Pattern Analysis of “The Rectangular Microstrip Patch Antenna”

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Abstract

In the recent years the development in communication systems requires the development of low cost, minimal weight, low profile antennas that are capable of maintaining high performance over a wide spectrum of frequencies. This technological trend has focused much effort into the design of a Microstrip patch antenna. In this work, the pattern of two designs of a Microstrip patch antenna have been analyzed and studied.

Design1 (LxWxH: 23mm x 30mm x 1.5mm) with a dielectric constant of 9.8(alumina) at 2.1GHz and Design2 (LxWxH: 47mm x 31mm x 1.59mm) with a dielectric constant 2.32 at 2.1GHz.

These two designs have been compared with other two from the literature by using SonnetLite software and IE3D from Zeland.

After the design when we compared the results of the Design1 and Design2, Design2 has the highest Antenna Efficiency (the configuration can be seen above) of 80%. With this we suggest the best configuration that can be used in practice would be Design 2.

A rigorous analysis of the problem begins with the application of the equivalence principle that introduces the unknown electric and magnetic surface current densities on the dielectric surface. The formulation of the radiation problems is based on the combined field integral equations coupled to the Method of Moments (MoM) as a numerical solution of the integral equations.
Dedicated to

The hardworking Students all over.
Acknowledgements

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I also would like to thank my friends for their support and constant help in lending me their laptop with higher configuration in order to run the simulations for this work.

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And last but not the least I express my hearty thanks to GOD and all those who supported us directly or indirectly to complete this task.

Vivekananda S Lanka
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3D – Three Dimension
2D – Two Dimensional
MOM – Methods of Moments
LCP – Liquid Crystal Polymer
RF – Radio Frequency
dB – decibel
c – Velocity of light
L – Length of the patch
h- – Height of the substrate
\( \varepsilon_r \) – Dielectric Constant of the substrate
\( \varepsilon_{reff} \) – Effective Dielectric Constant
\( \lambda \) – Free space Wavelength
\( f_0 \) – Resonant Frequency
Chapter 1

Introduction
1. Introduction

Antennas play a very important role in the field of wireless communications. Some of them are Parabolic Reflectors, Patch Antennas, Slot Antennas, and Folded Dipole Antennas. Each type of antenna is good in their own properties and usage. We can say antennas are the backbone and almost everything in the wireless communication without which the world could have not reached at this age of technology.

Patch antennas play a very significant role in today’s world of wireless communication systems. A Microstrip patch antenna (Fig 1) [1] is very simple in the construction using a conventional Microstrip fabrication technique. The most commonly used Microstrip patch antennas are rectangular and circular patch antennas. These patch antennas are used as simple and for the widest and most demanding applications. Dual characteristics, circular polarizations, dual frequency operation, frequency agility, broad band width, feed line flexibility, beam scanning can be easily obtained from these patch antennas.

![Figure 1: a. An edge-fed patch antenna, b. A probe-fed patch antenna, c. Its cross section](image)
1.1 **Merits and De-merits of the Microstrip antennas**

The Microstrip antennas have a lot of popularity based on their applications, which has some Merits and De-merits as any other.

The merits of these antennas have some similarities as of the conventional microwave antennas, as these cover a broader range of frequency from 100 MHz to 100 GHz, same is the case with these Microstrip antennas.

These are widely used in the handheld devices (wireless) such as pager, mobile phones, etc...

Some merits and demerits of these Microstrip antennas are: [2]

**1.1 (a) Merits:**

- Low weight, low volume and thin profile configurations which can be made conformal.

- Low fabrication cost, readily available to mass production.

- Required no cavity backing.

- Linear and circular polarizations are possible.

- Easily integrated with microwave integrated circuits.

- Capable of dual and triple frequency operations.

- Feed lines and matching network can be fabricated simultaneously.
1.1 (b) De Merits

Even though these Microstrip antennas are compared with conventional antennas these Microstrip antennas have some number of demerits:

- Low efficiency.
- Low grain.
- Lower gain (somewhat → -6dB)
- Large ohmic loss in the feed structure of arrays.
- Poor end fire radiator except tapered slot antennas,
- Extraneous radiation from feeds and junctions.
- Low power handling capacity (approx 100W).
- Excitation of surface waves.
- Polarization purity is difficult to achieve.
- Complex feed structures require high performance arrays.
- There is reduced gain and efficiency as said before and also unacceptably high levels of cross polarization and mutual coupling within the array environment at high frequencies.
- Antennas are fabricated on a substrate with a high dielectric constant are strongly preferred for easy integration with MMIC RF front end circuitry as this can lead to the poor efficiency and a narrow bandwidth.

Let us see some new results in the world of antenna and propagation:

There has been a new method proposed by Alla. I Abunjaileh about the multi banding matching of a circular patch antenna. Using the analysis of the microwave theory the antenna can also be used as the dual band antenna as the circular and triangular shapes can support two orthogonal resonant modes. An antenna can operate as a transceiver multimode patch antenna. [3]
A 31.5GHz Microstrip patch antenna has been designed for medical implants, a transmission line model, smaller in size, explaining that the return loss increases inside the body, with some frequency detuning. [4]

The Technique of using an inset feed patch antenna with modified ground plane can achieve widest bandwidth. An L-shaped feed rectangular patch antenna modified C-slot on the ground plane which influenced the Bandwidth of the patch antenna. [5]

The Aircell Company has designed a *Aircell Iridium Patch Antenna*, a tiny sitcom antenna which fits in our hand, this antenna can be used for both rotary and fixed wing aircraft, high-speed military aircrafts, and all aeronautic applications. [6]

![Rectangular Microstrip patch antenna (General View)](image)

Of course these demerits can be reduces to some extent by using some techniques, the broadband can be increased by 60% by these techniques which if needed will be discussed in the coming chapters.

These Microstrip patch antennas have a very antenna quality factor (Q). ‘q’ representing the losses with the antenna and the Q gives the narrow bandwidth and low frequency.
The losses \( (q) \) can be reduced by increasing thickness of the dielectric substrate, there is a catch here -> increasing the thickness, results the increasing factor of the power delivered by the source goes into a surface wave.

The surface wave limitations (such as increased mutual coupling, poor efficiency, etc...) can be overcome by the use of photonic band gap structures.

*Antenna Development corporation*, Las Cruces, has designed UHF antennas for space which are of low mass and high performance, which are capable of supporting high data rates to at least 10 Watts of transmitted power, they are of low mass, gives high performance and are of course space qualified[7].

It is not an easy task for an antenna to perform at different frequencies at a time especially where the usage is very high, in an aircraft, in a boat, or even in a moving vehicle where the antenna catches signal from various locations. It is very difficult to perform at these situations.

The wire patch antenna structure is a very useful method in the integration of the antennas using ceramic materials and regrouping the different functions in the malfunction antennas. [8]
Chapter 2

Theory of Microstrip Patch Antennas
2.1 Types of Microstrip Antennas

There are different types of Microstrip antennas which are classified based on their physical parameters. There different types of antennas have many different shapes and dimensions. The basic categories of these Microstrip antennas can be classified into four [2], which are:

- Microstrip patch antennas
- Microstrip dipoles
- Printed slot antennas
- Microstrip travelling wave antennas

Going further let’s have a small description on each of the type of the Microstrip antennas as it will give us good sound knowledge on how each type is classified and on what basis:

![Figure 3: Common shapes of the Microstrip patch antennas which are commonly in use. [2]](image-url)
2.1.1 Microstrip Patch antennas

A Microstrip patch antenna is a thin square patch on one side of a dielectric substrate and the other side having a plane to the ground. The simplest Microstrip patch antenna configuration would be the rectangular patch antenna.

![Diagram of Microstrip patch antenna](image)

**Figure 4: Structure of Microstrip patch antenna.**

The patch in the antenna is made of a conducting material Cu (Copper) or Au (Gold) and this can be in any shape Fig 3 [2], rectangular, circular, triangular, elliptical or some other common shape [2]. The basic antenna element is a strip conductor of length L and width W on a dielectric substrate with constant \( \varepsilon_r \), thickness or height of the patch being \( h \) with a height and thickness \( t \) is supported by a ground plane. The rectangular patch antenna is designed so as it can operate at the resonance frequency. The length that is for the patch does depend on the height, width of the patch and the dielectric substrate.

The length of the patch for a rectangular patch antenna normally would be \( 0.333\lambda < L < 0.5 \lambda \), \( \lambda \) being the free space wavelength. The thickness of the patch is selected to be in such a way that is \( t << \lambda \).
The length of the patch can be calculated by the simple calculation from [9]

\[ L \approx 0.49 \lambda_d = \frac{0.49 \lambda}{\sqrt{\varepsilon_r}} \]  

---------- Eq (2.1)

The height \( h \) of the dielectric substrate that supports the patch usually ranges between 0.003 \( \lambda \) & 0.05\( \lambda \) so as the dielectric constant, \( \varepsilon_r \) of the substrate ranging between 2.19 and 12.

The patch of the antenna is being excited by feed which is done by edge feed or a probe feed. When the patch is excited by feed a charge distribution is being established between the ground plane and the underneath of the patch. The underneath of the patch is charged to positive and the ground plane is charged to negative after the excitation by feed. The attractive forces are being setup between the planes i.e., patch underneath and the ground plane. The patch antennas radiate in the first case due to the fringing fields between the underneath of the patch and the ground plane.

These patch antennas are narrow band devices with a bandwidth 10% of the \( \lambda \), poor radiation efficiency is always more than expected from these patch antennas. A good performance from the patch antenna can be expected with a thick dielectric substrate with a low dielectric constant as this gives better efficiency, larger bandwidth and a better radiation [2]. These types of antennas are larger than expected in the construction. But the case with us is completely different as to design a compact device needs high dielectric constant which is less efficient, having a narrow bandwidth as discussed above.

### 2.1.2 Microstrip or Printed Dipole Antennas

The Microstrip or Printed Dipole Antennas differ from the Microstrip Patch antennas in their geometric shape i.e. in their length to width ratio and the radiation patterns of this antennas type is similar to that of patch antenna, i.e. having same longitudinal current directions. The length of this printed dipole antenna is less than 0.05\( \lambda \). Bandwidth, radiation resistance, and the cross polar radiation differs widely when compared to the patch antennas.
These Microstrip dipole antennas are very attractive when it is seen on the cases of the size and linear polarization. The feed mechanism is very important here in these types of antennas and should be taken care of. These types of antennas can be operated at high frequencies as the substrate is electrically thick which leads to the desired band width.

The figures above show the printed dipole antenna which are said to be very attractive on their size and linear polarization.

The figure below is the folded dipole combined with another related dipole give way to the symmetrical structure. And this particular construction can be used or is considered to be the rectangular patch with an H shaped slot.
2.1.3 Printed Slot Antennas

The printed slot antennas are those which have the slot in the ground plane of a grounded substrate, these slot antennas are bi-directional radiators; it means that they radiate both sides of the slot. There is no specific shape for the slot here, it can have any shape. Most of the Microstrip patch shapes are in the form of printed slots. This can be used for the unidirectional radiation as well by placing a reflector on the other side of the slot. Just like the Microstrip patch antennas these slot antennas can be fed by a Microstrip line.

Figure 7: (a) Rectangular slot with Microstrip feed (b) Annular slot with Microstrip feed (c) Tapered slot
2.1.4 Microstrip Travelling Wave Antennas

These Microstrip travelling wave antennas are designed having a long Microstrip line with enough width to support the TE. These antennas are designed so that the main beam lying in any direction from broadside to end fire. The other end of the microwave is ended in a matched resistive load in order to avoid the standing waves of the antenna. The use of these antennas like rampart line antenna, chain antenna, square loop antenna are in circular polarization.

We have seen the 4 types of Microstrip antennas and here the table 1 gives the characteristics of the Microstrip patch antennas, Microstrip slot antennas, and printed dipole antennas [2].

