CHAPTER 3

DESIGN OF MULTIDIELECTRIC LAYER MICROSTRIP ANTENNA AND SUPERSTRATE EFFECTS

The multilayer microstrip antenna structure involves addition of a superstrate layer over the substrate. When a microstrip antenna is covered with a superstrate dielectric layer, its properties like resonance frequency, gain and bandwidth are changed which may seriously degrade the system performance [78-81]. With proper choice of the thickness of substrate and superstrate layer, significant increase in gain can be achieved for practical applications. The addition of a cover layer over the substrate can also result in structural resonance referred to as the resonance gain method. By choosing the thicknesses of the substrate and the superstrate layers, a very large gain can be realized [82-86]. Therefore in view of inherent narrow bandwidth of the microstrip patch antennas, the antennas with multidielectric layered structure must be designed to ensure that there is minimum drift in the resonant frequency [24].

#This chapter presents the design of multidielectric layer microstrip antenna with improved accuracy in performance using conformal mapping techniques. The design algorithm developed eliminates the effects of inaccuracies that can have compounding effect from the design stage to fabrication of multidielectric layer microstrip antenna. The algorithm has been successfully tested on both thin and thick dielectric substrates having low permittivity. The antenna designed for the given resonant frequency has been observed to be in correspondence to the patch dimension with accuracy to sixth decimal place.

3.1 Resonant Frequency Accuracy

There is a need to accurately design the microstrip patch antenna at a desired frequency of operation. Next to accurately predict the behavior of the antenna under consideration, a proper analysis technique needs to be followed. In applications of microstrip antenna in aircraft, spacecraft, missiles and those structures where it needs protection against environment, use of superstrate layer is desirable. Further the gain of the antenna can be increased by employing the superstrate layer.
The design and analysis of rectangular patch microstrip antenna based on the multidielectric structure is carried out using conformal mapping techniques. The design considerations are based on the characteristics of the substrate, the patch geometry and the location of the feed. The closed form of expressions, based on conformal mapping approach and generalized transmission line model have been employed to transform a multilayer superstrate-substrate structure to a single layered rectangular patch antenna. It has been shown that with the proper choice of thickness of the superstrate layer, the performance of the antenna can be improved. Determination of resonant frequency accurately requires determination of effective permittivity $\varepsilon_{\text{eff}}$ of the multilayer structure. It is therefore necessary to determine the resonant frequency and impedance to predict the performance of the antenna using a proper analysis technique. Next important aspect is to use a technique so that multidielectric layers with patch antenna and without superstrate layer can be effectively analyzed [87].

Though number of analytical methods has been suggested for analysis of such a structure, closed form empirical expressions for determination of resonant frequency have also been explored [88]. Design parameters may therefore be determined using empirical formulae for every variable but this is time consuming as the parameters are interdependent. An effective and efficient algorithm has therefore been developed and a program using MATLAB 7 gives the result, accurate to 6th decimal place. Configurations of stack patch antennas of different dimensions designed for a given resonant frequency have been analyzed. The accuracy in the physical dimension of the patch calculated is found to increase at each step. In the following section we consider the design of multidielectric layer microstrip rectangular patch antenna.

### 3.2 Design of Multidielectric Layer Microstrip Rectangular Patch Antenna

#### 3.2.1 Design Criteria

The design parameters of a rectangular patch of width $W$ and length $L$ with three dielectric layers having permittivity $\varepsilon_{r1}$, $\varepsilon_{r2}$ and $\varepsilon_{r3}$ and height $h_1$, $h_2$ and $h_3$ respectively
are shown in Figure 3.1(a) & Figure 3.1(b). Three dimensional layout of the rectangular microstrip patch structure is shown in Figure 3.1(c). The ratio of $W$ to $h_{12}$ in Figure 3.1(b) should be greater than or equal to 1 and ratio of width $W$ to length $L$ should lie between 1 and 2 [56],[57].

![Figure 3.1(a): Rectangular microstrip antenna patch on multidielectric layer][1]

![Figure 3.1(b): A multilayer dielectric rectangular microstrip antenna][2]

![Figure 3.1(c): The rectangular patch structure][3]

Microstrip antennas have inherent limitation of narrow bandwidth. Shun-Shi Zhong, Gang Liu, and Ghulam Qasim [78] described the significance of determining accuracy of the resonant frequency in design of microstrip antenna with multidielectric layers. Theoretical methods for calculating the resonant frequency of such structures have been reported using the variation technique, the multiport network approach, the spectral domain analysis and other full-wave analysis methods. Highly accurate numerical methods are too laborious and time consuming for direct use in CAD programs. It has been suggested to obtain a set of closed form expressions for the
resonant frequency for the general case of multidielectric layers. Relatively simple expressions based on the conformal mapping technique and the transmission line model is therefore used even for more complicated multidielectric structures. Generalization of the transmission line model treats a rectangular microstrip antenna with several dielectric layers as a multilayer microstrip line. With quasi-TEM wave propagating in the microstrip line, a quasistatic value of the effective permittivity $\varepsilon_{\text{eff}}$ is derived by means of the conformal mapping technique. The conformal transformation used by Wheeler [89] and by Svacina [81] has been used. The frequency dependence of $\varepsilon_{\text{eff}}$ and the open-end extension of a patch, results in determination of resonant frequency of such antenna structures with good accuracy.

Samir Dev Gupta et. al [87] have shown that the dimension of substrate and the patch of the microstrip antenna, and the corresponding calculated resonant frequency are such that a very small variation in the dimension of the antenna parameters results into a very significant change in the actual resonant frequency. Since these calculations are repetitively carried out, the errors are cumulative at every step, thereby resulting in a notable change in the frequency. To minimize the compounding errors an algorithm has been developed. The algorithm aims towards minimization of errors at each step thereby providing a result which is highly accurate.

### 3.2.2 Conformal Mapping Technique for Design of Multilayer Dielectric Antenna

Before considering the design of multilayer dielectric antenna using conformal mapping technique, it is necessary to present the basic concept of mapping and transformations.

**Figure 3.2: Conformal Mapping**
3.2.2.1 Fundamentals of Conformal Mapping

- A complex mapping \( w = f(z) \) defined on a domain \( D \) is called conformal at \( z = z_0 \) in \( D \) when \( f \) preserves that angle between two curves in \( D \) that intersect at \( z_0 \) as shown in Figure 3.2.

Example

(a) The analytic function \( f(z) = e^z \) is conformal at all points, since \( f'(z) = e^z \) is never zero.

(b) The analytic function \( g(z) = z^2 \) is conformal at all points except \( z = 0 \), since \( g'(z) = 2z \neq 0 \), for \( z \neq 0 \).

