwidth and average gain are 45.3% from 2.00 to 3.17 GHz and 6.7 dBi, respectively without metallic cover. However, in the presence of a metallic wall, the impedance bandwidth is 46.3% for with an average gain of about 7.9 dBi. The advantages of the proposed antenna include: wide bandwidth, low profile, low cross-polarization level, and stable gain over the operating band (Figure 2.8).

![Graph showing measured gain and SWR of the proposed antenna with and without wall](image)

Figure 2.8 Measured gain and SWR of the proposed antenna with and without wall

H.A. Hammas [22], analyzed the effects of dielectric loading on an aperture coupled antenna, and calculated antenna parameters such as, Radiation efficiency, Half-Power Beam width (HPBW) and directivity using MOM. And found that variation of resonance frequency with dielectric thickness is as usual, however as dielectric thickness increases, gain of antennas decrease (Table 2.5).
<table>
<thead>
<tr>
<th>Dielectric Thickness (mm)</th>
<th>Antenna Efficiency (%)</th>
<th>Radiation Efficiency (%)</th>
<th>HPBW (deg)</th>
<th>Gain (dBi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>92.34</td>
<td>92.41</td>
<td>109.94</td>
<td>6.9</td>
</tr>
<tr>
<td>5</td>
<td>72.33</td>
<td>78.46</td>
<td>102.45</td>
<td>7.25</td>
</tr>
<tr>
<td>10</td>
<td>66.08</td>
<td>71.56</td>
<td>91.11</td>
<td>7.64</td>
</tr>
<tr>
<td>15</td>
<td>60.13</td>
<td>69.86</td>
<td>90.19</td>
<td>7.877</td>
</tr>
</tbody>
</table>

Therefore, from the above study it may be concluded that dielectric loading alters the antenna performances, particularly the resonance frequency of rectangular patch antenna, and degree of effects vary with thickness of dielectric, types of dielectrics, shifts in feed position, impedance matching and polarization characteristics of microstrip antenna.

2.3. THE DIELECTRIC COVERED CIRCULAR MICROSTRIP ANTENNAS

2.3.1. Effect on Resonance Frequency

As the antenna is a resonance device, its resonance frequency is the most important parameter, because it also affects other parameters such as bandwidth, gain and efficiency etc. The available literatures on dielectric loading patch antenna reveals that, dielectric loading significantly changes the resonance frequency hence causes detuning. K. M. Luk et al. in 1989 first studied the characteristics of circular patch under various dielectric cover thicknesses. Using Hankel transform analysis method for TM$_{11}$ mode, they found that resonant frequency decreases with increasing the thickness of dielectric, while half-power bandwidth changes slightly [23] as shown in Figure 2.9. While A. K. Bhattacharyya [24], in year 1991, derived the expressions for wall admittance, wall conductance and radiation efficiency of dielectric loaded circular patch antenna. In this study, he used principle of equivalence, which yields equivalent electric and magnetic surface currents for the outside fields, that is responsible for radiation. He concluded that for a small substrate thickness, the magnetic current model yields fairly accurate results, which deteriorates with an increase in the substrate thickness.
Figure 2.9 Variations of resonant frequency and bandwidth with dielectric thickness

The radiation efficiency decreases initially and then increases with the thickness of the dielectric layer. The maximum value of the radiation efficiency is obtained in the case of an antenna with different substrate and dielectric materials than that of an antenna with substrate and dielectric of same dielectric. The wall admittance of the patch is representative of the total power output and this output power has two components; the space wall power ($P_{sp}$) and surface wave power ($P_{su}$).

Figure 2.10 Variations of space wave conductance’s with substrate and dielectric thickness ($a = 1.1$ cm, $f = 5$ GHz)

The radiation efficiency $\eta$ is defined as [25]

$$\eta = \frac{g_{sp}}{g_{sp} + g_{su}} \% \quad (2.7)$$

Where $g_{sp}$ and $g_{su}$ are the space and surface wave conductance’s respectively.
The variations of space and surface wave conductances are shown in Figures 2.10 and 2.11 respectively; whereas radiation efficiency is computed and plotted against the normalized substrate/dielectric thickness as shown in Figure 2.12.