Table 1: Characteristics of the Microstrip Patch Antennas

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Microstrip Patch Antennas</th>
<th>Microstrip Slot Antennas</th>
<th>Printed Dipole antennas</th>
</tr>
</thead>
<tbody>
<tr>
<td>profile</td>
<td>Thin</td>
<td>Thin</td>
<td>Thin</td>
</tr>
<tr>
<td>Fabrication</td>
<td>Very easy</td>
<td>Easy</td>
<td>Easy</td>
</tr>
<tr>
<td>Polarization</td>
<td>Both linear and circular</td>
<td>Both linear and circular</td>
<td>Linear</td>
</tr>
<tr>
<td>Dual-Frequency Operation</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
</tr>
<tr>
<td>Shape Flexibility</td>
<td>Any shape</td>
<td>Mostly rectangular and circular shapes</td>
<td>Rectangular and triangular</td>
</tr>
<tr>
<td>Spurious Radiation</td>
<td>Exists</td>
<td>Exists</td>
<td>Exists</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>2-50%</td>
<td>5-30%</td>
<td>≈30%</td>
</tr>
</tbody>
</table>
2.2 Feed Techniques and Modeling of Microstrip Antennas

Microstrip patch antenna has various methods of feeding techniques. As these antennas having dielectric substrate on one side and the radiating element on the other. These feed techniques or methods are being put as two different categories contacting and non-contacting.

Contacting feed technique is the one where the power is being fed directly to radiating patch through the connecting element i.e. through the Microstrip line.

Non-contacting technique is the one where an electromagnetic magnetic coupling is done to transfer the power between the Microstrip line and the radiating patch. Even though there are many new methods of feed techniques the most popular or commonly used techniques are [2]

1. Microstrip line
2. Coaxial probe
3. Aperture coupling
4. Proximity coupling and
5. Co planar wave guide feed.

1 and 2 being the contacting feed techniques and 3, 4 being non-contacting feed techniques.

There are few factors which lead or involve in the selection of a particular type of feed technique.

The first and the foremost factor is the efficient power transfer between the radiating structure and the feed structure, i.e. the impedance that is matching between the two. The minimization of the radiation and the effect of it’s on the radiation pattern is one of the most important aspect for the evaluation of feed.
2.2.1 Microstrip Line feed.

This type of feed technique excitation of the antenna would be by the Microstrip line of the same substrate as the patch that is here can be considered as an extension to the Microstrip line, and these both can be fabricated simultaneously. This conducting strip is directly connected to the edge of the Microstrip patch, as known the conducting strip is smaller than that of the patch in width. This type of structure has actually an advantage of feeding the directly done to the same substrate to yield a planar structure as said above. The coupling between the Microstrip line and the patch is in the form of the edge or butt-in coupling as shown in the figure. Or it is through a gap between them.

![Diagram of Microstrip Line feed](image)

*Figure 8: A Type of Microstrip feed and the corresponding equivalent ckt s, Microstrip feed at a radiating edge,*
There is an inset cut in the patch to match the impedance of the feed line to the patch without the need of additional matching element. This avoidance of the additional matching element can be done by the proper control of the inset position. On the whole this particular model provides easy ways in the fabrication and a simple ways in modeling and especially in the impedance matching. The surface waves and the spurious feed radiation increases as the thickness of the dielectric substrate increases which obviously hampers the bandwidth of the antenna. And this feed radiation which also leads to the undesired cross polarized radiation.

As the description of the excitation of the patch by an edge coupled Microstrip line can be given in terms of the equivalent current density $J_z$ associated with a magnetic field $H_y$ of the Microstrip line at the junction place as in fig [2]

Figure 9: : Gap Coupled Microstrip Feed

Figure 10: : Representation of $H1an$ at the interface between the patch antenna and the feed Microstrip line by an equivalent current density $Jz$ – dotted lines signify H lines, solid lines are current lines.
The current $J_z$ couples with the $E_Z$ of the patch antenna and the coupling magnitude is being given by the equation

$$\text{Coupling} \approx \int \int \int E_Z J_z \, dv \approx \cos \left( \frac{\pi x_0}{L} \right) \quad \text{Eq (2.2)}$$

### 2.2. 2 Co Axial Feed Technique

This type of feed is the common technique used for the feeding of the Microstrip patch antennas. Coupling of the power through a probe is one of the basic studies that can be seen in the transfer of the microwave power.

It can be seen in the figure 11 below that the external or the outer conductor is connected to the ground plane and the inner conductor of the coaxial connector extends through the dielectric and is soldered to that of the radiating patch. The coaxial probe in this feed would be an inner conductor of the coaxial line or this can be used as the power transfer from the strip line to the Microstrip antenna from the slot in the ground plane.

![Figure 11: Probe Fed Rectangular Microstrip Patch Antenna](image)
Unlike from the other feed techniques, here the advantage is that it has the flexibility to place the feed anywhere in the inside the patch in order to match the input impedance. This gives an easy way for the fabrication and it has low spurious radiation. Of course there is a disadvantage as well from this type of feed as this gives a narrow bandwidth. And as the hole has to be put drill in the substrate there is a difficulty in the model.

With the connector extending out of the ground plane, this results in non planar surface to the substrates which are thick, i.e. Having a height that is greater than $0.02\lambda$. With the extended or the increase probe length the input impedance becomes more inductive, which leads to the matching problems of the impedance.

As discussed above about the feed point location, it is determined in order to have the best matching of the impedance. The excitation of the patch is mainly by the coupling of $J_z$ (feed current) and $E_z$ of the patch mode [10].

The coupling is given by the equation 3.2 [2]

$$\int \int \int E_z J_z \, dv \approx \cos \left( \frac{\pi x_0}{L} \right) \quad \text{Eq (2.3)}$$

- $L$ is the resonate length
- $X_0$ offset of the feed point from the patch edge

The location of $X_0$ is at the radiating edge of the path $X_0 = 0$ or $L$

From the above discussion its is seen that the thick substrate, giving broad bandwidth Co axial Feed and the Microstrip line feed has disadvantages which are said to be the contacting feed techniques where as the non contacting feed techniques solve these problems which are discussed from below.
2.2.3 Aperture Couple Feed Technique

This type of feed technique comes under the non-contacting feed techniques and here the radiating patch and the micro strip feed line are being divided by the ground plane. The main features in this particular feed technique is that it has a wider bandwidth and the shielding of the radiating patch from the radiation gets from the structure, [12]

From the figure 12 below it can be seen that the configuration of this feed and as said above the radiating patch and Microstrip feed line are separated by the ground plane.

The coupling between the patch and the feed line is trough aperture in the ground plane i.e. the line feed on the lower substrate of coupled electromagnetically to the patch through the aperture. The amount of coupling depends on the size, shape and also the location of the aperture.

There is minimization of the spurious radiation as the ground plane separates the feed line and the patch; this can be achieved when there is a usage of thin, high dielectric material for the lower substrate and thick, low dielectric constant material for the upper substrate.

The aperture slot can be of any size shape and these design parameters drive the bandwidth i.e. these parameters improve the bandwidth.

![Diagram](image-url)

**Figure 12: Aperture-couple feed technique general view**

The lower and the upper substrate parameters are chosen separately to improve the bandwidth and for the optimization of the feed and radiation separately. So as said the patch’s substrate is of thick and lower dielectric const and for the feed line it’s thin & has a high dielectric const.
In this feed technique there is a feature of improving the polarization purity. The black lobe radiation from the slot is typically 15 to 20db below the main beam of the coupling slot, is non resonant [2]. The position of the coupling slot is almost centered with respect to patch where there is a maximum magnetic field of patch to improve the magnetic coupling between the magnetic field of the patch and the magnetic current near the slot.

The coupling can be given by the expression [10]

\[
\text{Coupling} = \iiint_M \overline{M \cdot H} \, dv \approx \sin \left( \pi \frac{X_0}{L} \right)
\]

\[\text{---------- Eq}(2.4)\]

Where \(X_0\) – offset of the slot from the edge.

In order to improve the bandwidth in this particular feed technique is by adjusting the location of the slot, its shape, length and the width of the feed line and its stub length. There is obviously a disadvantage for the feed technique, it’s difficult to fabricate as this has got multiple layers, due to this the thickness of the antenna increases.

2.2.4 Proximity Coupled Microstrip Feed

This is one of the non-contacting non coplanar Microstrip feed technique. In this particular configuration, the patch antenna is on the upper layer substrate and the Microstrip feed line on the lower layer substrate as its uses 2 layers of substrate.

![Figure 13: Proximity Coupled feed Technique](image)

There is an open end to the feed line beneath the path. This feed technique is also known as electromagnetically the current coupled (proximity coupled Microstrip feed). A particular
feature of this differs from the other feed techniques i.e. the coupling capacitive in nature between the patch and the Microstrip.

The circuit that is shown below gives the configuration of this feed [2]:

![Circuit Diagram]

Figure 14: Proximity Coupled Microstrip Feed

In this the capacitor is also designed to get the impedance matching of the antenna and even for tuning the patch for the bandwidth. The advantage of this feed is the high bandwidth and the optimization of the spurious radiation.

As the terminology goes in order to improve the Bandwidth the open end of the line can be terminated in a substrate and the parameters are used for the improvement. As in the previous feed technique the improvement of the Bandwidth and the optimization of the radiation can be done by the selection of the substrate and the open end of the Microstrip and the lower substrate is to be thin, the larger bandwidth is achieved by placing the radiating patch on the double layer.

Matching does depend on the length of the feed line and the width/line ratio of the patch. The disadvantage goes as it’s difficult to fabricate due to the 2 substrate layers which require accurate alignment which directly or indirectly increases the thickness of the antenna.
<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Co-axial Probe Feed</th>
<th>Radiating Edge Coupled</th>
<th>Non radiating Edge Coupled</th>
<th>Gap Coupled</th>
<th>Insert Feed</th>
<th>Proximity Coupled</th>
<th>Aperture Coupled</th>
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</thead>
<tbody>
<tr>
<td>Configuration</td>
<td>Non Planar</td>
<td>Coplanar</td>
<td>Coplanar</td>
<td>Coplanar</td>
<td>Coplanar</td>
<td>Planar</td>
<td>Planar</td>
</tr>
<tr>
<td>Polarization Purity</td>
<td>Poor</td>
<td>Good</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
<td>excellent</td>
</tr>
<tr>
<td>Ease of fabrication</td>
<td>Soldering and drilling needed</td>
<td>Easy</td>
<td>Easy</td>
<td>Easy</td>
<td>Easy</td>
<td>Alignment required</td>
<td>Alignment required</td>
</tr>
<tr>
<td>Reliability</td>
<td>Poor due to soldering</td>
<td>Better</td>
<td>Better</td>
<td>Better</td>
<td>Better</td>
<td>Good</td>
<td>good</td>
</tr>
<tr>
<td>Impedance Matching</td>
<td>Easy</td>
<td>Poor</td>
<td>Easy</td>
<td>Easy</td>
<td>Easy</td>
<td>Easy</td>
<td>Easy</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>2-5%</td>
<td>9-12%</td>
<td>2-5%</td>
<td>2-5%</td>
<td>12%</td>
<td>21%</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: [2] gives the comparison of the different feed techniques and their characteristics
2.3 Radiation Fields and Microstrip Antenna Characteristics calculations

2.3.1 Radiation Fields

As known that the radiation of the Microstrip antenna is due to a ribbon like magnetic surface current at the patch periphery. In the other way the radiation field is determined by the surface electric current on the patch of Microstrip antenna.

These radiation types of determining the radiation fields are said to be simpler and are of course based on different types of the models of the Microstrip antennas.