- Conformal mapping analyzes complex geometric structures by transforming into simple, analyzable formations.
- A rectangular grid and its image under a conformal map \( f \) is shown in Figure 3.3. It is seen that \( f \) maps pairs of lines intersecting at 90° to pairs of curves still intersecting at 90°.

![Figure 3.3: Conformal Mapping of a Rectangular Grid](image)

- Microstrip Line Model ‘The Magnetic Wall’: The direct solution of fields in a microstrip line, difficulty is encountered. To solve the same, ‘conformal mapping’ technique transforms the structure in a ‘parallel plate waveguide’. Magnetic wall are assumed to have no fringing fields at the edges as shown in Figure 3.3 [90].
3.2.2.2 Conformal Mapping of Multilayer Dielectric

A mapping \( w = f(z) \) that preserves the size and sense of the angle of intersection between any two curves intersecting at \( z_0 \) is said to be conformal at \( z_0 \). A mapping that is conformal at every point in the domain \( D \) is called conformal in \( D \). The conformal mapping of a boundary between dielectrics is valid since it retains the angles of refraction of the electric fields at the boundary, while maintaining the electrical properties of the geometry in the mapped plane. This property helps in determining the capacitance (or effective dielectric constant) and hence its resonant frequency. Hence the relation for the quasi static permittivity is as described in subsequent paragraphs.

\[
\varepsilon_e = \frac{\varepsilon_{r1} \varepsilon_{r2} (q_1 + q_2)^2}{\varepsilon_{r1} q_2 + \varepsilon_{r2} q_1 + \varepsilon_{r3} (1-q_1-q_2)} + \frac{\varepsilon_{r3} (1-q_1-q_2)}{q_3} + q_3
\]  

... (3.1)

In the conformal mapping technique, the complex variable plane \( z = x + jy \) is mapped to a plane \( g = u + jv \) as shown in Figure 3.5(a) and Figure 3.5(b) using Wheeler’s transformation [81]. The areas \( S_0, S_1, S_2 \), and \( S_3 \) may be considered to remain unchanged as first approximation of the transformation. The relation for the quasi-static permittivity \( \varepsilon_e \) may therefore be expressed as per equation (3.1), where \( q_1, q_2 \) and \( q_3 \) are the filling factor, defined respectively, as the ratio of each area of \( S_1, S_2 \) and \( S_3 \) to the whole area \( S_c \) of the cross-section in the g-plane [78].
The dispersive behavior i.e. the effective permittivity $\varepsilon_{\text{eff}}$ can be determined \[80\] as given by equation (3.2).

\[
\varepsilon_{\text{eff}} = \varepsilon' - \frac{\varepsilon_r - \varepsilon_e}{1 + P(f)}
\] … (3.2)

Figure 3.5(a): Conformal mapping of a multilayer dielectric rectangular microstrip antenna \[78\]

\[
\varepsilon_r = \frac{(\varepsilon_e * 2)^{1 + A} - 1 + A}{1 + A}
\] … (3.3)

where $\varepsilon_e$ is determined by equation (3.1) and $\varepsilon_r$, the permittivity that takes into account the multilayer effect on a microstrip line, as if all the formulas calculated were for single layer. Following I. J. Bahl, P. Bhartia and S.S. Stuchly \[88\], the permittivity $\varepsilon_r$ may be expressed as in equation (3.3)
The parameter $A$ may be expressed in terms of $h_{12}$ and $W$ as given in equation (3.4)

$$A = \left(1 + \frac{12 \cdot h_{12}}{W}\right)^{-\frac{1}{2}}$$

... (3.4)

The increase in length $\Delta L$ due to fringing effect [91] may be determined using the relation in [92] with $(\varepsilon_r, u)$ replaced by $(\varepsilon_r', u')$ and the height $h$ replaced by $h_{12}$ as given in equation (3.5).

$$\Delta L = \frac{h_{12} \cdot \varepsilon_1 \cdot \varepsilon_3 \cdot \varepsilon_5}{\varepsilon_4}$$

... (3.5)

where the relations for the terms $\xi_1, \xi_3, \xi_4, and \xi_5$ used in equation (3.5) are given in [92]. The length $L$ of a patch for a given patch width $W$ and resonant frequency $f_r$ may be determined using the equation (3.6) [88].

3.3 Multilayer Dielectric Antenna Design using Algorithm for High Accuracy

A. FIRST MODULE

I Inputs:

(a) Multidielectric patch antenna parameters, viz. the three layers height $h_1, h_2$ and $h_3$ along with the associated values of relative permittivity $\varepsilon_{r1}, \varepsilon_{r2}, \varepsilon_{r3}$ (Figure 3.1(b) refers), above the three layers $\varepsilon_{r0}=1$ (permittivity of free space).

(b) The resonant frequency $f_r$ chosen for antenna to be designed.

(c) Patch dimensions i.e. width $W$ (Figure 3.1(a) refers), criterion for the width of the patch dimension being $W/h_{12} \geq 1$ (refer Figure 3.1(b) for $h_{12}$).

II. Steps for computation of length $L$ of the patch, using the formulae in [78]:

(a) Determination of the effective line width $w_e$ and quantity $v_e$ values:

$$w_e = w + \frac{2h_{12}}{\pi} \ln \left[ 17.08 \left( \frac{w}{2h_{12}} + 0.92 \right) \right]$$

and

$$v_e = \frac{2h_{12}}{\pi} \tan^{-1} \left[ \frac{2\pi}{\pi w_e - 4h_{12}} (h_{13} - h_{12}) \right]$$
(b) Computation of filling factors $q_1$, $q_2$ and $q_3$ (Figure 3.5(a) & 3.5(b) refers)

\[
q_1 = \frac{s_1}{s_c} = \frac{h_1}{2h_{12}} \left\{ 1 + \frac{\pi}{4} - \frac{h_{12}}{h_1} \times \ln \left[ \frac{2w_e}{h_1} \sin \left( \frac{\pi h_1}{2h_{12}} \right) + \cos \left( \frac{\pi h_1}{2h_{12}} \right) \right] \right\},
\]

\[
q_2 = \frac{s_2}{s_c} = 1 - q_1 - \frac{h_{12}}{2w_e} \ln \left( \frac{\pi w_e}{h_{12}} - 1 \right),
\]

\[
q_3 = \frac{s_3}{s_c} = 1 - q_1 - q_2 - \frac{h_{12} - v_e}{2w_e} \ln \left[ \frac{2w_e}{2h_{12} - h_1 + v_e} \cos \left( \frac{\pi v_e}{2h_{12}} \right) + \sin \left( \frac{\pi v_e}{2h_{12}} \right) \right].
\]

(c) Calculation of the quasi static effective permittivity $\varepsilon_e$ as per equation (3.1).