![Figure 2.11 Surface wave conductance’s vs dielectric thickness (a = 1.1 cm, f = 5 GHz)](image1)

![Figure 2.12 Radiation efficiency vs normalized substrate /dielectric thickness](image2)

A new modified Wolff model (MWM) has also been proposed to calculate the resonance frequency of the circular covered and uncovered patch antenna. And found that for uncovered patches the calculated frequency is within 0.5% of the measured value whereas for covered patch antennas the resonance frequency is within 1% of the results using from SDA. The resonance frequency of circular covered and uncovered patch obtained;

\[
f_r = \frac{v_o \cdot a_{nm}}{2\pi c_r \sqrt{\varepsilon_{dyn}}} \tag{2.8}\]
Where for the fundamental TM$_{11}$ mode, $\alpha_{nm} = 1.841$ and $v_o$ is the velocity of light. Wolff and Knoppik have calculated effective radius $r_{ef}$ by using the Kirchhoff approximate result which is suitable only for an air filled capacitor, (Equations 2-7, [25]). The values of resonance frequencies calculated using various models are tabulated in Table 2.6.

Table 2.6 Data comparison of the resonance frequencies for various models

<table>
<thead>
<tr>
<th>Radius $r_0$(cm)</th>
<th>$h_1$ (mm)</th>
<th>$\varepsilon_r$</th>
<th>$f_r$(Measured) GHz</th>
<th>Wolff Original GHz</th>
<th>Error* %</th>
<th>Modified Wolff GHz</th>
<th>Error* %</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.493</td>
<td>1.588</td>
<td>2.50</td>
<td>1.570</td>
<td>1.569</td>
<td>0.06</td>
<td>1.570</td>
<td>0.0</td>
</tr>
<tr>
<td>1.270</td>
<td>0.794</td>
<td>2.59</td>
<td>4.070</td>
<td>4.267</td>
<td>4.84</td>
<td>4.179</td>
<td>2.60</td>
</tr>
<tr>
<td>3.493</td>
<td>3.175</td>
<td>2.50</td>
<td>1.510</td>
<td>1.526</td>
<td>1.06</td>
<td>1.525</td>
<td>1.00</td>
</tr>
<tr>
<td>13.894</td>
<td>12.70</td>
<td>2.70</td>
<td>0.378</td>
<td>0.362</td>
<td>4.23</td>
<td>0.374</td>
<td>0.95</td>
</tr>
<tr>
<td>4.950</td>
<td>2.350</td>
<td>4.55</td>
<td>0.825</td>
<td>0.836</td>
<td>1.34</td>
<td>0.826</td>
<td>0.20</td>
</tr>
<tr>
<td>3.975</td>
<td>2.350</td>
<td>4.55</td>
<td>1.030</td>
<td>1.042</td>
<td>1.17</td>
<td>1.027</td>
<td>0.20</td>
</tr>
<tr>
<td>2.990</td>
<td>2.350</td>
<td>4.55</td>
<td>1.360</td>
<td>1.17</td>
<td>1.77</td>
<td>1.368</td>
<td>0.60</td>
</tr>
<tr>
<td>2.000</td>
<td>2.350</td>
<td>4.55</td>
<td>2.003</td>
<td>3.19</td>
<td>3.19</td>
<td>2.017</td>
<td>0.70</td>
</tr>
<tr>
<td>1.040</td>
<td>2.350</td>
<td>4.55</td>
<td>3.750</td>
<td>5.68</td>
<td>5.68</td>
<td>3.761</td>
<td>0.30</td>
</tr>
<tr>
<td>0.770</td>
<td>2.350</td>
<td>4.55</td>
<td>4.945</td>
<td>7.34</td>
<td>7.34</td>
<td>4.946</td>
<td>0.02</td>
</tr>
</tbody>
</table>

* Error in $f_r = (f_r$ measured $- f_r$ theoretical)/ (f, measured)

Therefore the MWM is capable of giving highly accurate resonance frequency for both dielectrics covered and uncovered microstrip rectangular and circular patches.