The study of the radiation of the discontinuous was studied first by Lewin and this analysis was based on the current flowing on conductors [13]. The radiation patterns from this mechanism & Hertzian magnetic dipole are found to be similar & this tends to calculate the effect of radiation on Q – the Quality factor of the Microstrip resonators.

There was an analysis by Sobol which was based on fields in aperture by open end of the Microstrip and the ground plane.

The effect of radiation on Q – the quality factor can be given as the function of resonator dimensions, thickness of substrate, operating frequency and relative dielectric constant. The radiation loss is larger that of the dielectric losses and the conductor at the high frequencies, the analysis also yielded results that the open ended Microstrip lines radiate more power when they are fabricated with thick, low dielectric constant substrates.

The figures below show the radiation from the Microstrip antenna from a Microstrip open end. (See figures 15(a) (b) (c))[2]
Figure 15: (a) an arbitrary current sheet $M$ or $J$, (b) Rectangular Magnetic sheet, (c) Circular electric current sheet.
2.3.2 Microstrip Antenna Calculations

There is a need of finding the characteristics of antennas to determine the performance of the same. Characteristics such as quality factor, efficiency, losses etc.

Dissipated Power

This power has 2 losses

Conductor Loss – $P_c$ and

Dielectric Loss – $P_d$

The Conductor loss ($P_c$) can be calculated as follows:

$$P_c = I^2 R$$  \hspace{1cm} \text{Eq (2.5)}

- The integrated relationship of the current density on plates and ground plane are [2]

$$P_c = 2 R_S \iint_s (\vec{J} \cdot \vec{J}^*) \, ds$$  \hspace{1cm} \text{Eq (2.6)}

$R_S$ -- the real part of the surface impedance.

$s$ – Patch area.

$J$ in the above equation (2.6) is obtained by the tangential component of the magnetic field.

The Dielectric loss ($P_d$) is calculated by the integration of electric field on Volume ‘V’ of the Microstrip cavity.[2]

$$P_d = \omega \varepsilon_0 n \iiint_v |E|^2 \, dv = (\omega \varepsilon_0 n^2 / 2) h \iiint_s |E|^2 \, ds$$  \hspace{1cm} \text{Eq (2.7)}
\( \omega \) – Radiation frequency.

\( \varepsilon^a \) – imaginary part of permittivity of substrate.

\( h \) – Thickness of the substrate.

Radiated power

The Radiated Power \((P_r)\) is given by the integration of Poynting vector to radiating aperture. [2]

\[
P_r = \frac{1}{2} \text{Re} \int_{\text{aperture}} (\mathbf{E} \times \mathbf{H}^*) \, ds
\]

---

Eq (2.8)

The \( E \) in the patch is normal to strip conductor & to the ground plane in Microstrip antenna & the \( H \) is parallel to strip edge. [2]

Therefore \( P_r = (1/2\varepsilon_0) \int \int (|E_{\theta}|^2 + |E_{\phi}|^2) \, r^2 \sin \theta \, d\theta \, d\phi \)       --- Eq (2.9)

Input impedance

There is always a need of matching of the impedance to the Microstrip antenna to load input impedance.

The feed technique would be anything such as > Microstrip line,

- Coaxial feed,
- Coplanar waveguide.

When the antenna is fed with the coaxial feed technique

The input power is calculated by [2]

\[
P_{in} = - \iiint_v (\mathbf{E} \cdot \mathbf{J}^*) \, dv
\]

---

Eq (2.10)

\( J \) – Current density in A/m\(^2\).

\( \circ \) – coaxial feed.
For a electrically thin coaxial feed with current $z$

The power is [2]

$$P_{in}^e = -E(X_0, Y_0) \int_0^h I'(z') \, dz'$$  \hspace{1cm} \text{Eq (2.11)}

$(X_0, Y_0)$ – feed point co-ordinates.

Input impedance becomes

$$P_{in} = |I_{in}|^2 Z_{in}$$  \hspace{1cm} \text{Eq (2.12)}

The equation (2.12) becomes

$$Z_{in} = - \frac{(E(X_0, Y_0)/|I_{in}|^2) \int_0^h I'(z') \, dz'}{\int_0^h E(X_0, Y_0) \, dz'}$$  \hspace{1cm} \text{Eq (2.13)}

When $h << \lambda_0$, $E$ and $I(z')$ are constant

$$Z_{in} = \frac{V_{in}}{I_{in}}$$  \hspace{1cm} \text{Eq (2.14)}

Where

$$V_{in} = -E(X_0, Y_0) \int_0^h dz' = -h E(X_0, Y_0)$$  \hspace{1cm} \text{Eq (2.15)}

As done above for the Coaxial feed it can also be done for the other feed techniques with the same principle technique and mechanism.
2.4 Rectangular Microstrip Patch Antenna

The rectangular Microstrip patch antenna is the widely used of all the types of Microstrip antennas that are present. For the reason to be more easy in fabrication and robust design and of course very easy to handle. The most two models of the rectangular patch antenna are transmission line model and the cavity model which were discussed in the chapter 5. Here in this chapter we briefly go through the characteristics and other few topics which were not discussed earlier and the design aspects of the Rectangular Patch Antenna.

A patch antenna – low profile antenna which has more advantages when compared to the other type of antennas, they are cheap at cost, easy to carry and install, the integration of these antennas is very easy to other electronic media than the conventional antennas. The figure 16 shows the basic structure of the patch antenna [14] consists of - a flat plate on the ground plane, the conductor in the centre of the coax is serving as the feed probe in order to couple electromagnetic energy in or out of the patch. We can also find the field distribution of the rectangular patch.

![Figure 16: The basic structure of the patch antenna](image)
The electric field at the centre is zero and maximum to positive on one side and max to the negative on the opposite side. For an applied signal it has to see to it that the maximum and minimum change continuously are maintained according to the instantaneous phase.

As these antennas are in wide usage in almost all the fields because of their advantages, it also has some limitations taking bandwidth, efficiency in to consideration, due to this as the research went on the Microstrip antenna having a thin in fact very thin film and is separated from the ground plane by the foam was designed in a good manner [29].

2.4.1 Patch Antenna Materials

In the wide range of antenna models there are different structures of Microstrip antennas, but on the whole we have four basic parts in the antenna [15]:

They are:

- The patch
- Dielectric Substrate
- Ground Plane
- Feed Line

![Figure 17: Side view of Microstrip Rectangular Patch Antenna](image-url)
A thin metallic region which has different shapes and sizes is the patch where the ground plane is usually of the same material. The common operation that we should be aware of is that the RF supplies the power to the patch.

The dielectric material is commonly known as ‘substrate’ [16] there is features that are to be considered in the selection of the substrate such as dielectric constant [17], cost of the material, dielectric loss tangent, the surface adhesion properties for the conductor coatings, and the ease of fabrication[18]. We have a wide range of materials for the substrate selection which are in use for the planar and also for the conformal antenna configurations. The dielectric constant for the materials range from 1.17 to $\approx 25$ [19].

In this research the dielectric materials for Design 1 with $\varepsilon_r=9.8$ (alumina), which is the well known to have the high unloaded Q material the substrates patch antennas and the dielectric resonators [20] and for the Design 2 $\varepsilon_r=2.32$ has been used.

The material $\varepsilon_r=9.8$ (alumina) requires a sintering temperature that is higher than $1600^0$C, the alumina processes a quality factor of 333,000 at $1500^0$C for 5 hours [21].
2.5 Model Analysis of Microstrip Antenna

In the previous text we had discussed about the types, applications, feed techniques etc about the Microstrip antennas, feed techniques etc about the Microstrip antennas. There is a lot of importance in analyzing the models of antennas which [2]

- Takes us on to a platform of antennas performance advantages and also their limitations.
- The correct design process will help us reduce the cost, in fact having a cost analysis as well as to get the best design at the lowest cost possible with a better performance.
- Analyzing the models and their performance gives an idea to use the best combinations in practice and also to update the older designs to the newer specifications.

For every task we do irrespective of where ever and whatever there are always some main objectives to have the concentration on. In the same way here in the analysis of Microstrip antennas the objective is to calculate the radiation characteristics of the Microstrip antenna in order to have an edge over the failures. The following are calculated during the analysis [22]

- Radiation patterns,
- Polarization, and
- Gain.

In addition to these the near field characteristics are also analyzed during the analysis such as [2]

- Impedance Bandwidth,
- Input Impedance,
- Antenna efficiency, and
- Mutual coupling.
The analysis of Microstrip antennas are not that easy as it is thought there are many complicated issues involved in it such as the narrow frequency band characteristics, it has wide range of feed techniques, substrate characteristics, configurations and of course the patch shape and size which is the most important aspect.

Not all characterizes are taken in to consideration for the final analysis are it is very difficult to manage every aspect, so it is often happens to put some under the mat, antenna with a good performance are said to have the following characteristics [10]:

- The antenna is to be as simple as it can be when it provides the near field characteristics and the radiation characteristics.
- It should be useful enough to calculate the radiation characteristics and near field characteristics.
- The results are to be as accurate it can give for the required purpose

2.5.1 Transmission Line Model

In this model we can see the Microstrip Antenna in 2 slots with the design of height ‘h’, and width ‘w’ and are separated by the transmission line ‘L’. We can see the same in the figures below.

![Microstrip Line](image)

*Figure 18: Microstrip Line*
The electric field lines in the antenna mostly move in the substrate and even a bit out of the substrate into the air. Due to this the transmission lines are not able to support the pure transverse electric magnetic (TEM) mode of transmission because the lines in the substrate and lines in the air have different phase velocities [35].

In order to have a notice of wave propagation and the fringing in the line the $\varepsilon_{\text{reff}}$ — the effective dielectric constant has to be calculated. The value of $\varepsilon_{\text{reff}}$ is slightly less than that of $\varepsilon_r$ as we can see that the fringing fields are not confined only in the substrate but some are out in the air.

![Electric field Lines](image)

**Figure 19: Electric field Lines**

$\varepsilon_{\text{reff}}$ is calculated as follows [24]

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

------------------- Eq (2.16)

$\varepsilon_r$ — The dielectric constant of the substrate

$\varepsilon_{\text{reff}}$ — Effective dielectric constant.

$h$ — Height of the dielectric substrate.

$W$ — Width of the patch.

Let us consider a rectangular Microstrip patch antenna with width $W$, height $h$, and length $L$. see fig below.
Figure 20: Microstrip Patch Antenna

The parameters are given on the co-ordinate axis such as Width on y axis height on z direction and length on x direction.

For the analysis of the antenna it has to be operated in the basic mode i.e. TM$_{10}$ and for this the length of the patch should be less than $\lambda/2$ where $\lambda$ – the wavelength in the dielectric medium and should be equal to $\lambda_0/\sqrt{\varepsilon_{reff}}$ where $\lambda_0$ – free space wavelength.

In TM$_{10}$ mode the field varies by one $\lambda/2$ cycle towards length and there is no variation along the width of the patch. [23]

The Microstrip patch antenna is represented by 2 slots, which are separated by the transmission line as said previously with a length L and it is open circuited on the two ends. The width of the structure has a maximum voltage and minimum current as it is an open ended circuit. The tangential and the normal components of the fields at the edges are resolved with respect to the ground plane.
Figure 21: The top and the side views of the antenna

The field lines, some reside in the substrate and some are spread in to the air, the normal components are towards the width and opposite in direction, i.e. they are not in phase as the patch is \( \lambda/2 \) long. So they are cancelled as they are opposite in direction. The tangential components are in phase which makes the resulting fields to combine for a maximum radiating field to the surface of the structure.