(d) Taking into account the multidielectric layers effect as per equation (3.3), determination of the $\varepsilon'$. 

(e) Computation of $U=W/h_{12}$ and $U'=w_e/h_{12}$.

(f) Calculation of $k_0$ free space wave number at resonant frequency $f_r$.

(g) Determination of the function $P(f)$, which is a frequency dependent term

\[
P(f) = P_1 P_2 \left\{ (0.1844 + P_3 P_4) f_n \right\}^{0.5763} \quad [92] \text{ notation } (\varepsilon_e', u') \text{ replaces } (\varepsilon_e, u) \text{ and } f_n=47.713* k_0 * h_{12} \text{ (refer [91]) replaces the approximation } f_n = h/\lambda_0 \text{ (refer [80])}.
\]

\[
P_1 = 0.27488 + u' \left[ 0.6315 + \frac{0.525}{(1 + 0.0157 f_n)^{20}} \right] - 0.065683 e^{\left( -8.7513 u' \right)}
\]

\[
P_2 = 0.33622 \left\{ 1 - e^{\left( -0.03442 \varepsilon_e' \right)} \right\},
\]

\[
P_3 = 0.0363 e^{\left( -4.6 u' \right)} \left\{ 1 - e^{\left( -\left( \frac{f_n}{3.87} \right)^4 \right)} \right\} \text{ and}
\]
\[ P_4 = 1 + 2.751 \left(1 - e^{\frac{\left(\frac{\varepsilon'_r}{15.916}\right)^8}{1 - e^{0.1}}} \right) \]

\[ f_n = f \frac{h}{\varepsilon_0} \text{ (in GHz.mm)} = 47.713 \frac{k_0 h}{\varepsilon_r} \quad u' = \frac{W_e}{h_{12}} \]

Accuracy of the above model is found to be good provided

\[ \frac{h_1}{\lambda d_1} + \frac{h_2}{\lambda d_2} + \frac{h_3}{\lambda d_3} \leq 0.1, \text{ where } \lambda d_i \text{ is the wavelength in the } i^{th} \text{ dielectric layer.} \]

(h) Computation of the effective permittivity \( \varepsilon_{\text{eff}} \) based on the frequency factor as per equation (3.2).

(i) Finding the \( \Delta L \) due to fringing effect (refer [92]) where \((\varepsilon_r, u')\) replaces \((\varepsilon_e, u)\).

(j) Length \( L \) of the patch computed based on the expression

\[ L = \frac{C}{2 \cdot f_v \cdot (\varepsilon_{\text{eff}})^{1/2}} - 2\Delta L \]

III Transfer the values \( h_1, h_2, h_3, \varepsilon_{r1}, \varepsilon_{r2}, \varepsilon_{r3}, k_0, W \) and \( L \) to SECOND MODULE

SECOND MODULE

(A) Computation of resonant frequency \( f_v \) (verification frequency) for the Length \( L \) found in FIRST MODULE. Next follow the steps in similar lines as in the FIRST MODULE.

(B) The effective line width \( w_e \) and quantity \( v_e \) values.

(C) The filling factors \( q_1, q_2 \) and \( q_3 \) (refer Figure 3.5(a) & Figure 3.5(b)).

(D) The quasi static effective permittivity \( \varepsilon_e \) using equation (3.1).

(E) The effective permittivity \( \varepsilon'_{r} \) which takes into account the Multidielectric layers equation (3.3).

(F) \( U = W/h_{12} \) and \( U' = w_e/h_{12} \).
(G) Function $P(f)$, is a frequency dependent term refer [80] notation $(\varepsilon', u')$ replaces $(\varepsilon_e, u)$ and $f_h=47.713*k_0^* h_{12}$ as per [91] replaces the approximation $f_h = h/\lambda_0$ as per [80].

(H) The effective permittivity $\varepsilon_{\text{eff}}$ based on the frequency factor refers equation (3.2).

(I) The $\Delta L$ due to fringing effect, refer [92], where $(\varepsilon', u')$ replaces $(\varepsilon_e, u)$.

(J) The verification frequency $f_v$ based on the formulae in [78] where notation $f_v$ replaces $f_r$ and the formula is given as:

$$f_v = \frac{c}{2*(L + 2*\Delta L)*(\varepsilon_{\text{eff}})^{1/2}}$$

IV. Return the values of $f_v$ to the FIRST MODULE.

V. STOP THE SECOND MODULE.

VI. Compare $f_v$ and $f_r$ if equal than FIRST MODULE is validated.

VII. STOP THE FIRST MODULE

The algorithm has been converted into a MATLAB7 program and the results obtained are shown in a tabular form (Refer Table 3.1).

### 3.4 Accurate Computation of Antenna Parameters

The analysis of multidielectric layers microstrip antenna is based on empirical relations. Further, during fabrication of the antenna certain errors in the desired performance may result due to the manufacturing processes. The errors need to be minimized as the anomalies can have a compounding effect. As illustrated in Table 3.1, there is significant effect on the resonant frequency due to change in length of the patch effect. With increase in the length of patch by 0.0001mm (from 0.0334 to 0.0335 mm) there is a change in resonant frequency of 7.4 MHz (from 2.718GHz to 2.7106 GHz), which is significant as compared to change in the length.

Calculation of the various parameters of the antenna involves the large number of computational steps that are repetitive and prone to calculation errors. Conformal mapping technique involving Wheeler Transformation function [81] to map one complex plane into another complex plane involves equations, which require rigorous calculations. The dimension of the antenna i.e. the substrate and the patch are in millimeters and micrometers respectively.
Hence, minor changes in the dimension of the antenna parameters will contribute in a very significantly altered resonant frequency which is in GHz range. Further, repetitive nature of calculation involves cumulative compounding of errors at every step thereby resulting in a notable change in the resonant frequency.

In an environment where multi emitters operate in the same frequency band, a few MHz deviations in resonant frequency may result in interference. Critical design through rigorous simulation can not only ensure accuracy in fabrication, but can also provide the requisite tolerance for minor variation in dielectric properties of the substrate obtained from the manufacturer. An algorithm has therefore been developed to minimize errors at each step such that highly accurate results are obtained. The algorithm, presented in the following section overcomes the manual tedious process of determining patch dimension for a required frequency of operation where criticality can be accounted for different values of substrate permittivity.

3.5 Performance Analysis

Significance of accurate length calculation and its effect on the resonant frequency can be observed from the results shown in Table 3.1. The changes in the resonant frequency are observed when there is variation of patch length at 4th, 5th, even at 6th decimal place. For example with patch resonant frequency of operation at 2.7010 GHz, positive variation in its length at 4th, 5th, at 6th decimal place results at corresponding changes of frequency 8MHz, 0.8MHz and 0.1MHz respectively. Similarly variation in patch length in the negative direction leads to variation in resonant frequency.