However, Z. Shen and R. H. Mac Phie proposed a waveguide modal analysis to calculate the input impedance of a circular patch antenna covered by a uniaxial anisotropic dielectric and fed by a centered coaxial line. The obtained results indicate that both the thickness and the dielectric constant of the dielectric have a significant influence on the antenna’s performances. Finally, the effect of the anisotropy of the substrate and dielectric on the input impedance of a center-fed microstrip disk antenna was also examined for a circular patch of radius 15 mm on a substrate of thickness $h = 1.6$ mm and covered with a dielectric with the same parameters as the substrate.

It is also noted that the substrate anisotropy decreases the resonant frequency, because a negative uniaxial substrate equivalently produces a large effective dielectric constant of the substrate [26].
Later, D. Guha and J. Y. Siddiqui minimized the complexity of calculating the resonant frequencies of dielectric loaded circular microstrip antennas to both low and high dielectric constant [27]. The proposed method is based on cavity model, and found to be closest approximations with the experiments with average percentage error as low as 0.52%. [Equations: 1-12, 27]. In addition to dielectric loading effects of air gap between substrate and dielectric on the performance of a circular patch antenna has also been studied [28]. The resonance frequency of the proposed antenna was estimated by:

$$f_{mn} = \frac{\alpha_{n,m} \cdot c}{2\pi a_e (\varepsilon_e)^{1/2}}$$  \hspace{1cm} (2.9)

$\alpha_{n,m} = m^{th}$ Zero of the derivative of Bessel’s Function of order $n$.

$c$ = velocity of light

$a_e$ = effective radius of circular patch

$\varepsilon_e$ = effective relative permittivity

Analysis indicates that % change in $f_r$, is more for small air-gap and tends towards CMP for very long air gap. In particular % fractional change is less than 0.4% and 0.75% for superstrates of $\varepsilon_r \approx 3.27$ respectively.
While, K. Guney has proposed a method to study the performance characteristics of a circular patch antenna loaded with the dielectric covers. The method is based on adaptive network fuzzy interference system (ANFIS). The ANFIS used in this work implements a first-order Sugeno fuzzy model which is the most widely applied one for its high interpretability and computational efficiency, and built-in optimal and adaptive techniques. For the ANFIS, the inputs are $h_1/a$, $h_2/a$, $\varepsilon_{r1}$, and $\varepsilon_{r2}$, and the output is the normalized resonant frequency $f_r/f_{no}$. $f_r$ and $f_{no}$ represent, respectively, the resonant frequencies of the TM$_{11}$ mode (dominant mode) of the circular MSA with and without dielectric cover. The ANFIS utilized six different optimization algorithms; HL, LSQ, NM, GA, DEA, and PSO, which are used to determine the optimum values of the design parameters and adapt the FIS [29]. The optimum design parameters of the ANFIS determined with the use of HL, LSQ, NM, GA, DEA, and PSO are given in Table 2.7.

Table 2.7 Training and test errors of ANFIS models optimized by different algorithms

<table>
<thead>
<tr>
<th>Optimization algorithms</th>
<th>RMS training errors</th>
<th>RMS test errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>HL</td>
<td>0.0004860</td>
<td>0.0013710</td>
</tr>
<tr>
<td>LSQ</td>
<td>0.0003898</td>
<td>0.0002597</td>
</tr>
<tr>
<td>NM</td>
<td>0.0004809</td>
<td>0.0005790</td>
</tr>
<tr>
<td>GA</td>
<td>0.0004868</td>
<td>0.0009843</td>
</tr>
<tr>
<td>DEA</td>
<td>0.0004867</td>
<td>0.0009824</td>
</tr>
<tr>
<td>PSO</td>
<td>0.0004899</td>
<td>0.0009589</td>
</tr>
</tbody>
</table>

These RMS error values clearly show that the best results for training and testing are obtained from the ANFIS model optimized by the LSQ optimization algorithm. The test results of ANFIS optimized by the LSQ were compared with the results of the moment-method full-wave analysis and the CAD formula in (Figures 4–6, [30]), which are in very good agreement.
In order to make a further validation, the results of ANFIS optimized by the LSQ were compared with the results of Galerkin’s method in the Hankel transform domain as shown in Figure 2.14.