The fringing fields along the width of the structure are taken as radiating slots and the patch of the antenna electrically seen to be a bit larger than usual design. So the dimensions are changed and extended a bit for a better performance i.e. it is been extended by \( \Delta L \), \( E_H \)

\( \Delta L \) is calculated as below [24]:

\[
\Delta L = 0.412h \left( \frac{\epsilon_{\text{eff}} + 0.3}{\epsilon_{\text{eff}} - 0.258} \right) \left( \frac{w}{h} + 0.264 \right) \left( \frac{w}{h} + 0.8 \right) \\
\]

\( L_{\text{eff}} \) the effective length of the patch is given by:

\[
L_{\text{eff}} = L + 2\Delta L \\
\]

\[\text{Eq (2.17)}\]

\[\text{Eq (2.18)}\]
For the particular resonate frequency the effective length of the patch is calculated by:

\[ L_{\text{eff}} = \frac{c}{2 f_0 \sqrt{\varepsilon_{\text{reff}}}} \quad \text{Eq (2.19)} \]

Considering the rectangular patch Microstrip antenna the resonating frequency for the mode \( \text{TM}_{mn} \) is given by [1]

\[ f_0 = \frac{c}{2 \sqrt{\varepsilon_{\text{reff}}} \left[ \left( \frac{m}{L} \right)^2 + \left( \frac{n}{w} \right)^2 \right]} \quad \text{Eq (2.20)} \]

\( m, n \) are the operating modes of the Microstrip patch antenna, along with \( L \) – length \( W \)- width.

For the effective radiation the design of the structure is the utmost important aspect and for this the width is calculated as [24]:

\[ w = \frac{c}{2 f_0} \sqrt{\frac{2}{\varepsilon_r + 1}} \quad \text{Eq (2.21)} \]

### 2.5.2 Cavity Model

The transmission line model was impressive and was good at usage, robust and easy – even after having disadvantages, like ignorance of the field variations on the radiating edges of the patch. To overcome these types of disadvantages we have another model – cavity model – this is preferred the most to analyze the Microstrip antenna.

The structure of the model goes this way – the inner region of the patch is filled as a cavity, bounded by the electric walls on both ways i.e. on top and bottom, it has a magnetic wall thorough the periphery. Few observations have been made for the thin substrates taking \( h \ll \lambda_0 \) in to consideration [2]

- As the thin substrate is considered the interior fields doesn’t vary with ‘z’ i.e. \( d/dz \approx 0 \).
- The electric field is towards the ‘z’ direction and the magnetic field components $H_x$ & $H_y$ in the region that is bounded by the patch metallization & the ground plane.

- There is no component for the electric current which is normal to the patch edge, saying that the tangential components of the magnetic field is negligible, i.e. $\delta E_z/\delta n=0$ for the magnetic wall to be placed along the periphery.

The operation goes as follows, we can see the charge distribution on the upper and the lower surfaces of the patch and even at the bottom of the ground plane, this happens when there is a power given to the Microstrip patch (see figure 22).

Figure 22: Charge distribution and the current density creation on the Microstrip patch [23]

There exists two mechanisms in order to control the charge distribution those are – attractive mechanism and the repulsive mechanism, there are opposite charges at the bottom side of the patch and on the ground plane here the former mechanism is used. This helps in controlling the charge distribution and has the concentration on the bottom of the patch. The latter mechanism is used when there are same charges at the bottom of the patch; these charges normally cause the pushing of the charge from the bottom of the patch to the surface. The currents flow from top to the bottom of the patch due to the charge movement and due to the height to width ratio of the cavity model is less this results in the domination of the attractive mechanism causing the charge and even the current to move down to the bottom surface of the patch.

The flow of current on the top reduces gradually as the height to width ratio still goes down resulting the current flowing on the top surface to zero(almost to zero) this results in no
tangential magnetic field components through the patch edges. That is the reason why the walls are being designed as the magnetic conducting surfaces. This creates a free flow and the operation for the electric and magnetic fields below the patch. In practice there is a chance of not making the width to height ratio very less which can give a way to create the tangential magnetic fields, but as the components being very small the walls would be operating perfectly i.e. magnetic conducting.

In order to have the radiation and the loss mechanism there is a need of having a radiation resistance $R_r$ and loss resistance $R_L$.

The lossy cavity represents the antenna and the loss is taken in to consideration by – effective loss tangent $\delta_{eff}$

$$\delta_{eff} = 1/Q_T \quad \text{Eq (2.22)}$$

$Q_T$ -- total antenna quality factor [2]

$$\frac{1}{Q_T} = \frac{1}{Q_d} + \frac{1}{Q_c} + \frac{1}{Q_r} \quad \text{Eq (2.23)}$$

$Q_d$ -- quality factor of the dielectric [2]

$$Q_d = \frac{\omega_r W_r}{P_d} = \frac{1}{\tan \delta} \quad \text{Eq (2.24)}$$

$\omega_r$ - angular resonant frequency.

$W_r$ - total energy stored in the patch at the resonant freq.

$P_d$ - dielectric loss.

$\tan \delta$ – loss tangent of the dielectric.
\( Q_c \) -- quality factor of the conductor

\[
Q_c = \frac{\omega_r W_r}{P_c} = \frac{h}{\Delta} \quad \text{Eq (2.25)}
\]

\( P_c \) – Conductor loss.

\( h \) – Height of the substrate

\( \Delta \) - skin depth of the conductor.

\( Q_r \) -- Quality factor for radiation

\[
Q_r = \frac{\omega_r W_r}{P_r} \quad \text{Eq (2.26)}
\]

\( P_r \) – power radiated from the patch.

Having all the above equations 6.8 to 6.11 for calculating \( \delta_{\text{eff}} \) we get [2]

\[
\delta_{\text{eff}} = [\tan \delta] + \left[ \frac{\Delta}{h} \right] + \left[ \frac{P_r}{\omega_r W_r} \right] \quad \text{Eq (2.27)}
\]

The above equation gives the total effective loss tangent for the Microstrip patch antenna.
2.6 Overview of the Antenna Parameters

From here we discuss the overview of the patch antenna design parameters of the rectangular patch antenna:

In a simple way we can say that “an antenna is the transitional radio b/w free space and a guiding device” [19][25-26]. For designing a perfect antenna there are certain parameters that are to be considered that define the configuration of the antenna.

2.6.1 Return Loss

This is the best and convenient method to calculate the input and output of the signal sources. It can be said that when the load is mismatched the whole power is not delivered to the load there is a return of the power and that is called loss, and this loss that is returned is called the ‘Return loss’.

This Return Loss is determined in dB as follows: [24]

\[ RL = -20\log |\Gamma| \text{ (dB)} \quad \text{------------------- Eq (2.28)} \]

Where \( |\Gamma| = \frac{V_0^-}{V_0^+} = \frac{Z_L - Z_0}{Z_L + Z_0} \)

|\(\Gamma| is the reflection coefficient

\(V_0^+\) The incident voltage

\(V_0^-\) The reflected voltage

\(Z_L\) and \(Z_0\) are the load and characteristic impedances.

During the process of the design of the rectangular patch antenna there is a response taken from the magnitude of \(S_{11}\) Vs the frequency (this is known as the return loss), as shown in the figure, just as the verification of the design. [36]
In the figure above it shows that the rectangular patch antenna resonating at 20GHz having a return loss of -21.5dB and those -3dB and -10dB bandwidths are 0.74GHz and 0.25GHz, due to the reason that the radio amplifier reduces the output power, can be more worse and can become unstable if the VSWR is large. [22]

To have a perfect matching between the antenna and the transmitter, $\Gamma=0$ and $RL = \infty$, this indicates that there is no power that is returned or reflected but when $\Gamma=0$ and $RL = 0\text{dB}$, this indicated that the power that is sent is all reflected back. It sis said that for the practical applications $VSWR=2$ is acceptable as the return loss would be -9.54dB [22].

### 2.6.2 Radiation Pattern

Microstrip Patch Antenna has radiation patterns that can be calculated easily. The source of the radiation of the electric field at the gap of the edge of the Microstrip element and the ground plane is the key factor to the accurate calculation of the pattern for the patch antenna.

Simply it can be said that the power radiated or received by the antenna is the function of angular position and radial distribution from the antenna [24]. In the figure 24[9] below we can see the side view of the rectangular Microstrip element associated with source, and also the radiating of E fields.
Figure 24: Side view of the rectangular Microstrip element and associated radiation.

The radiation pattern of a generic dimensional antenna can be seen below, which consist of side lobe, black lobes, and are undesirable as they represent the energy that is wasted for transmitting antennas and noise sources at the receiving end.

Figure 25: Radiation Pattern of a generic dimensional antenna [22]
2.6.3 Gain & Directivity

The gain of the antenna is the quantity which describes the performance of the antenna or the capability to concentrate energy through a direction to give a better picture of the radiation performance. This is expressed in dB, in a simple way we can say that this refers to the direction of the maximum radiation [24].

The expression for the maximum gain of an antenna is as follows:

\[ G = \eta \times D \]  

\[ \text{Eq (2.29)} \]

\( \eta \) – The efficiency of the antenna

D – Directivity

In order to receive or transmit the power it can be chosen to maximize the radiation pattern of the response of the antenna in a particular direction.

The directivity of an antenna can be defined as – the ratio of radiation intensity in a given direction from the antenna to the radiation intensity averaged in all the directions. And the gain can be known as the ratio between the amounts of energy propagated in these directions to the energy that would be propagated if there is an Omni-directional antenna. [22][24]
The directivity of the antenna depends on the shape of the radiation pattern. The measurement is done taking a reference of isotropic point source from the response. The quantitative measure of this response is known as the directive gain for the antenna on a given direction.

2.6.4 Polarization

The polarization of the electric field vector of the radiated wave or from source Vs time the observation of the orientation of the electric fields does also refer to the polarization. It is defined as” the property of an electromagnetic wave describing the time varying direction and relative magnitude of the electric filed vector”[22].

The direction or position of the electric field w.r.t the ground gives the wave polarization. The common types of the polarization are circular and linear the former includes horizontal and vertical and the latter includes right hand polarization and left hand polarization.
It is said to be linearly polarized when the path of the electric field vector is back and forth along the line. The commonly used polarized schemes can be seen in the figure 29 below:

![Polarization Schemes](image)

**Figure 29: The commonly used polarized schemes [22]**

It can be noted that the circular polarization has the electric field vector’s length constant but rotates in a circular path [24].

### 2.6.5 Reflection Coefficient $|\Gamma|$ and Character Impedance ($Z_0$)

There is a reflection that occurs in the transmission line when we take the higher frequencies into consideration. There is a resistance that is associated with each transmission line which comes with the construction of the transmission line. This is called as character impedance ($Z_0$). The standard value of this impedance is 50ohm. Always the every transmission line is being terminated with an arbitrary load $Z_L$ and this is not equivalent to the impedance i.e. $Z_0$. Here occurs the reflected wave.

The degree of impedance mismatch is represented by the reflection coefficient [1] at that load and is given by:
We can observe here that the reflection coefficient for the shorted load \( Z_L = 0 \), there is a match in the load \( Z_L = Z_0 \) and an open load \( Z_L = \infty \) are -1, 0, +1. [22]

Hence we can say that the reflection coefficient ranges from 0 to +1.

### 2.6.6 Voltage Standing Wave Ratio

There should be a maximum power transfer between the transmitter and the antenna for the antenna to perform efficiently. This happens only when the impedance \( Z_{in} \) is matched to the transmitter impedance, \( Z_t \).

In the process of achieving this particular configuration for an antenna to perform efficiently there is always a reflection of the power which leads to the standing waves, which is characterized by the Voltage Standing Wave Ratio (\( VSWR \)).

This is given by [22]:

\[
VSWR = \frac{V_{\text{max}}}{V_{\text{min}}} = \frac{1 + |\Gamma|}{1 - |\Gamma|} = \frac{1 + S_{11}}{1 - S_{11}} \quad \text{------------------- Eq (2.31)}
\]

As the reflection coefficient ranges from 0 to 1, the \( VSWR \) ranges from 1 to \( \infty \).