Next we present the simulation results for various case studies. As per [91] we consider two cases (i) the ratio $W$ to $h_{12} \geq 1$ and (ii) $1 < W/L < 2$. In both the cases the parameters for antenna design are width of the patch, length of the patch, substrate permittivity of three layers 1 ($\varepsilon_{r1}$), 2 ($\varepsilon_{r2}$) and 3 ($\varepsilon_{r3}$), the length of the microstrip feed line with edge feeding technique, and heights of three substrates $h_1$, $h_2$ and $h_3$. The height of third substrate $h_3$ has been varied for the case studies [78].
Table 3.1: Determination of length of the patch for a given frequency and accuracy in the frequency by varying the length

3.5.1 Case I (Thin Substrate)

For simulation in this case $W$ (width of the patch) and $L$ (length of the patch) are respectively taken as 32.25mm and 33.48mm, and the length of the microstrip feed line is taken as 52.715mm with edge feeding technique. The substrate permittivity of three layers 1, 2 and 3 are respectively taken as $\varepsilon_{r1} = 1$ (Air), $\varepsilon_{r2} = 2.32$ (RT/Duroid 5870, tan $\delta$=0.0012) and $\varepsilon_{r3} = 2.32$ (RT/Duroid 5870, tan $\delta$=0.0012). The heights of substrates 1, 2 and 3, are respectively taken as $h_1 = 0$ mm, $h_2 = 3.18$mm and $h_3 = 3.18$mm.

```
<table>
<thead>
<tr>
<th>Superstrate Characteristics</th>
<th>Superstrate Thickness (mm)</th>
<th>Change in Resonant Frequency (GHz)</th>
<th>Length $L$ (Design Calculated) (mm)</th>
<th>Change in Length $\Delta L$ ($5^{th}$ Decimal)</th>
<th>Change in Length $\Delta L$ ($5^{th}$ Decimal) Verified Calculated (mm)</th>
<th>Change in Length $\Delta L$ ($5^{th}$ Decimal) Verified Calculated (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thin Dielectric Cover Layer</td>
<td>3.18</td>
<td>2.715</td>
<td>0.033488578</td>
<td>$\Delta L = 1\times10^{-4}$</td>
<td>$\Delta L = 1\times10^{-4}$</td>
<td>$\Delta L = 1\times10^{-4}$</td>
</tr>
<tr>
<td></td>
<td>6.36</td>
<td>2.701</td>
<td>0.03346891</td>
<td>$\Delta L = 1\times10^{-4}$</td>
<td>$\Delta L = 1\times10^{-4}$</td>
<td>$\Delta L = 1\times10^{-4}$</td>
</tr>
<tr>
<td>Thick Dielectric Cover Layer</td>
<td>9.54</td>
<td>2.688</td>
<td>0.03345803</td>
<td>$\Delta L = 1\times10^{-4}$</td>
<td>$\Delta L = 1\times10^{-4}$</td>
<td>$\Delta L = 1\times10^{-4}$</td>
</tr>
<tr>
<td></td>
<td>12.72</td>
<td>2.673</td>
<td>0.03344509</td>
<td>$\Delta L = 1\times10^{-4}$</td>
<td>$\Delta L = 1\times10^{-4}$</td>
<td>$\Delta L = 1\times10^{-4}$</td>
</tr>
</tbody>
</table>
```

$X = 0.03225\pi, \sigma_{r1} - 1, \sigma_{r2} - \sigma_{r3} - 2.32, h_1 = 0, h_2 = h_3 = 0.00318\text{mm}$

![Figure 3.6(a): Basic Patch Construction on Momentum](image)

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The dimensions of the basic patch construction on Momentum are shown in Figure 3.6(a). Deviation in the frequency is obtained $f_r = 2.719 \text{ GHz}$ after simulation from the one required i.e. $f_r = 2.718 \text{ GHz}$ and is about 1 MHz, which is acceptable. Figure 3.6(b) shows the return loss ($S_{11}$) of -17.7db at a resonant frequency of 2.719GHz, which may be considered to be an acceptable design. Figure 3.6(c) shows field plot in Cartesian coordinate.
3.5.2 Case II (Thick Substrate)

In this case, same values of parameters \( W \) (width of the patch = 32.25mm), \( L \) (length of the patch = 33.48mm), and length of the microstrip feed line = 52.715mm with edge feeding technique are retained as in the Case I. With the same values of substrate permittivity of three layers (\( \varepsilon_{r1} = 1 \), \( \varepsilon_{r2} = 2.32 \) and \( \varepsilon_{r3} = 2.32 \)) and heights of two substrates (\( h_1 = 0 \) mm, \( h_2 = 3.18 \) mm) taken as in Case I, the simulation results are obtained with the height of the third substrate taken as \( h_3 = 12.72 \) mm. The layout of the basic patch construction using Momentum is shown in Figure 3.7(a).

![Figure 3.7(a): Schematic of Patch (ADS-Momentum based)](image)

Figure 3.7(b): Return loss at the resonant frequency

Figure 3.7(b) shows the return loss (\( S_{11} \)) of -11.265dB at resonant frequency of 2.677 GHz. \( S_{11} \) is low because of the surface wave losses due to the thick substrate. Deviation in the frequency obtained at \( f_r = 2.677 \) GHz after simulation from the required i.e. \( f_r = 2.678 \) GHz and is about 1MHz, which is acceptable. Fig. 3.7(c) shows field plot in Cartesian coordinate.
As observed from Table 3.2, variation in the resonant frequency with change in the length of the patch is comparable with that obtained based on ADS Momentum results. In other words the frequency obtained after the simulation is compared to the original frequency used for constructing the patch and an error in the third decimal place has been observed which is acceptable as the scale of reference is in GHz.
The power radiated remains close to 2mW. The radiation efficiency in each case comes out to be more than 90%. The progressive reduction in the return loss is attributed to surface wave losses.

The results show that the patch is optimized for the parameters calculated by implementing the algorithm in MATLAB7 program. By devising the algorithm the various parameters of the multidielectric layer microstrip antenna have been calculated with the help of MATLAB7 program. The results have been verified and validated by carrying out the simulation of the antenna using Momentum, Advanced Design System software. The antenna design has thus been achieved with utmost precision with insignificant errors after 6th decimal place in case of a thin substrate multidielectric layer and after 5th decimal place in case of thick substrate multidielectric layer.