Figure 2.14 Comparison of the resonant frequency results of the ANFIS optimized by the LSQ and Galerkin’s method in the Hankel transform domain (HTD) for \( h_2 = 1.5875 \) mm, \( a/h_2 = 5 \), and \( \varepsilon_{r2} = 2.5 \).

From Figure 2.14, it is seen that the results of ANFIS are in good agreement with the results of Galerkin’s method in the Hankel, Transform domain. It is found that the result of ANFIS agrees better with the measured result than the results of [29]. In this paper, only the resonant frequency of the TM_{11} mode is calculated by using the ANFIS, because this circular microstrip patch mode is widely used in MSA applications. However, the ANFIS can be easily adapted to compute the resonant frequencies of higher order modes of practical interest if the data sets for these modes are available. It must also be emphasized that the proposed method is not limited to the resonant frequency calculation of circular patches. The ANFIS has the advantages of easy implementation and good learning ability. The high-speed real-time computation feature of the ANFIS recommends its use in antenna CAD programs.

2.3.2. Effect on Radiation Pattern and Half Power Bandwidth

Kin-Lu Wong et al, have described the effect of dielectric loading especially of different thickness on spherical-circular microstrip antenna particularly its resonance and radiation characteristics. They investigated these parameters by using the Green’s function formulation in the spectral domain and Galerkin moment method, and calculated the
resonance frequency, half power bandwidth and radiated the antenna in the $TM_{11}$ mode. Two different sizes of the sphere, with $a = 5$ and $10$ cm, are shown in Figure 2.15.

![Figure 2.15 Geometry of a dielectric-loaded spherical-circular microstrip patch antenna](image)

The obtained results indicates that resonant frequency and half power bandwidth vary significantly for higher dielectric constants dielectrics especially when dielectric constants of dielectric is greater than that of substrate whereas beam width of $E$-plane pattern is found to be decreasing with increasing cover thickness.

![Figure 2.16 Dependence of (a) the resonant frequency (b) the half-power bandwidth on dielectric thickness for cases of $\varepsilon_2 = 1.5, 2.5, 8.2$; $\varepsilon_1 = 2.5$, $r_d = 2.5$ cm, and $d = 1.588$ mm](image)

Figure 2.16 Dependence of (a) the resonant frequency (b) the half-power bandwidth on dielectric thickness for cases of $\varepsilon_2 = 1.5, 2.5, 8.2$; $\varepsilon_1 = 2.5$, $r_d = 2.5$ cm, and $d = 1.588$ mm.
Figure 2.17 Far-field radiation patterns (a) E-plane pattern (b) H-plane pattern with $a = 5 \text{ cm}$ $d = 1.6$, $r_d = 1.88 \text{ cm}$ $\varepsilon_1 = 2.47$, $\varepsilon_2 = 2.32$, $t/d = 0$, 1, 2, and 3

But the $H$-plane radiation pattern is slightly affected by the dielectric loading [30]. It is also found that side lobe and back lobe levels for $E$-plane patterns increases with increasing the radius of sphere.

Figure 2.18 Contour plots of (a) $E_\theta$ and (b) $E_\phi$ for an elliptical patch with Duroid substrate ($\varepsilon_{r1} = 2.33$) and Duroid dielectric ($\varepsilon_{r2} = 2.33$)

Later R. J. Allard, *et al* extended the reciprocity approach for the analysis of arbitrarily $Y$-shaped dielectric loaded microstrip antenna mounted on circularly-cylindrical platforms,
and has been studied the effects of a dielectric in the far-field radiation patterns of the elliptical patch antennas [31]. The obtained results agree well with the expected results, Figure 2.18.