### 2.6.7 Input Impedance

This is the ratio of the voltage to current at the pair of terminals or the ratio of the appropriate components of the electric fields to the magnetic fields at a point. Or in other words we can say it is the impedance presented by the antenna at the input terminal.

\[
Z_{in} = (R_{in} + jX_{in}) \quad \text{------------------- Eq (2.32)}
\]
R_in – the real part, representing the power dissipated though heat or through radiation losses.

X_in = imaginary part, representing the reactance of the antenna & the power stored in the near field of the antenna. [24]

### 2.6.8 Bandwidth

Bandwidth can be said as the frequencies on both the sides of the centre frequency in which the characteristics of antenna such as the input impedance, polarization, beam width, radiation pattern etc are almost close to that of this value. As the definition goes [22] “the range of suitable frequencies within which the performance of the antenna, w.r.t some characteristic, conforms to a specific standard”.

The bandwidth is the ratio of the upper and lower frequencies of an operation. According to [22] the bandwidth can be obtained as:

\[
BW_{\text{broadband}} = \frac{f_H}{f_L} \quad \text{---------------- Eq (2.33)}
\]

\[
BW_{\text{narrowband}} (%) = \left[ \frac{f_H - f_L}{f_C} \right] \times 100 \quad \text{---------------- Eq (2.34)}
\]

When the ratio \( \frac{f_H}{f_L} = 2 \) the antenna is said to be broadband. We can judge the antenna’s performance by operating the antenna at a high frequency by observing VSWR, when \( VSWR \leq 2 \) \( (RL \geq -9.5\text{dB}) \) the antenna is said to have performed well.
2.7 Dimension Parameters

Here we take a short tour of the dimensions of the Microstrip patch antenna i.e. Length \( (L) \), width \( (w) \).

### 2.7.1 Length

The length of the rectangular patch antenna, the resonate length, it determines the resonate frequency and is \( \lambda/2 \) for a rectangular patch in its fundamental mode. In a practical view due to the fringing fields the patch is a bit larger than the theoretical calculated dimensions. [14]

The length is calculated by the formula [11]

\[
L \approx 0.49 \lambda_d = 0.49 \frac{\lambda_0}{\sqrt{\varepsilon_r}}
\]

\( L \) – Resonate length.

\( \lambda_0 \) – wave length of the free space.

\( \lambda_d \) – wavelength of the PC board.

\( \varepsilon_r \) – dielectric constant.

### 2.7.2 Width

As we know that the dimensions of the patch antenna effects in the results as the main part, especially length \( (L) \) and the width \( (W) \).

The width of the patch can be calculated by the formula[36]:

\[
Width = \frac{c}{2 f_r \sqrt{\frac{2}{\varepsilon_r + 1}}}
\]

\( c \) – The speed of light,

\( f_r \) – the resonant frequency which is equal to 1GHz
2.7.3 Length Extension ($\Delta L$)

The calculation of the extension of the length is given by a very popular relation for the normalized extension of the length is \cite{36} \cite{30}:

$$
\Delta L = 0.412h \left[ \frac{\varepsilon_{\text{reff}} + 0.3}{\varepsilon_{\text{reff}} - 0.258} \right] \left[ \frac{w}{h} + 0.264 \right] \left[ \frac{w}{h} + 0.8 \right]
$$

---------- Eq (2.37)

$h$- Height

$w$- Width of the patch

$\varepsilon_{\text{reff}}$— Effective Dielectric Constant

2.8 Applications of Microstrip Patch Antenna

The Microstrip patch antennas are well known for their performance and their robust design, fabrication and their extent usage. The advantages of this Microstrip patch antenna are to overcome their de-merits such as easy to design, light weight etc., the applications are in the various fields such as in the medical applications, satellites and of course even in the military systems just like in the rockets, aircrafts missiles etc. the usage of the Microstrip antennas are spreading widely in all the fields and areas and now they are booming in the commercial aspects due to their low cost of the substrate material and the fabrication. It is also expected that due to the increasing usage of the patch antennas in the wide range this could take over the usage of the conventional antennas for the maximum applications.

Some of the applications for the Microstrip Patch Antenna are as follows: \cite{2}

- Radio altimeters,
- Command and control systems
- Remote sensing and environmental instrumentation
- Feed elements in complex antennas
Satellite navigation receivers.

Mobile radio

Integrated antennas

Biomedical radiators and intruder alarms

Doppler and other radars

Satellite communication, direct broadcast services (DBS)

2.8.1 Medicinal applications of patch

It is found that in the treatment of malignant tumors the microwave energy is said to be the most effective way of inducing hyperthermia. The design of the particular radiator which is to be used for this purpose should possess light weight, easy in handling and to be rugged. Only the patch radiator fulfils these requirements. The initial designs for the Microstrip radiator for inducing hyperthermia was based on the printed dipoles and annular rings which were designed on S-band. And later on the design was based on the circular Microstrip disk at L-band. There is a simple operation that goes on with the instrument; two coupled Microstrip lines are separated with a flexible separation which is used to measure the temperature inside the human body. A flexible patch applicator can be seen in the figure below which operates at 430 MHz.

Figure 30: Flexible Microstrip Applicator for hyperthermia medicinal applications [2][31]
Chapter 3

Design of the Rectangular Microstrip Patch Antenna

Calculations, simulation and results
3. Design of the rectangular patch antenna

3.1 Design Calculation

- **Dielectric Constant of the Substrate \( (\varepsilon_r) \):**

The dielectric material that is used in my design of the Microstrip Patch Antenna is Alumina with \( \varepsilon_r = 9.8 \), as this one of the maximum values of the dielectric substrate has been taken in order to reduce the size of the antenna.

- **The frequency of the operation \( (f_0) \):**

The frequency of operation for the Patch antenna I am trying to design has been selected as 2.1GHz.

- **Height of the dielectric substrate \( (h) \):**

Microstrip Patch antenna has been designed in order to rule out the conventional antenna as the patch antennas are used in most of the compact devices. Therefore the height of the antenna has been decided as 1.5mm.

![Figure 31: Top view of the Microstrip Patch Antenna](image-url)
The parameters that are decided by default in order to continue to the design process are:

\[ \varepsilon_r = 9.8 \]
\[ h = 1.5\text{mm} \]
\[ f_0 = 2.1\text{GHz} \]

Let us continue with the calculation of the design of the patch antenna:

A rectangular Patch antenna has been in the process of design; it is easy in the fabrication analysis and also in the prediction of the performance. The design of the antenna is being under process at 2.1GHz [33] frequency using the Dielectric material with \( \varepsilon_r = 9.8 \) with a dielectric loss tangent (\( \tan \delta \)) = 0.0001 with a height of 1.5mm.

The antenna is being excited with the coaxial feed point located at distance \( dx \), from the centre of the patch.

The following table 3 gives us the design parameter specifications of the Microstrip Antenna.

<table>
<thead>
<tr>
<th>Type of the antenna</th>
<th>Rectangular Patch antenna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dielectric Constant of the substrate</td>
<td>9.8(alumina)</td>
</tr>
<tr>
<td>Operating frequency</td>
<td>2.1GHz</td>
</tr>
<tr>
<td>Height of the substrate</td>
<td>1.5mm</td>
</tr>
<tr>
<td>Feeding method</td>
<td>Microstrip Line Feed &amp; Co-Axial Feed</td>
</tr>
<tr>
<td>Gain</td>
<td>5dB-8dB</td>
</tr>
<tr>
<td>Polarization</td>
<td>Linear</td>
</tr>
</tbody>
</table>

Table 3: Design Parameter Specifications of the Rectangular Microstrip Patch Antenna
1) **Calculation of Width**(w):

By the formula:

\[
Width = \frac{c}{2f_r} \sqrt{\frac{2}{\varepsilon_r + 1}}
\]

With the substituting the values of \(c=3 \times 10^8 \text{ m/s}\), \(f_r=2.1\text{GHz}\) and \(h=1.5\text{mm}\)

\[Width \ w = 0.0307\text{m} = 30.7\text{mm}\]

2) **Calculation of Effective dielectric constant**(\(\varepsilon_{reff}\)):

From the equation

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

With the substituting the values \(\varepsilon_r = 9.8\), \(h = 1.5\text{mm}\), \(w=30.7\text{mm}\)

Effective Dielectric Constant \(\varepsilon_{reff} = 8.89\)

3) **Calculation of effective length**(\(L_{eff}\)):

From the equation

\[
L_{eff} = \frac{c}{2f_r \sqrt{\varepsilon_{reff}}}
\]

With the values \(\varepsilon_{reff} = 8.89\), \(c=3 \times 10^8 \text{ m/s}\), \(f_r=2.1\text{GHz}\)

\[L_{eff} = 0.0239\text{m} = 23.9\text{mm}\]
4) Calculation of the length extension ($\Delta L$) with $h=1.5\text{mm}, w=30.7\text{mm}$

From the equation

$$\Delta L = 0.412h \left[ \frac{\varepsilon_{\text{eff}} + 0.3}{\varepsilon_{\text{eff}} - 0.258} \right] \left[ \frac{w}{h} + 0.264 \right]$$

With the values from $h$, $w$ and $\varepsilon_{\text{eff}}$ the $\Delta L$ is being calculated as $0.6\text{mm}$

$$\Delta L = 0.6\text{mm}$$

5) Calculation of the length of the patch ($L$): 

By the equation

$$L = L_{\text{eff}} - 2\Delta L$$

Where $\Delta L = 0.6\text{mm}$, $L_{\text{eff}} = 23.9\text{mm}$

$$L = 23.2\text{mm}$$

6) The feed point determination.

As there feed type has been specified and the parameters are calculated. The matching impedance is $50\Omega$. In order to have a matching of the impedance the connector has to be placed at some distance from the edge which has a match of $50\Omega$. There is a trial and error method that has been adopted to check the minimum value of the Return loss. That is the reason why the coordinate $Y_f$ is set to be zero and $X_f$ is varied to have the optimal feed point [17].
3.2 Results

As the design process goes the calculation of the parameters are done above and with the dimensions the rectangular patch antenna has been designed by two different feed techniques

1) Co Axial Feed Technique
2) Microstrip Line Feed Technique

The software 1) SonnetLite\(^1\) [38] with Matlab and

2) IE3D\(^2\) from Zeland Software Inc. has been used for the simulation and the design respectively.

Firstly we take the co axial feed technique in practice and the results are as shown below,

- A Matlab program [37] has been compiled with the integration on sonnet lite in order to produce the design and the responses for the Rectangular Microstrip patch antenna and its design.

The table 4 below gives the possible parameters for the design of the Microstrip patch antenna which will be used in the software for the results to examine. The width and the length of the patch have been rounded up to the close integer value.

Table 4: Parameters used in the software for the responses and simulations.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dielectric Constant of the Substrate</td>
<td>9.8</td>
</tr>
<tr>
<td>Centre Frequency</td>
<td>2.1GHz</td>
</tr>
<tr>
<td>Loss tangent</td>
<td>0.0001</td>
</tr>
<tr>
<td>Width of the patch</td>
<td>30mm</td>
</tr>
<tr>
<td>Length of the Patch</td>
<td>23mm</td>
</tr>
<tr>
<td>Height</td>
<td>1.5mm (50.9 mils)</td>
</tr>
<tr>
<td>(Z_0)</td>
<td>50 ohms</td>
</tr>
</tbody>
</table>

\(^1\) SonnetLite is EM software from www.Sonnetsoftware.com, emstatus 11.55-Lite has been used for this thesis work.