##3.6 Effect of Changing Superstrate Layer Thickness on the Antenna Parameters

The design of the microstrip antenna operating at 10 GHz frequency has been considered. The design is based on various selection criteria such as the thickness of the substrate and superstrate, width and length of the element. Effects on antenna parameters with respect to the change in thickness of the superstrate layer have also been analyzed in the following subsections.

###3.6.1 Substrate Selection in the Design of the Patch Antenna

Suitable dielectric substrate of appropriate thickness and loss tangent is chosen. A thicker substrate is mechanically strong with improved impedance bandwidth [71]. However it will increase weight and surface wave losses. The substrate’s dielectric constant $\varepsilon_r$ plays an important role similar to that of substrate thickness. A low value of $\varepsilon_r$ for the substrate will increase the fringing field of the patch and thus the radiated power. The Substrate Parameters chosen are as follows:

Top layer chosen is RT_Duroid_5880 having a thickness of 0.787mm, permittivity $\varepsilon_r = 2.2$ and loss tangent $\tan\delta = 0.0009$. Bottom layer dielectric is RT_Duroid_5870 with a thickness of 0.787mm, permittivity $\varepsilon_r = 2.33$ and loss tangent $\tan\delta = 0.0012$. A high loss tangent increases the dielectric loss and therefore reduces the antenna efficiency.
### 3.6.2 Element Width and Length

The selection criteria for an efficient radiator with patch size not too large are: (i) a low value of \( W \) and (ii) the ratio between width and length that leads to good radiation efficiency. For the antenna to be an excellent radiator, the ratio between \( W \) and \( L \) should lie between 1<\( W/L < 2 \) [56], [57]. The patch dimensions determine the resonant frequency. Various parameters in design of microstrip antenna are critical because of the inherent narrow band width of the patch. Initial calculation as shown in Table 3.3, has all the entered values of the length in meters and frequency in GHz. Using the algorithm as given in section 3.3 [87] we first calculate antenna design parameters. Calculated length and width of the patch obtained is 8.69638 mm and 9.6 mm respectively. Effective permittivity obtained is 2.15644, for the net height of the substrate 1.574 mm. So accordingly, as shown in Table 3.4, the calculated \( R_{in} \) (the value of the patch resistance at the input slot) comes out to be 326.8508 ohms.

\[
G_1 = \left( \frac{W}{120 \lambda_0} \right) \times \left( 1 - \left( \frac{1}{24} \right) \times (k_0 h)^2 \right) \quad \text{… (3.7)}
\]

\[
B_1 = \left( \frac{W}{120 \lambda_0} \right) \times (1 - 0.636 \log_e (k_0 h) ) \quad \text{… (3.8)}
\]

For the condition \( h < \frac{1}{10} \lambda_0 \) we obtain the values of self conductance \( G_1 \) and Susceptance \( B_1 \) [54] using equation (3.7) and (3.8) respectively. Treating element as two narrow slots, one at each end of the line resonator, the interaction between the two slots is considered by defining a mutual conductance. From the far fields, the directivity of a patch and the mutual conductance between patches are calculated [66].

\[
G_3 = \frac{\int_0^\pi \sin^2 \left( \frac{k_0 W}{2} \right) \cos^2 \theta \sin^3 \theta d\theta}{120 \pi^2}
\]

---

Table 3.3: Parameters in design of microstrip antenna

<table>
<thead>
<tr>
<th>Variable Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enter height h1</td>
<td>0.000739 meter</td>
</tr>
<tr>
<td>Enter the height h2</td>
<td>0.000739 meter</td>
</tr>
<tr>
<td>Enter the height h3</td>
<td>0</td>
</tr>
<tr>
<td>Enter the substrate permittivity</td>
<td>2.33</td>
</tr>
<tr>
<td>Enter the substrate permittivity</td>
<td>2.2</td>
</tr>
<tr>
<td>Enter the substrate permittivity</td>
<td>1</td>
</tr>
<tr>
<td>Enter the Resonant Frequency</td>
<td>10 GHz</td>
</tr>
<tr>
<td>Enter the patch width W</td>
<td>0.0006 meter</td>
</tr>
</tbody>
</table>

Thus applying the formula for the impedance matching we get the matching line impedance to be $(326.8508 \times 90)^{0.5} = 171.512$ ohm

Calculation of the strip impedance process based on the microstrip patch antenna parameters width $W$, height $h$ of the substrate having relative permittivity $\varepsilon_r$ and $t$ the
thickness of the patch involves the following sets of equations. For the condition \( W/h > 1 \) Characteristic impedance of the strip is obtained based on the equation 2.33.

**Table 3.4:** Input resistance determination in the design of microstrip antenna

![Table 3.4](image)

Refer Table 3.5, using ADS based calculator, the impedance matching feed line width works out to be around 0.31 mm.

**Table 3.5:** ADS calculator of feed line impedance

![Table 3.5](image)

\[
Z = \frac{120\pi}{2 \times 2^{0.5} \times \pi \times (\varepsilon_r + 1)^{0.5}} \log \left( 1 + \left( \frac{4 \times h}{W_e} \times (A + B) \right) \right) \times 100
\]
where $W_e = W + \nabla W_e$ and $\nabla W_e = \nabla W \times \left(1 + \left(\frac{1}{\varepsilon_{eff}}\right)\right) \left(\frac{1}{2}\right)$

We obtain $\nabla W$ from the following equation

\[
\nabla W = \left(\frac{t}{\pi}\right) \times \log \left(4 \times \frac{e}{\left(\frac{t}{h}\right)^2 + \left(\frac{1}{\pi} \frac{W}{t} + 1.1\right)^2}\right)
\]

Also the parameters $A$ and $B$ are obtained using the following equations.

\[
A = \left(14 + \left(\frac{8}{11}\right) \frac{h}{W_e}\right) \quad \text{and} \quad B = \left(1 + \frac{1}{\varepsilon_{eff}}\right) \times \pi^2 \left(\frac{1}{2}\right)^{0.5}
\]

or $\varepsilon_{eff} = \frac{\varepsilon_r + 1 + \frac{\varepsilon_r}{\varepsilon_r - 1}}{\left(1 + \frac{12h}{W}\right)^{\frac{1}{2}}} + \left[0.04 \left(1 - \left(\frac{W}{h}\right)^2\right)\right]
$

Changed design of the patch based on the calculated values is respectively the length and width is 8.7mm and 9.6mm.

### 3.6.3 Impedance Calculation

With the matching transformer impedance = 178.8 ohm and width = 0.26 mm.