2.3.3. Multilayer Loading

F. Zavoslt and J. T. Aberle described a cavity-backed multi-layers circular patch-antenna, and found that the antenna can provide improved performances; gain enhancement, polarization diversity, frequency agility or increased bandwidth. In particular, \(E\)-plane co-pol. (co-polarization) pattern for varying dielectric permittivity indicates that the broadside gain of the antenna increases and side-lobe levels as well as bandwidth decreases, with increasing dielectric permittivity (Figure 2.19), which illustrates that the bandwidth decreases from about 2%, for the lowest-gain design, to less than 1%, for the highest-gain case [32].

![Figure 2.19 Co-pol. gain pattern of a high-gain microstrip antenna for varying superstrate permittivity (E-plane)](image)

In addition, Figure 2.20 shows that the resonant frequency of the patch antenna, with dielectric of relative permittivity of 10 and 20, decreases by nearly 1.8 GHz and 2.3 GHz respectively. Although substantial reduction in the operating frequency is achieved with a corresponding decrease in impedance bandwidth, it may also be noted that the presence of
the cavity suppresses guided waves that are excited in the dielectric; hence, no reduction in radiation efficiency occurs.

Figure 2.20 Return loss of a recessed cavity-backed patch antenna versus frequency for varying superstrate permittivity

Later V. Losada et al have used Galerkin’s method in the Hankel transform domain (HTD), for computing the resonant frequencies, quality factors, and radiation patterns of the resonant modes of circular microstrip patch antenna embedded in multilayered dielectric substrates.

Figure 2.21 Resonant frequencies and quality factors of the fundamental resonant mode \((m = 1; n = 1)\) of a circular microstrip patch printed on a dielectric substrate with two different dielectric of varying thickness
The numerical results obtained via Galerkin’s method in the HTD have been compared with previously published numerical results. Measurements and numerical results obtained via the electromagnetic simulator “Ensemble.” Good agreement has been found in all cases. The variation of resonance frequency and quality factor for dielectric thickness is shown in Figure 2.21, which shows that the effect of the dielectric on the resonant frequency and quality factor of the circular patch analyzed is stronger as both the thickness and permittivity of the dielectric increases [33]. Using FDTD method, Raj Kumar, et al have analyzed dielectric loading effects on multilayer antenna and design a four layered circular microstrip patch antenna as well as calculated resonant frequency [34]. The average deviation for circular patch antenna with and without dielectric cover is found to be 0.4% and 0.56% respectively. However gain enhancement effect of doubling the layer on a cavity-backed slot antenna at 9.5 GHz has been studied using transmission line model. And it is found that if the thickness and dielectric constant of each of the dielectrics are chosen properly, gain up to 16.7 dB with 10 dB return loss bandwidth around 12% can be achieved.

Table 2.8 Resonant frequencies calculated by present method and FDTD method

| $\varepsilon_{r1} = 2.43$, $\varepsilon_{r3} = 2.5515$, $\varepsilon_{r4} = 3.2$, $h_{12} = 0.49$ mm, $h_3 = 0.49$ mm, $a = 11.78$ mm, $h_{11} = 0$, $\varepsilon_{r2} = 1.0$ |
|---|---|---|---|---|
| $h_4$ (mm) | $h_4/h_3$ | $f_r$ (FDTD) | Return loss | $f_r$ (PM) |
| 0.2 | 0.408 | 4.40 | -18.17 | 4.3923 |
| 0.5 | 1.022 | 4.39 | -18.82 | 4.3701 |
| 1 | 2.04 | 4.36 | -19.5 | 4.3496 |
| 2 | 4.08 | 4.34 | -18.58 | 4.3229 |
| 5 | 10.2 | 4.29 | -23.19 | 4.2636 |

Resonant frequency of circular microstrip patch $f_r = 4.5611$ GHz.
Resonant frequency of covered microstrip patch $f_r = 4.5276$ GHz for $h_3/h_{12} = 1$.