\(^2\) IE3D is an EM Design Environment from Zeland Software Inc. version 14.0 has been used to design the Antenna for the Microstrip line feed technique.
3.2.1 Co-axial Probe Feed

The Matlab program\(^3\)[37] has been compiled which gives us the following interface (fig 32) to fill the requirements as per our design calculations:

![Figure 32: Interface from the Matlab program compilation](image)

After we enter the desired values to the interface to calculate the responses and the design of the patch antenna, the Matlab integrates with the SonnetLite\(^3\)[38] and the process runs as shown in the figure 33 below, this take the trial and error method, it calculates all the possible measurements: \(^4\)

---

\(^3\) The Matlab Program can be seen in the Appendix II

\(^4\) The substrate thickness in the figure 32 is taken in “mils” 1 mil = 0.0254 mm
Figure 33: SonnetLite interface while the simulation is ON.

In this case it has taken 14 simulations and the final simulation 15 is given with the optimized values of the design for the dimensions that are entered\(^5\) (simulations (calculations) can be seen in the Appendix I)

---

\(^5\) PS: The units that are taken in the software is in Inches.
The patch antenna design given by the SonnetLite in integration with the Matlab can be seen below fig 34:

Figure 34: Patch Antenna.

Figure 35: 3D view of the patch antenna from SonnetLite
As the simulation runs, it takes an initial guess of the

Length = 0.87993 in and

Width = 1.2865 in and

Initial probe offset = 0.34581 in

With an expected performance of input impedance = 49.9994 Ohms and 2:1 VSWR
Bandwidth = 0.53049 % with the measurements that are provided.

The sonnet lite performs the simulation with the integration of Matlab 14 times and the optimizations values are given with the responses as follows:

![Graph](image)

**Figure 36: The Input impedance (ReZ\textsubscript{in}) Vs Frequency.**
We can observe the return loss of the Rectangular patch antenna here at the 2.1GHz is -21dB in the figure 38, the BW -10dB as calculated is 0.61905%.
The responses are given by the Matlab with integration of SonnetLite and the final optimized report is been given below in the table:

<table>
<thead>
<tr>
<th>Patch Length</th>
<th>0.87094 inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patch Width</td>
<td>1.2865 inches</td>
</tr>
<tr>
<td>Probe Offset</td>
<td>0.31504 inches</td>
</tr>
<tr>
<td>Resonance Frequency</td>
<td>2.1 GHz</td>
</tr>
<tr>
<td>Resonance Frequency Error</td>
<td>0%</td>
</tr>
<tr>
<td>Input Impedance</td>
<td>45.6 Ohms</td>
</tr>
<tr>
<td>Input Impedance Error</td>
<td>9.328%</td>
</tr>
<tr>
<td>VSWR 2:1 Bandwidth</td>
<td>0.61905</td>
</tr>
</tbody>
</table>

Table 5: Final Optimized measurements ans report by the SonnetLite

The design of the rectangular Patch Antenna with the Co-Axial Probe feeds Technique has been processed with the help of Matlab and SonnetLite giving the probe offset to be at 0.31504 inches = 8.0020 mm from the edge.
3.2.2 Microstrip Line Feed

As the discussion went in the previous section about the Design of the Rectangular patch antenna with the co-axial Feed technique, now here in this section we discuss about the Design of the Antenna with Microstrip Feed line Technique Using IE3D software:

As per the calculated Dimension Parameters let us design the Rectangular Patch Antenna with the Microstrip Feed Line Technique:

IE3D software is EM software which is extensively used for the Design and the Simulation of the Patch Antenna. Let us see the procedure of the design step by step and finally the responses and the simulation.

The calculated measurements can be found in the table in the previous section

With the length = 23mm and the width = 30mm a rectangle is drawn as below:

![Figure 40: A Rectangle drawn with L & W](image-url)
The rest of the structure of the antenna is drawn now connecting the vertices and the Microstrip feed line as shown in figure 41.

A feed line is to be installed to the antenna in order to get the RF power to the patch and now we design the feed line and a port number is assigned in order to have a reference while calculating the S-Parameters.

The feeding Microstrip line is a 50Ohm line and the impedance of the antenna is matched to 50Ohm by the inset feed.

![Diagram of antenna](image)

*Figure 41: Port number has been assigned in order to give an excitation.*

Now the stage has come to setup the excitation. The port that is already numbered is taken in to consideration for the excitation. Then we next come to the simulation as the antenna has to be meshed up with the Method of Moment (MoM) calculation.

The centre frequency for this design is taken to be 2.1GHz, so for the MoM the maximum frequency is given as 3GHz i.e. the range of the frequency is given as 1 to 3Hz, and 30 cells per wavelength(CPW) is selected which determines the density of the mesh.(Higher the number of the CPW, so is the simulation accuracy). In most of the simulations 20 to 30 CPW are used which said that they should provide enough accuracy.

The meshed antenna can be seen in the figure 42,
As now we have the excitation and the meshed antenna we can proceed for the simulation with the starting frequency as 2GHz and highest frequency as 3GHz, with the number of frequency = 200 i.e. the field is spaced evenly with 200 frequency points between the starting and the highest frequency.

But before we run the simulation we can have a look at the 3D structure of the meshed antenna with the simple Microstrip feed line in the figure 43

The simulation is run with the specifications that are mentioned above with an option of the ‘Adaptive Intelli-Fit’ ON, as this saves the time by not performing the simulation at all the points of the specified frequencies. [32]
The simulation is run and is completed which gives the S-Parameters of the simulated structure. The S-parameters can be seen in the appendix. The response of the S-Parameters can be seen below

![Return loss for the feed located.](image)

**Figure 44: Return loss for the feed located.**

We can observe from the above figure the return loss is -3.15dB at 2.1GHz. The negative return loss here depicts that the antenna have not many losses during the transmission.
As now we have simulated the structure and the response is shown, we shall study the radiation parameters. After this response from the range of the frequencies we can see that the operation point is at 2.1GHz for this design. The antenna is well matched to 50ohms at 2.1 GHz.

Table 6: The result after the simulation by the Zeland, IE3D.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>2.1 GHz</td>
</tr>
<tr>
<td>Incident Power</td>
<td>0.1 W</td>
</tr>
<tr>
<td>Input Power</td>
<td>0.00173 W</td>
</tr>
<tr>
<td>Radiated Power</td>
<td>0.000610 W</td>
</tr>
<tr>
<td>Radiation Efficiency</td>
<td>35.095 %</td>
</tr>
<tr>
<td>Antenna Efficiency</td>
<td>6.103 %</td>
</tr>
<tr>
<td>Directivity</td>
<td>8.742 dBi</td>
</tr>
<tr>
<td>Gain</td>
<td>2.402 dBi</td>
</tr>
<tr>
<td>3dB Beam Width</td>
<td>(46.8851, 64.2093) deg.</td>
</tr>
</tbody>
</table>
Now for the radiation pattern the antenna shall be simulated only at 2.1GHz, which is the operating frequency for this design of the patch antenna. Here we have a few different specifications than for the S-Parameters, as frequency at 2.1GHz CPW as 70 and giving new values for the Meshing Parameters. In the first step the current distribution along the antenna is being examined as shown in the figures 46(a) (b).

The average current density is shown in different colors. We can see the average current distribution on the surface of the antenna. As we can observe the current is in the range of -18 to -21 on the top edge, it is almost maximum at the centre and it is minimum at the edge of the feed line.

![3D view if the Current Distribution along the Rectangular Microstrip Patch antenna](image)

*Figure 46(a) (b): 3D view if the Current Distribution along the Rectangular Microstrip Patch antenna*
We now reach the stage where we are ready to start the pattern calculation. In order to perform the pattern calculation we here have some specifications as angle points (by default the IE3D takes 37) [32].

However the results that are inferred from the Microstrip line feed technique can be seen in the table 6.

Radiation Pattern Plots

There are certain things that are to be taken in to consideration as said before a screen shot is given about what happens before the software calculates the radiations pattern in the figure 47.

The patterns can be obtained after feeding the required fields of the radiation pattern has the following structure as shown in the figure 48.

![3D Pattern Selection](image)

**Figure 47: A screen shot of the required fields for the generation of the radiation pattern on IE3D.**

As the Microstrip Patch antenna radiates normal to its surface, the elevating pattern for the $\phi = 0$ and $\phi = 90$ degrees would be important. The figure 49 below shows the gain of the antenna at 2.1GHz for $\phi = 0$ and $\phi = 90$.

The radiation pattern in 3D is obtained as follows in the figure from the different angles on the different axis. We can observe the directivity on the left hand side of the figure 48. The two figures 48(a) (b) below shows the radiation pattern from different angles.
Figure 48(a) (b): 3D view of the radiation pattern of the 2.1GHz Rectangular Microstrip Patch Antenna
Now we compare the different designs of the Microstrip patch antenna with regards to their dimension parameters and results.
Table 7: Comparison between the different Designs with their responses and results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Design No 1. (Primary Design)</th>
<th>Design No 2 (Secondary Design)</th>
<th>Design No 3[34]</th>
<th>Design No 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of feed</td>
<td>Co Axial Probe Feed(SonnetLite Integration With Matlab)</td>
<td>Microstrip Line feed(IE3D)</td>
<td>Microstrip Line Feed</td>
<td>Co-axial Probe Feed</td>
</tr>
<tr>
<td>Height</td>
<td>1.5 mm</td>
<td>1.5 mm</td>
<td>1.59 mm</td>
<td>1.5 mm</td>
</tr>
<tr>
<td>Length</td>
<td>23 mm</td>
<td>23 mm</td>
<td>47 mm</td>
<td>22 mm</td>
</tr>
<tr>
<td>Width</td>
<td>30mm</td>
<td>30 mm</td>
<td>31 mm</td>
<td>29 mm</td>
</tr>
<tr>
<td>Resonance Frequency</td>
<td>2.1 GHz</td>
<td>2.1 GHz</td>
<td>2.1 GHz</td>
<td>1.9 GHz</td>
</tr>
<tr>
<td>Dielectric Constant</td>
<td>9.8(alumina)</td>
<td>9.8(alumina)</td>
<td>2.32</td>
<td>11.9(silica)</td>
</tr>
<tr>
<td>Loss Tangent</td>
<td>0.0001</td>
<td>0.0001</td>
<td>----</td>
<td>-----</td>
</tr>
<tr>
<td>Antenna Efficiency</td>
<td>6.103%</td>
<td>80.1%</td>
<td>42.77%</td>
<td>11.52%</td>
</tr>
<tr>
<td>Directivity</td>
<td>8.74 dBi</td>
<td>7.32 dBi</td>
<td>5.56 dBi</td>
<td>7.12 dBi</td>
</tr>
<tr>
<td>Return Loss</td>
<td>-21 dB</td>
<td>-3.1 dB</td>
<td>-16.2dB</td>
<td>-31.35 dB</td>
</tr>
<tr>
<td>Gain</td>
<td>5.31 dBi</td>
<td>6.35 dBi</td>
<td>1.87 dBi</td>
<td>3.26 dB</td>
</tr>
<tr>
<td>VSWR</td>
<td>1.1</td>
<td>1.8</td>
<td>1.02</td>
<td>1</td>
</tr>
</tbody>
</table>

As we can see in the above table 7 the results have been compared between different designs it is a good sign that the return loss value is a negative as it indicates that there is not much of losses during the transmission.

And the antenna efficiency is quiet low in some of the designs as we can see; the best efficiency is obtained by the design no.4, and next comes the thesis Design. We discuss about this in detail in the next chapter.
For the Design 1 considering both the Feed techniques the responses and the simulation, and the radiation patterns have been given in the previous chapter now let us see in brief the other Design’s responses, simulations and the radiation pattern (including Design 1).

**Return Loss**

![Return Loss for Design 1](image1.png)

**Figure 50: Return Loss for the Design1, at -3.1dB**

The return loss for the Design1 can be seen in the above figure 50 as -3.1dB, and for the Design2 is -16.2dB in the figure 51.

![Return Loss for Design 2](image2.png)

**Figure 51: Return loss for the Design2 at -16.2dB**
The Return loss for the designs 3 and 4 are in the figures 52 & 53 of -31.35dB and -10.2dB.