Therefore patch impedance = \frac{(\text{Impedance matching transformer impedance})^2}{\text{Feed line impedance}}

\[
\frac{(178.8)^2}{98.4} = 325.1 \text{ohm. Impedance for the patch having width of 9.6 mm and length of 8.6 mm is found to be 324.1 ohm (from ADS Design).}
\]
Table 3.6: ADS based layout of the patch

Figure 3.8: ADS based layout of the patch with impedance line parameters
Figure 3.9(a): ADS layout of the Patch with port impedance

Figure 3.9(b): ADS based Patch layout with dimensions
Table 3.7: Strip Impedance and Length.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permittivity of the Substrate</td>
<td>2.15444</td>
</tr>
<tr>
<td>Width of the Slot</td>
<td>1.5</td>
</tr>
<tr>
<td>Height of the Slot</td>
<td>0.0045</td>
</tr>
<tr>
<td>Height of the Substrate</td>
<td>1.504</td>
</tr>
<tr>
<td>Impedance Calculated on the edge of the Patch</td>
<td>90.3645</td>
</tr>
</tbody>
</table>

The ADS based layout of the patch is shown in Table 3.6. The effective permittivity $\varepsilon_{eff} = 2.16$. Therefore the input resistance of the patch comes out to be 326.9 ohm. Impedance of the port used is 90 ohm. Hence the impedance line parameters are: Width = 0.26 mm and Height = 7.25 mm, as shown in Figure 3.8. Figure 3.9(a) and Figure 3.9(b) shows the ADS layout of the Patch with port impedance and Patch layout with dimensions respectively. Feed line Impedance=98.4 ohm and width = 1.5 mm, this comes fairly same as the calculated for the design as shown in Table 3.7 and Table 3.8.

Table 3.8: Verified Input Impedance Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width of the patch</td>
<td>9.6</td>
</tr>
<tr>
<td>Height of the Patch</td>
<td>0.68</td>
</tr>
<tr>
<td>Height of the substrate</td>
<td>1.574</td>
</tr>
<tr>
<td>Permittivity of the substrate</td>
<td>2.15444</td>
</tr>
<tr>
<td>Resonant Frequency of the Patch</td>
<td>10.00</td>
</tr>
<tr>
<td>Input Resistance</td>
<td>326.9673</td>
</tr>
</tbody>
</table>
Figure 3.10: ADS Momentum based Patch Layout

Figure 3.10 shows the Momentum based patch layout for the calculated antenna parameters. Table 3.9 shows multidielectric microstrip antenna designed is seen to radiate 1.03 mW power, having directivity of 6.77 dB and gain of 5.95 dB thereby achieving antenna efficiency of 87.88%. Antenna is seen to resonate at the designed frequency of 10 GHz at a return loss of -31.8 dB as depicted in Figure 3.11.

Table 3.9: Antenna Parameters without Superstrate Layer

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power radiated (Watts)</td>
<td>0.00109421</td>
</tr>
<tr>
<td>Effective angle (Steradians)</td>
<td>2.64042</td>
</tr>
<tr>
<td>Directivity (dB)</td>
<td>6.77043</td>
</tr>
<tr>
<td>Gain (dB)</td>
<td>5.95032</td>
</tr>
<tr>
<td>Maximum intensity (Watts/Steradian)</td>
<td>0.002991230</td>
</tr>
<tr>
<td>Angle of U Max (theta, phi)</td>
<td>14</td>
</tr>
<tr>
<td>E(theta) max (mag, phase)</td>
<td>0.542939</td>
</tr>
<tr>
<td>E(phi) max (mag, phase)</td>
<td>0.0007515151</td>
</tr>
<tr>
<td>E(z) max (mag, phase)</td>
<td>0.0007515151</td>
</tr>
<tr>
<td>E(y) max (mag, phase)</td>
<td>0.5268111</td>
</tr>
<tr>
<td>E(z) max (mag, phase)</td>
<td>0.131349</td>
</tr>
</tbody>
</table>

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Considering the frequency of resonance at the designed frequency along with significantly low return loss as shown in Figure 3.11, it confirms accuracy of feed design to achieve impedance match along with perfect radiation pattern $E_{\phi}$ and $E_{\theta}$ as shown in Figure 3.12 and Figure 3.13 respectively. In addition, veracity of algorithm used [87], ensures multidielectric layer microstrip antenna design to accuracy overcomes anomalies likely to occur during fabrication along with measurement errors. Importantly, operation in X-band at 10 GHz for defence application demands design accuracy for operational efficacy.

**Figure 3.11:** Return Loss of Multidielectric antenna without Superstrate layer

**Figure 3.12:** Radiation Pattern $E_{\phi}$ both front and back
3.7 Effect of Changing Superstrate Layer Thickness on the Antenna Parameters

3.7.1 Superstrates Selection

Superstrates are selected to compare the effects of its permittivity and its thickness on various antenna parameters. The two superstrate selected are from the data sheet of Roger’s Corporation are: High Permittivity: RT/Duroid_6010LM having relative permittivity of 10.2 and loss tangent = 0.0023. Low Permittivity: RT/Duroid_5880LZ having relative permittivity of 1.96 and loss tangent = 0.0019. Low thickness and high thickness of the substrate under consideration are 0.254mm and 2.54mm respectively. Analysis of the antenna structure is based on method of moments utilizing Momentum tool in Advanced Design System (ADS) of Agilent Technologies. The Momentum based optimization process varies geometry parameters automatically to help us achieve derived antenna structure.

3.7.2 Analysis Based on Superstrate Layer Properties

Effect of superstrate layer on antenna parameters including radiation pattern is described in subsequent paragraphs. Study involves selection of combination of superstrate layer viz. high/low permittivity and thick/thin substrates.

As described in section 3.7.1, superstate relative permittivity chosen is either 10.2 or 1.96 corresponding to high or low relative permittivity respectively. Thickness of the superstate considered 2.54 or .254 mm corresponds to thick or thin superstrate respectively. Table 3.10 shows the effect on antenna parameters due to change in permittivity and thickness of superstrate layer.
Table 3.10: Comparative Chart Depicting Effect of Superstrate Layer on Antenna Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>High Permittivity Thick Superstrate</th>
<th>Low Permittivity Thick Superstrate</th>
<th>High Permittivity Thin Superstrate</th>
<th>Low Permittivity Thin Superstrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover thickness</td>
<td>2.54 mm</td>
<td>2.54 mm</td>
<td>0.254 mm</td>
<td>0.254 mm</td>
</tr>
<tr>
<td>Return Loss</td>
<td>-3.574 dB</td>
<td>-14.405 dB</td>
<td>-21.331 dB</td>
<td>-35.041 dB</td>
</tr>
<tr>
<td>Power Radiated</td>
<td>0.1929 mW</td>
<td>0.8413 mW</td>
<td>0.9895 mW</td>
<td>1.015 mW</td>
</tr>
<tr>
<td>Directivity</td>
<td>8.842 dB</td>
<td>7.443 dB</td>
<td>7.1255 dB</td>
<td>6.876 dB</td>
</tr>
<tr>
<td>Gain</td>
<td>3.329 dB</td>
<td>5.883 dB</td>
<td>6.1425 dB</td>
<td>5.977 dB</td>
</tr>
<tr>
<td>Efficiency</td>
<td>37.65 %</td>
<td>79.04 %</td>
<td>86.20 %</td>
<td>86.92 %</td>
</tr>
</tbody>
</table>

3.7.2.1 Case 1

High Permittivity Thick Superstrate used as shown in Table 3.11, has effect on antenna parameters as depicted in Table 3.12. Poor gain accompanied by very low antenna efficiency of the order of 37.65%. In addition for the Case 1, return loss is also very poor and at frequency of 8.537 GHz, it is -3.754 dB as shown in Figure 3.14.