The performance of the TM$_{02}$ mode circular patch antenna with two dielectric layers has also been investigated by Jun Xia et al in year 2000. The study indicates that the antenna pattern exhibits minimum radiation in the zenith direction and is fairly symmetrical in azimuth, which is suited for wireless LAN application. It is also found that the gain is
increased by about 1.6 dBi when the two dielectric layers are added. That is with the two dielectric layers, the maximum gain of the antenna increase, and by tuning the thickness of the dielectric layers, the elevation angle of the maximum gain can be changed to suit the various wireless LAN applications [35].

2.2.4. Polarisation

Hong-Twu Chen et al analyzed a section-spherical dielectric loaded circular microstrip patch antenna and found that there are two resonant peaks in the resistance locus. The first peak, around 1.97 GHz, is due to the presence of the section spherical dielectric cover; the second peak, around 2.1 GHz, is due to the circular microstrip patch antenna. The $E$-plane and $H$-plane radiation patterns for the antenna operated at 2.1 GHz are also determined and shown in Figure 2.22.

![Simulated radiation patterns](image)

Figure 2.22 Simulated radiation patterns for the section-spherical dielectric loaded circular microstrip patch antenna

It is also seen that co-polarization patterns are broadside, the cross-polarization radiations for both $E$ and $H$-planes are below -20 dBi, and the antenna gain is increased up to 8 dBi [36].
In addition, it was also found that, L. Economou et al has analyzed circular patches printed on RT Duroid, with glass laminated dielectrics and found that the glass improved the bandwidth of the antenna significantly, from under 2% to about 7% due to the thick high permittivity glass dielectric. However, variations in the dimensions of the glass in production are significant, up to 15%. The effect of such dimensional tolerances was to change the resonant frequency by about 3%, and the bandwidth also varied by about 1.7%.

Figure 2.23 Measured input impedance of circular patch antenna 16mm in diameter
(a) with and (b) without glass dielectric attached

Figure 2.23 shows the measured input impedances for a 16 mm diameter disc before, and after, it was attached to the glass laminate and found that the bandwidth for the patch alone was initially 1.8%, and this increased to 6.8% when attached to the glass; the input impedance fell from 58 Ω to 47 Ω respectively. This is a useful improvement in bandwidth; particularly in communication systems often need bandwidths exceeding 5% [37].

Later, D. D. Krishna et al [38] proposed a dielectric loaded slotted circular dual frequency microstrip antenna shown in Figure 2.24, and found that the dielectric, not only acts as a random, but also improves the operating bandwidth of the antenna.
Figure 2.24 Geometry of the microstrip-fed sector slotted circular patch antenna with a redome

The overall size of the antenna reduces to about 60% than that of unslotted patch along with good efficiency, gain and bandwidth. The resonance frequency $f_r$ of a circular patch antenna with air as substrate ($\varepsilon_r = 1$) and a thin dielectric ($\varepsilon_r$, $h_1$) is approximated as follows:

$$f_{r1} = \frac{1.841c}{P_e \cdot \sqrt{\varepsilon_{eff}}}$$  \hspace{1cm} \text{(2.10)}$$

Where

$\varepsilon_{eff} = \text{effective permittivity of a two layered patch antenna.}$

$P_e = \text{effective circumference of the equivalent circular patches } C_1 \text{ or } C_2.$

$$P_e = P_l \left[ 1 + \frac{2h}{\pi R \cdot \varepsilon_{re}} \left( \ln \frac{\pi R}{2h} + 1.7726 \right) \right]^{1/2}$$  \hspace{1cm} \text{(2.11)}$$

The values of ‘$i$’ may be chosen as per requirement [38]. The main findings of their studies are: by varying the slot angles from $10^0$ to $90^0$, the ratio of the two resonances can be changed from 1.402 to 1.51. The radiation efficiency and bandwidth can also improved up to 98% and 3.9% respectively.
2.3. DIELECTRIC LOADING ON VARIOUS MICROSTRIP PATCH ANTENNAS