As we have seen the return loss for the 4 designs at different Frequencies, now let us have a look at the Radiation Pattern of the Designs in the following figures from the next page.
Firstly we shall have a look at the 3D figures of the Radiation patterns from all the designs that are compared in the table 7.

The four figures show the Radiation pattern from the Design 1 to 4 respectively.

Figure 54: The 3D radiation patterns of the Designs 1, 2, 3, 4 respectively.
Let us now go through the elevation pattern of all the designs simply to say the 2D figures of the radiation pattern.
The above figures 55(a) (b) (c) (d) show the radiation pattern of the different designs, as we observe the lobes design 1, 2 and 4 have no back or side lobes which represent the waste of energy during the transmission but the design 3 which has the return loss of -31.35dB has a back lobe which indicates undesirably has a loss of the energy during the transmission, however the design has the efficiency of 42.77% and the design2 has an efficiency of 80.1%. The current distribution of the four designs can be seen in the Appendix.IV
Chapter 4

Conclusion
4. Conclusion

The aim of this project is to design a rectangular patch Microstrip antenna and to study the responses and the radiation properties of the same. In this project an antenna has been designed with 2 different design parameters (Design1 & 2).

For the Design1 two different feed techniques were being adopted – Microstrip Feed technique and Co-axial feed technique and Microstrip Line feed for the Design2, Co-axial Feed for the Design3 and Microstrip feed line for Design4.

For the design1, an antenna has been designed with the dimensions as Length – 23mm, width – 30mm, height – 1.5mm, with a dielectric constant of 9.8(alumina), which has a loss tangent of 0.0001 at 2.1GHz.

For the design2 an antenna has been designed with the dimension parameters Length- 47mm, Width – 31mm, height – 1.59mm, with a dielectric constant 2.32 at 2.1GHz with Microstrip feed line at 2.1GHz.

And another 2 designs have been taken in to consideration to compare the responses, simulations, in fact the properties of the radiation patterns.

Designs 3&4 are being designed at a frequency of 1.9GHz and 2.1GHz.

As we observe the table7 which displays all the parameters and the results for each design. There are different dimensions, feed techniques, dielectric constant, and frequencies. Having gone through the results it happened to be a bit difficult to decide the optimized design of the antenna, as there are different aspects that are involved in the design of each antenna.

It is good to see that the return loss has a negative value in all the cases which states that the losses are minimum during the transmission. In the design the RL is -3.1dB in Microstrip feed line technique and -21dB in Coaxial feed technique. For the Design2 the return loss measured was -16.2dB and for the Design3 it is -31.5dB and finally, for the design4 RL is -10.2dB.

The VSWR for the design performed in the project has a good value of 1.1(co-axial Probe feed) and 1.8(Microstrip feed line) as we can say the level of mismatch is not so high. For the Design2,
3, and 4 has the value that was measured can be appreciated as were the most desired –> 1.02, 1 and 1 respectively.

When the antenna efficiency is compared the Design2 has the most desired efficiency of 80.1% followed by the Design3 with 42.77% followed by Design 4 and 1 with 11.52% and 6.103 respectively. With having the return loss $RL$ of -31.35dB for the Design3 it stands the second in the efficiency.

Taking all this in to consideration we can say that there are many aspects that affect the performance of the antenna. Dimensions, selection of the substrate, feed technique and also the Operating frequency can take their position in effecting the performance.

When the radiation patterns are considered from figure 55(a) (b) (c) (d) the Design3 having back lode indicating the wastage of energy during the transmission. And for the other designs we can say that the energy loss is very minimum with the $RL$ values of -21/3.1dB, -16.2dB and -10.2dB for the designs 1, 2 and 4 respectively.

By comparing all the responses and the patterns the Design2 can be said as the optimized design with an antenna efficiency of 80.1% from Table7.

A Microstrip Line fed Rectangular Microstrip Patch Antenna with the dimension parameters $h$-1.59mm, $L$- 47mm, $W$- 31mm with a dielectric constant of 2.32 at an operating frequency of 2.1GHz from this project can be said as the optimized design.
4.1 Future Suggestions

A Microstrip Line fed Rectangular Microstrip Patch Antenna with the dimension parameters $h=1.59\text{mm}$, $L=47\text{mm}$, $W=31\text{mm}$ with a dielectric constant of 2.32 at an operating frequency of 2.1GHz from this project can be said as the optimized design.

It is very important to take the feed technique the impedance and the substrate is the main parameters into consideration. The proper position to terminate the Feed line also affects the performance of the antenna. As said different type of feed technique affects the performance of the antenna. The difference between two feed techniques Co-axial feed and Microstrip feed line is shown in this thesis and the results implies the performance of the antenna.

In future other different type of feed techniques can be used to calculate the overall performance of the antenna without missing the optimized parameters in the action. Extensively and exclusively focusing on the area of different design methods especially in enhancing the impedance bandwidth, and the efficiency.
True Electromagnetic Antenna Design Using Sonnet

This program will take in your design specifications. (Goals, materials, etc.) After estimating the patch length, patch width, and probe placement, a Sonnet Project file is written, and Sonnet is called. Sonnet performs a true ELECTROMAGNETIC simulation on the design, and returns various performance parameters. Based on this data, the program alters the design and resubmits the project to Sonnet. This is repeated until the antenna is tuned to the correct frequency. Probe placement for tuning input impedance is performed in a similar manner. Extension of the code (by the user) to enable tuning of the patch width is encouraged.

NOTE: If you are using SonnetLite, the maximum memory usage allowed is 16MB.

INPUTS

Height = 0.05905 in

Permittivity = 9.8

Desired Input Impedance = 50 Ohms

Frequency = 2.1 GHz

Free Space Wavelength = 5.6217 in

INITIAL GUESSES

Initial Length = 0.87993 in

Initial Width = 1.2865 in

Initial Probe Offset = 0.34581 in

EXPECTED PERFORMANCE

Input Impedance = 49.9994 Ohms

2:1 VSWR Bandwidth = 0.53049 %

Commencing Patch Length Optimization

Simulation # 1

Patch Length = 0.83593 (in).

This project is expected to utilize 9 MB of Memory.

Electromagnetic Simulation Complete. Simulation took 74 seconds.

Resonance Frequency = 2.18 GHz.
Resonance Frequency Error = 3.8095 %

Simulation # 2

Patch Length = 0.92393 (in).

This project is expected to utilize 9 MB of Memory.

Electromagnetic Simulation Complete. Simulation took 88 seconds.

Resonance Frequency = 1.988 GHz.

Resonance Frequency Error = -5.3333 %

Simulation # 3

Patch Length = 0.8726 (in).

This project is expected to utilize 9 MB of Memory.

Electromagnetic Simulation Complete. Simulation took 61 seconds.

Resonance Frequency = 2.096 GHz.

Resonance Frequency Error = -0.19048 %

Simulation # 4

Patch Length = 0.87085 (in).

This project is expected to utilize 9 MB of Memory.

Electromagnetic Simulation Complete. Simulation took 74 seconds.

Resonance Frequency = 2.099 GHz.

Resonance Frequency Error = -0.047619 %

Simulation # 5

Patch Length = 0.87042 (in).

This project is expected to utilize 9 MB of Memory.

Electromagnetic Simulation Complete. Simulation took 61 seconds.

Resonance Frequency = 2.1 GHz.

Resonance Frequency Error = 0 %
Patch Length Optimization Completed

R E P O R T

Patch Length = 0.87042 (in).
Patch Width = 1.2865 (in).
Probe Offset = 0.34208 (in).
Resonance Frequency = 2.1 GHz.
Resonance Frequency Error = 0 %
Input Impedance = 34.5174 Ohms
Input Impedance Error = 30.9651 %
VSWR 2:1 Bandwidth = 0.42857

Commencing Probe Position Optimization

Simulation # 6

Probe Position = 0.39169 (in).
This project is expected to utilize 9 MB of Memory.
Electromagnetic Simulation Complete. Simulation took 76 seconds.
Real(Zin) = 7.4053 (Ohm).
Zin Error = -85.1894 %

Simulation # 7

Probe Position = 0.34817 (in).
This project is expected to utilize 8 MB of Memory.
Electromagnetic Simulation Complete. Simulation took 61 seconds.
Real(Zin) = 28.8522 (Ohm).
Zin Error = -42.2956 %

Simulation # 8

Probe Position = 0.30465 (in).
This project is expected to utilize 9 MB of Memory.
Electromagnetic Simulation Complete. Simulation took 89 seconds.

Real (Zin) = 58.8634 (Ohm).

Zin Error = 17.7267 %

Simulation # 9

Probe Position = 0.3175 (in).

This project is expected to utilize 9 MB of Memory.

Electromagnetic Simulation Complete. Simulation took 92 seconds.

Real(Zin) = 45.5861 (Ohm).

Zin Error = -8.8279 %

Simulation # 10

Probe Position = 0.31323 (in).

This project is expected to utilize 9 MB of Memory.

Electromagnetic Simulation Complete. Simulation took 76 seconds.

Real(Zin) = 52.7024 (Ohm).

Zin Error = 5.4047 %

Simulation # 11

Probe Position = 0.31485 (in).

This project is expected to utilize 9 MB of Memory.

Electromagnetic Simulation Complete. Simulation took 90 seconds.

Real(Zin) = 45.5861 (Ohm).

Zin Error = -8.8279 %

Probe Position Optimization Completed

REPORT

Patch Length = 0.87042 (in).

Patch Width = 1.2865 (in).

Probe Offset = 0.31485 (in).

Resonance Frequency = 2.101 GHz.
Input Impedance Approximately = 45.5861 Ohms
Maximum Input Impedance Error = 8.8279 %
VSWR 2:1 Bandwidth = 0.66635

Simulation # 12
Patch Length = 0.8269 (in).
This project is expected to utilize 9 MB of Memory.
Electromagnetic Simulation Complete. Simulation took 110 seconds.
Resonance Frequency = 2.202 GHz.
Resonance Frequency Error = 4.8571 %

Simulation # 13
Patch Length = 0.91394 (in).
This project is expected to utilize 9 MB of Memory.
Electromagnetic Simulation Complete. Simulation took 99 seconds.
Resonance Frequency = 2.008 GHz.
Resonance Frequency Error = -4.381 %

Simulation # 14
Patch Length = 0.87266 (in).
This project is expected to utilize 9 MB of Memory.
Electromagnetic Simulation Complete. Simulation took 117 seconds.
Resonance Frequency = 2.096 GHz.
Resonance Frequency Error = -0.19048 %

Simulation # 15
Patch Length = 0.87094 (in).
This project is expected to utilize 9 MB of Memory.
Electromagnetic Simulation Complete. Simulation took 134 seconds.
Resonance Frequency = 2.1 GHz.
Resonance Frequency Error = 0 %
Patch Length Optimization Completed

R E P O R T

Patch Length = 0.87094 (in).
Patch Width = 1.2865 (in).
Probe Offset = 0.31504 (in).
Resonance Frequency = 2.1 GHz.
Resonance Frequency Error = 0 %
Input Impedance = 45.336 Ohms
Input Impedance Error = 9.328 %
VSWR 2:1 Bandwidth = 0.61905

Patch Antenna Design Completed in 1367.578 seconds on SonnetLite
Appendix II

In this section we can have a look at the Matlab Program[37] that is used in order to get the responses with the integration of SonnetLite.