Table 3.11: High Permittivity Thick Superstrate
Table 3.12: High Permittivity Thick Superstrate Antenna parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power radiated (Watts)</td>
<td>0.000192921</td>
</tr>
<tr>
<td>Effective angle (Steradians)</td>
<td>1.64055</td>
</tr>
<tr>
<td>Directivity (dB)</td>
<td>8.84221</td>
</tr>
<tr>
<td>Gain (dB)</td>
<td>3.23901</td>
</tr>
<tr>
<td>Maximum intensity (Watts/Steradian)</td>
<td>0.000117595</td>
</tr>
<tr>
<td>Angle of U Max (theta, phi)</td>
<td>20</td>
</tr>
<tr>
<td>E(chem) max (mag, phase)</td>
<td>0.297655</td>
</tr>
<tr>
<td>E(chem) max (mag, phase)</td>
<td>-177.082</td>
</tr>
<tr>
<td>E(chem) max (mag, phase)</td>
<td>0.000179218</td>
</tr>
<tr>
<td>E(chem) max (mag, phase)</td>
<td>179.143</td>
</tr>
<tr>
<td>E(y) max (mag, phase)</td>
<td>0.265821</td>
</tr>
<tr>
<td>E(z) max (mag, phase)</td>
<td>2.51797</td>
</tr>
<tr>
<td>E(x) max (mag, phase)</td>
<td>0.139745</td>
</tr>
<tr>
<td>E(z) max (mag, phase)</td>
<td>2.51797</td>
</tr>
</tbody>
</table>

Figure 3.14: Return Loss for High Permittivity Thick Superstrate Antenna

Figure 3.15: Radiation Pattern $E_p$ both front and back
Lossy nature of the antenna combined with poor return loss is substantiated by the radiation pattern in both $\phi$ and $\theta$ plane highlighting minor lobes and distorted pattern as can be seen in Figure 3.15 and Figure 3.16. It is therefore concluded that combination of thick superstrate of high relative permittivity will result in antenna behavioral pattern not conforming to the design.

3.7.2.2 Case 2

**Table 3.13: Low Permittivity Thick Superstrate**
Low Permittivity Thick Superstrate used as shown above in Table 3.13. Antenna parameters as shown in Table 3.14, indicates improvement in antenna gain and efficiency. Return loss at 9.392 GHz shows marginal improvement as seen in Figure 3.17, it is -14.4 dB. Radiation pattern seen in Figure 3.18 and Figure 3.19 shows significant improvement so also radiated power output as compared to Case 1.

**Table 3.14:** Low Permittivity Thick Superstrate Antenna parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power radiated (Watts)</td>
<td>0.000841359</td>
</tr>
<tr>
<td>Effective angle (Steradians)</td>
<td>2.26402</td>
</tr>
<tr>
<td>Directivity (db)</td>
<td>7.4435</td>
</tr>
<tr>
<td>Gain (dB)</td>
<td>5.88343</td>
</tr>
<tr>
<td>Maximum intensity (Watts/Steradian)</td>
<td>0.000371622</td>
</tr>
<tr>
<td>Angle of U Max (theta, phi)</td>
<td>8 270</td>
</tr>
<tr>
<td>E(theta) max (mag, phase)</td>
<td>0.529153 46.9075</td>
</tr>
<tr>
<td>E(phi) max (mag, phase)</td>
<td>2.13559e-05 -130.013</td>
</tr>
<tr>
<td>E(z) max (mag, phase)</td>
<td>2.13559e-05 -130.013</td>
</tr>
<tr>
<td>E(y) max (mag, phase)</td>
<td>0.024103 -133.093</td>
</tr>
<tr>
<td>E(z) max (mag, phase)</td>
<td>0.0736430 -133.093</td>
</tr>
</tbody>
</table>

**Figure 3.17:** Return Loss for Low Permittivity Thick Superstrate Antenna
3.7.2.3 Case 3

High Permittivity Thin Superstrate used as shown in Table 3.15. Antenna parameters as seen in Table 3.16, antenna gain and efficiency improvement is significant. Return loss at 8.6 GHz shows good improvement as seen in Figure 3.20, is -21.3 dB. Radiation pattern seen in Figure 3.21 and Figure 3.22, shows similar radiation plots as seen in Case 2. Marginal increase in radiated power output is seen as compared to Case 2.
Table 3.15: High Permittivity Thin Superstrate

Table 3.16: High Permittivity Thin Superstrate Antenna parameters
3.7.2.4 Case 4

Low Permittivity Thin Superstrate used as shown in Table 3.17. Table 3.18 shows antenna parameters, there is drop antenna gain and marginal increase in efficiency.
Return loss at 9.721 GHz shows significant improvement and as seen in Figure 3.23, it is -35 dB.

**Table 3.17:** Low Permittivity Thin Superstrate

![Create/Modify Substrate:4](image1)

**Table 3.18:** Low Permittivity Thin Superstrate Antenna parameters

![Antenna Parameters](image2)

Figure 3.24 and Figure 3.25, shows radiation plots. Radiation pattern seen in is seen to be with perfect null in both the plane. Increase in radiated power output is 1.0 mW which the best among all the other three cases. Hence for antenna to resonate close to the desired frequency with return loss better than -30 dB, radiated power around 1 mW and pattern with no sidelobes and perfect null, Case 4 viz. Low Permittivity Thin Superstrate is the best choice for multidielectric antenna design.
3.7.2.5 Combined Result

Table 3.19 gives the birds eye view to analyze multidielectric antenna and effect of
relative permittivity and thickness of Superstrate (Cover) layer on antenna parameters and radiation pattern in both the planes.