In the above section we have described the progressive development for rectangular and circular patch antennas; however the present section is dedicated to such studies of miscellaneous patch antennas. The complex resonant frequencies of the rectangular and cylindrical– rectangular microstrip antenna with a dielectric cover have been studied by using rigorous full wave analysis and Galerkin moment method. The numerical convergence for sinusoidal basis functions with and without edge singularity condition are investigated for both patch antennas. The obtained results indicate that consideration of edge singularity for fast numerical convergence of the complex resonant frequency is necessary. In particular cylindrical-rectangular microstrip antenna both the resonant frequency and the radiation loss are higher than those of the planar structures, however the quality factor of the curved structure is lower than that of the planar case. On the other hand, as the dielectric cover is used, resonant frequency and the quality factor decrease and the radiation loss, however, increase.

Using transmission line model, S. Sancheti and V.F. Fusco, [39] analyzed the effect of dielectric cover on active patch antenna and found that the results are well agreed with the experimental results. The main emphasis is given on distance between patch and covers, and it is found that the distance should be an integral multiple ‘n’ of one half–wavelength i.e. $\lambda/2$. An experimental investigation using thermocol ($\varepsilon_r = 1.05$ and thickness 2.2 cm) was loaded on the top cover and to demonstrate the effect of frequency shift, a rectangular cover sheet (5.0 cm x 6.0 cm) using R.T. Duroid 6010 material of thickness 0.025 inch, relative dielectric constant ($\varepsilon_r$) of 10.8 and $\tan\delta$ of 0.0028 was selected to give a voltage reflection coefficient of 0.5. Effects of various dielectric covers on the two layers electromagnetically coupled (EMC) hexagonal microstrip antenna was studied in year 1999 [40], and observed that the patch antenna with dielectric behaves as an R L network, and offers considerable bandwidth with the bakelite dielectric, when the dielectric constant of the cover and antenna’s substrates are equal. The maximum bandwidth is 6.21% for $d = 0.0296 \lambda$, because return loss is found to be greatest (-8.95 dB).

The input impedance and resonance characteristics of dielectric loaded equilateral triangular microstrip patch antenna have been calculated using the closed form expression [41]. In this method fringing fields between the substrate and the ground plane has been
accounted for in terms of the effective dielectric constant. And resonant frequency is calculated by employing an equivalent relation between a circular and triangular geometry as \( r = \frac{2\pi a}{3}, \) \( a \) is radius of the equivalent circle. It is found that the considered path shows behavior like other patch antennas. Typically 2–4% shifting in resonant frequency can be achieved by dielectric loading for \( r = 37 \text{ mm}, \) \( h = 1.6 \text{ mm}, \) \( \varepsilon_{r,1} = 2.5, \) \( d = 13.5 \text{ mm}, \) at \( f_r = 3.156 \text{ GHz}. \) Very recently, R Mittra et al [42] proposed directivity enhancement technique through microstrip antenna using three layered dielectrics. The three layered dielectric are frequency selective surface (FSS) with dielectric elements: a dielectric slab and a double negative (DNG) slab. The obtained result shows that microstrip antenna covered with FSS or a dielectric cover offer higher directivity than realized by using a DNG cover. In particular, the directivity of the dielectric slab, FSS and DNG covers are 16.08 dB, 15.77 dB and 10.2 dB respectively at 15 GHz, following the aperture efficiencies: 84.85%, 83.22% and 53.83% respectively.

Therefore, the available literatures indicate that environmental effects (such as snow, raindrops, etc.) deteriorate the performance of antenna; particularly gain, radiation resistance and efficiency. This is the reason, dielectric cover are often used to protect printed circuit antennas (PCA’s) from external hazards, or may be naturally formed (e.g. ice layers) during flight or severe weather conditions. Whether a cover layer is naturally formed or imposed by design, it may affect adversely the antenna performance characteristics, such as gain, radiation resistance and efficiency. For this reason, it is important to analyze dielectric loading effects from a fundamental point of view, so that the performance may be understood better or a proper choice of cover parameters may be implemented. The detailed observations on dielectric loading effects have been described in subsequent chapters. However, the next chapter is dedicated to emphasize the influences of dielectric cover thickness on antenna performances.
REFERENCES