The file SonnetAntennaDesignGUI.m is RUN

function varargout = SonnetAntennaDesignGUI(varargin)
    % SONNETANTENNADESIGNGUI M-file for SonnetAntennaDesignGUI.fig

    %-----------------------------------
    gui_Singleton = 1;
    gui_State = struct('gui_Name', mfilename, ...
     'gui_Singleton', gui_Singleton, ...
     'gui_OpeningFcn', @SonnetAntennaDesignGUI_OpeningFcn, ...
     'gui_OutputFcn', @SonnetAntennaDesignGUI_OutputFcn, ...
     'gui_LayoutrFn', [], ...
     'gui_Callback', []);
    if nargin & isstr(varargin{1})
      gui_State.gui_Callback = str2func(varargin{1});
    end
    if nargout
      [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
    else
      gui_mainfcn(gui_State, varargin{:});
    end
    % End initialization code - DO NOT EDIT

    % Choose default command line output for SonnetAntennaDesignGUI
    handles.output = hObject;
    % Update handles structure
    guidata(hObject, handles);
    if strcmp(get(hObject,'Visible'),'off')
      initialize_gui(hObject, handles);
    end
    % UIWAIT makes SonnetAntennaDesignGUI wait for user response (see UIRESUME)
    % ulawait(handles.figure1);

    % --- Outputs from this function are returned to the command line.
    function varargout = SonnetAntennaDesignGUI_OutputFcn(hObject, eventdata, handles)
        % hObject    handle to SonnetAntennaDesignGUI (see GCBO)
        % eventdata  reserved - to be defined in a future version of MATLAB
        % handles    structure with handles and user data (see GUIDATA)
    varargout{1} = handles.output;

    %-----------------------------------------------
    % --- Executes just before SonnetAntennaDesignGUI is made visible.
    function SonnetAntennaDesignGUI_OpeningFcn(hObject, eventdata, handles, varargin)
    % hObject    handle to figure
    % eventdata  reserved - to be defined in a future version of MATLAB
    % handles    structure with handles and user data (see GUIDATA)
    % varargin   command line arguments to SonnetAntennaDesignGUI (see VARARGIN)
    % Choose default command line output for SonnetAntennaDesignGUI
    handles.output = hObject;
    % Update handles structure
    guidata(hObject, handles);
    if strcmp(get(hObject,'Visible'),'off')
      initialize_gui(hObject, handles);
    end
    % UIWAIT makes SonnetAntennaDesignGUI wait for user response (see UIRESUME)
    % ulawait(handles.figure1);

    % --- Executes during object creation, after setting all properties.
    function Freq_CreateFcn(hObject, eventdata, handles)
        % hObject    handle to Freq (see GCBO)
        % eventdata  reserved - to be defined in a future version of MATLAB
        % handles    empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background, change
% 'usewhitebg' to 0 to use default. See ISPC and COMPUTER.
usewhitebg = 1;
if usewhitebg
    set(hObject,'BackgroundColor','white');
else
    set(hObject,'BackgroundColor',get(0,'defaultUicontrolBackgroundColor'));
end

function Freq_Callback(hObject, eventdata, handles)
% hObject    handle to Freq (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
    % Hints: get(hObject,'String') returns contents of Freq as text
    % str2double(get(hObject,'String')) returns contents of Freq as a double
    % Freq = str2double(get(hObject, 'String'));
    if isnan(Freq)
        set(hObject, 'String', '1');
        errordlg('Input must be a number','Error');
    end
    data = getappdata(gcaf, 'metricdata');
data.Freq = Freq;
setappdata(gcaf, 'metricdata', data);

*********** Permittivity **********************

% --- Executes during object creation, after setting all properties.
function Perm_CreateFcn(hObject, eventdata, handles)
% hObject    handle to Perm (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called
    % Hint: edit controls usually have a white background, change
    % 'usewhitebg' to 0 to use default. See ISPC and COMPUTER.
usewhitebg = 1;
if usewhitebg
    set(hObject,'BackgroundColor','white');
else
    set(hObject,'BackgroundColor',get(0,'defaultUicontrolBackgroundColor'));
end

function Perm_Callback(hObject, eventdata, handles)
% hObject    handle to Perm (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
    % Hints: get(hObject,'String') returns contents of Perm as text
    % str2double(get(hObject,'String')) returns contents of Perm as a double
    % Perm = str2double(get(hObject, 'String'));
    if isnan(Perm)
        set(hObject, 'String', 2);
        errordlg('Input must be a number','Error');
    end
    data = getappdata(gcaf, 'metricdata');
data.Perm = Perm;
setappdata(gcaf, 'metricdata', data);

%%%%%%%%%%%%%%%% Height ****************
% --- Executes during object creation, after setting all properties.
function Height_CreateFcn(hObject, eventdata, handles)
% hObject    handle to Height (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called
    % Hint: edit controls usually have a white background, change
    % 'usewhitebg' to 0 to use default. See ISPC and COMPUTER.
usewhitebg = 1;
if usewhitebg
    set(hObject,'BackgroundColor','white');
else
    set(hObject,'BackgroundColor',get(0,'defaultUicontrolBackgroundColor'));
end

function Height_Callback(hObject, eventdata, handles)
    % hObject    handle to Height (see GCBO)
    % eventdata  reserved - to be defined in a future version of MATLAB
    % handles    structure with handles and user data (see GUIDATA)
    % Hints: get(hObject,'String') returns contents of Height as text
    % str2double(get(hObject,'String')) returns contents of Height as a double
    Height = str2double(get(hObject, 'String'));
    if isnan(Height)
        set(hObject, 'String', 50);
        errordlg('Input must be a number','Error');
    end
    data = getappdata(gcbf, 'metricdata');
    data.Height = Height;
    setappdata(gcbf, 'metricdata', data);
end

% --- Executes during object creation, after setting all properties.
function Zin_CreateFcn(hObject, eventdata, handles)
    % hObject    handle to Zin (see GCBO)
    % eventdata  reserved - to be defined in a future version of MATLAB
    % handles    empty - handles not created until after all CreateFcns called
    % Hint: edit controls usually have a white background on Windows.
    % See ISPC and COMPUTER.
    if ispc
        set(hObject,'BackgroundColor','white');
    else
        set(hObject,'BackgroundColor',get(0,'defaultUicontrolBackgroundColor'));
    end
end

function Zin_Callback(hObject, eventdata, handles)
    % hObject    handle to Zin (see GCBO)
    % eventdata  reserved - to be defined in a future version of MATLAB
    % handles    structure with handles and user data (see GUIDATA)
    % Hints: get(hObject,'String') returns contents of Zin as text
    % str2double(get(hObject,'String')) returns contents of Zin as a double
    Zin = str2double(get(hObject, 'String'));
    if isnan(Zin)
        set(hObject, 'String', 50);
        errordlg('Input must be a number','Error');
    end
    data = getappdata(gcbf, 'metricdata');
    data.Zin = Zin;
    setappdata(gcbf, 'metricdata', data);
end

% --- Executes on button press in GenSim.
function GenSim_Callback(hObject, eventdata, handles)
    clc
    data = getappdata(gcbf, 'metricdata');
    GenerateSimulate(data.Freq, data.Zin, data.Height, data.Perm, data.LossTangentD, data.MetalCond, data.MetalThickness);
end

% --- Executes on button press in pushbutton2.
function pushbutton2_Callback(hObject, eventdata, handles)
    % hObject    handle to pushbutton2 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
initialize_gui(gcbf, handles);

function initialize_gui(fig_handle, handles)
data.Height = 50;
data.Freq = 1;
data.Perm = 2;
data.Zin = 50;
data.LossTangentD = 0.0013;
data.MetalCond = inf;
data.MetalThickness = 0.7;
setappdata(fig_handle, 'metricdata', data);
set(handles.Freq, 'String', data.Freq);
set(handles.Perm, 'String', data.Perm);
set(handles.Height, 'String', data.Height);
set(handles.Zin, 'String', data.Zin);
set(handles.MetalCond, 'String', data.MetalCond);
set(handles.MetalThickness, 'String', data.MetalThickness);
set(handles.LossTangentD, 'String', data.LossTangentD);

function MetalCond_Callback(hObject, eventdata, handles)
% hObject    handle to MetalCond (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of MetalCond as text
%        str2double(get(hObject,'String')) returns contents of MetalCond as a double
Metadata = str2double(get(hObject, 'String'));
if isnan(MetalCond)
    set(hObject, 'String', 50);
    errordlg('Input must be a number','Error');
end
data = getappdata(gcbf, 'metricdata');
data.MetalCond = MetalCond;
setappdata(gcbf, 'metricdata', data);

% --- Executes during object creation, after setting all properties.
function MetalCond_CreateFcn(hObject, eventdata, handles)
% hObject    handle to MetalCond (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc
    set(hObject,'BackgroundColor','white');
else
    set(hObject,'BackgroundColor',get(0,'defaultUicontrolBackgroundColor'));
end

function MetalThickness_Callback(hObject, eventdata, handles)
% hObject    handle to MetalThickness (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of MetalThickness as text
%        str2double(get(hObject,'String')) returns contents of MetalThickness as a double
Metadata = str2double(get(hObject, 'String'));
if isnan(MetalThickness)
    set(hObject, 'String', 50);
    errordlg('Input must be a number','Error');
end
data = getappdata(gcbf, 'metricdata');
data.MetalThickness = MetalThickness;
setappdata(gcbf, 'metricdata', data);

% --- Executes during object creation, after setting all properties.
function MetalThickness_CreateFcn(hObject, eventdata, handles)
function LossTangentD_Callback(hObject, eventdata, handles)
% hObject    handle to LossTangentD (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of LossTangentD as text
%       str2double(get(hObject,'String')) returns contents of LossTangentD as a double
LossTangentD = str2double(get(hObject, 'String'));
if isnan(LossTangentD)
    set(hObject, 'String', 50);
    errordlg('Input must be a number','Error');
end

data = getappdata(gcf, 'metricdata');
data.LossTangentD = LossTangentD;
setappdata(gcf, 'metricdata', data);

% hObject    handle to LossTangentD (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB

if ispc
    set(hObject,'BackgroundColor','white');
else
    set(hObject,'BackgroundColor',get(0,'defaultUicontrolBackgroundColor'));
end
Appendix III

In the chapter 3 the responses for the S Parameters and the radiation pattern were calculated, here in this Appendix we can have a look of the S-Parameters. 401 number of frequencies have been taken for the accurate results.

The 1st line is the s-parameter file name if it is available. !The 2nd line is the comment identifying the model. !Any line starts with exclamation is a comment of the file and it will be discarded in parsing. !Zeland Frequency-Dependent Lumped Model File !Zeland File Type Number Version Model Type 6830 12.00 1 !Model Type is a unique number to denote the type of equivalent circuit. !Model Type Name: I-Port RL in Series !Port Number is the s-parameters port number. Final Port Number is the equiv ckt port number. !Port Number Final Port Number Precise Model 1 1 1 !Warning: Please understand that an equivalent ckt is just a fitted model. It is based upon !your selection of the model you want to fit the s-parameters into. The values of !of the ckt elements may or may not have or match any physical meaning. ! !L, R and Q are also referenced as L(1,1), R(1,1) and Q(1,1).

<table>
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<th>Q</th>
<th>L(nH)</th>
<th>R(Ohm)</th>
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<td>-5.2400387506e+001</td>
<td>-1.6764354154e+000</td>
<td>4.0200343525e+000</td>
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<td>2.02500000e+000</td>
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<td>-1.6351296796e+000</td>
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<td>4.0361900773e+000</td>
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<tr>
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<td>-1.5528262149e+000</td>
<td>4.0492273957e+000</td>
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<td>4.0864463365e+000</td>
</tr>
</tbody>
</table>

! Q = Omega L / R

L, R and Q are also referenced as L(1,1), R(1,1) and Q(1,1).
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<th>y</th>
<th>z</th>
</tr>
</thead>
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Appendix IV

Current Distribution along the Patch Antenna

Figure 56: The current distribution of the Designs 1, 2, and 4.
References

7. “UHF antennas for space”, Antenna Development Corporation, Las Cruces, NM 88001. (06/05/2008).
34. MSc Thesis, “Design of a patch Antenna”, chapter 4, Internet source, Florida State University, as on 2009/01/10.