Table 3.19: Multidielectric Layer Antenna Parameters with and without Superstrate Layer

<table>
<thead>
<tr>
<th>Permittivity Superstrate Types</th>
<th>Resonant Frequency (fz) (GHz)</th>
<th>S11 (dB) (Normalized)</th>
<th>Power Radiated (mW)</th>
<th>Gain (dB) (Normalized)</th>
<th>Directivity (dB) (Normalized)</th>
<th>Efficiency (%) (Normalized)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Superstrate</td>
<td>10</td>
<td>-31.8 (0.91)</td>
<td>1.03</td>
<td>5.95 (0.97)</td>
<td>6.77 (0.77)</td>
<td>87.89 (1.0)</td>
</tr>
<tr>
<td>Low Permittivity Thin Superstrate</td>
<td>9.721</td>
<td>-35 (1.0)</td>
<td>1.02</td>
<td>5.98 (0.97)</td>
<td>6.88 (0.78)</td>
<td>86.92 (0.99)</td>
</tr>
<tr>
<td>High Permittivity Thin Superstrate</td>
<td>8.607</td>
<td>-21 (0.61)</td>
<td>1.0</td>
<td>6.14 (1.0)</td>
<td>7.13 (0.81)</td>
<td>86.20 (0.98)</td>
</tr>
<tr>
<td>Low Permittivity Thick Superstrate</td>
<td>9.392</td>
<td>-14.4 (0.4)</td>
<td>0.84</td>
<td>5.88 (0.96)</td>
<td>7.44 (0.84)</td>
<td>79.04 (0.90)</td>
</tr>
<tr>
<td>High Permittivity Thick Superstrate</td>
<td>8.537</td>
<td>-3.6 (0.1)</td>
<td>0.2</td>
<td>3.24 (0.53)</td>
<td>8.84 (1.0)</td>
<td>36.63 (0.42)</td>
</tr>
</tbody>
</table>

Plots shown in Figures 3.26 to Figures 3.31 indicates change in resonant frequency, effect on return loss, variations in antenna directivity, gain, efficiency and finally the radiated power due to change in superstrates characteristics. To minimize losses and resonate close to the desired designed frequency, choice of thin and low permittivity superstrate having sufficient mechanical strength to withstand stress and weather vagaries is recommended for aerospace applications.

![Resonant Frequency (fz) (Ghz)](image)

**Figure 3.26:** Effect of Superstrate Parameters on Resonant Frequency
**Figure 3.27:** Effect of Superstrate Parameters on Return Loss

![S11(dB) Graph](image)

**Figure 3.28:** Effect of Superstrate Parameters on Antenna Directivity

![Directivity(dB) Graph](image)

**Figure 3.29:** Effect of Superstrate Parameters on Antenna Gain

![Gain (dB) Graph](image)
Though the results are reasonably attractive for low permittivity dielectric of the superstrate layer thickness of the order of 0.254mm, this choice may lead to fragile structure. Hence it is desirable to go for designs with low permittivity superstrate layer thickness of 2.54mm with good gain, antenna efficiency and radiated power output implying low losses.

The variations in antenna parameters, shown in the plots, and two acceptable and practicable results obtained for low permittivity are shown in Table 3.19.

### 3.8 Prototype Multidielectric Patch Antenna Parameters Measurement

Figure 3.32 shows the fabricated prototype multidielectric microstrip patch antenna. The said antenna is designed using the algorithm [87] to resonate at a frequency $f_r = 2.718$ GHz.
Figure 3.32: Prototype of the Multidielectric Patch Antenna Designed to Resonate at $f_r = 2.718$ GHz.

Figure 3.33: Experimental set for Antenna Frequency and Return Loss $S_{11}$ Measurement

Figure 3.33 shows the experimental set for the measurement of antenna resonating frequency and the return loss $S_{11}$. It was observed that the resonating frequency measured is 2.714 GHz. The multidielectric antenna resonating at 2.714 GHz, a
deviation of 4 MHz. Hence the veracity of the algorithm is proved in the practical realization of the multidielectric microstrip antenna. Return loss $S_{11}$ obtained is close to -16 dB.

Figure 3.34 (a): Experimental Setup for Measurement of Frequency $f_1$ at $S_{11} = -10\text{dB}$

Figure 3.34 (b): Experimental Setup for Measurement of Frequency $f_2$ at $S_{11} = -10\text{dB}$
Figure 3.34 (a) and Figure 3.34 (b) shows the experimental set for the measurement of frequencies $f_1$ and $f_2$ at -10dB $S_{11}$ on the either side of the resonant frequency $f_r$ for determination of the impedance bandwidth. The bandwidth obtained correspond to

$$\frac{f_2 - f_1}{f_r} = \frac{2.748 - 2.667}{2.714} \times 100 \approx 3\%$$

Figure 3.35 (a): Polar Plot $E_\theta$ in Receive Mode  
Figure 3.35 (b): Polar Plot $E_\phi$ in Receive Mode

Figure 3.36 (a): Polar Plot $E_\theta$ in Transmit Mode  
Figure 3.36 (a): Polar Plot $E_\phi$ in Transmit Mode

Figure 3.35 (a) and Figure 3.35 (b) depicts the radiation pattern in both $\theta$ and $\phi$ plane when the antenna is in receive mode and Figure 3.36 (a) and Figure 3.36 (b) is when the antenna is in transmit mode. The patterns are near identical, hence theory of reciprocity an important property of antenna is proved. It is concluded that the designed parameters along with the results obtained based on ADS Momentum simulation has been verified by the fabricated prototype multidielectric microstrip patch antenna.
3.9 Conclusions

It is observed that multidielectric layer microstrip antenna resonant frequency accuracy is significantly affected by various physical properties viz. permittivity, patch dimensions, height of the substrate and superstrate layer. Analysis of the antenna designed and fabricated for applications considers in minimizing changes in resonant frequency due inaccuracies in calculations of these properties. Parameters’ of microstrip antenna which inherently limits the gain, directivity, returns loss and radiated power is improved upon. Considering the effect of superstrate layer method for accurately determining the resonant frequency of such structures have been reported using the variation of patch dimension. To overcome the time consuming and laborious accurate numerical methods a direct use in algorithm for the design of the antenna is suggested. The algorithm is validated by realization of a prototype multidielectric microstrip antenna and a transformed single layer antenna obtained based on conformal mapping technique. Data obtained from simulation with variation of the height of the transformed antenna and its effect is plotted to show the impact on antenna parameters. The plots can be used to predict the antenna parameters including resonant frequency, return loss, power radiated, directivity and gain for a multilayer microstrip antenna subjected to the limits for the thickness of the superstrate layer (0.254mm-2.54mm). Gain of a multilayered structure increases as the height of the cover layer is decreased. As regard thin cover layer dielectric, conductor losses are dominant while for thicker cover layer surface wave losses are significant. It is found choice of low permittivity dielectric both thin and thick as cover layer is suitable for applications requiring high antenna efficiency.