Micro-strip Patch Antenna Design

By

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Abstract

With the rapid evolution of mobile communications, broadband antennas for multisystem are in great need. The demand for small and mobile communication devices, especially the RFID, has grown rapidly. Devices having internal antenna is a trend and is required for such applications. But, antenna size is a major factor that limits device miniaturization. To decrease the size, antenna design is based on micro strip and can be embedded into the RFID tag. However, reducing antenna size generally degrades antenna performance. The advancement of the technology has given birth to a lot of mobile communication standards. The increasing demand for higher data rates continues in wireless technology enabling wireless data, voice, and video applications at multigigabit speeds has recently been attracting much interest in both academic and industry. Thus, the bandwidth of the antenna is very important for high data rate transmission.

Conventional micro strip antennas suffer from narrow bandwidth. Increasing frequency results in larger size. This is a challenge for this type of antenna. Make one better results in degrading the other. From other side, compact antenna is a need for portable mobile devices. These make researchers to improve the antenna's methods have been suggested for upgrading size and bandwidth of antenna. Increasing substrate thickness, using low dielectric substrate, using impedance matching and feeding techniques and using slot geometry in antennas are some methods for improvement of bandwidth and size. Our objective is to improve the bandwidth of the micro strip antenna while retaining other desired parameters. The stack and notch technique is used for this purpose.

In this research, the simulation is done using high frequency structural simulator (HFSS) software. An Antenna was designed at 2.4 GHz at HFSS. By changing the certain parameters like patch width, patch length and the air gap, increased bandwidth is obtained up to 250 MHz which is more than double the previous simple micro stripantenna.This technique also provides improved efficiency i-e 77.0712%, high gain 5.989 GHz and more diversity 7.943 dB which are much better than that of simple micro strip antenna.

1. *Introduction*

The aim of the research is to change certain parameters like patch width, patch length and the air gap and see how it affects the bandwidth. The scope is to enhance the bandwidth of the simulated antenna at resonant frequency of 2.4 GHz.

1.1. Basic Antenna

Antennaconverts electric signals into radio waves and vice versa. Traditional metallic antenna consists of conductors, electrically connected (through a transmission line) to the receiver or transmitter [1]. Applied current (oscillating) creates magnetic field(oscillating) around the antenna elements. These timevarying fields radiate away from the antenna into space as a moving transverse electromagnetic waves. Conversely, during reception, the electromagnetic waves of an incoming radio wave exert force on the electrons in the antenna elements causing them to move back and forth, creating oscillating currents in the antenna.

Antennas are designed to transmit and receive radio waves either in all horizontal directions equally called Omni-directional antennas or preferentially in a particular direction called directional or high gain antennas [1]. Antennas are essential components forradio communications. Antennas are used inradio broadcasting, broadcast television, radars, cell phones and satellite communications etc.

For performance measures, antennas are designed or selected for a particular application. Two major factors related to the design of antennas are the resonant point of an antenna or center operating frequency and the bandwidth of an antenna or the frequency range at where the antenna operates. Other important parameters that influence the performance of an antenna are Gain, Directivity, Radiation efficiency, Return loss and VSWR [1].

1.2. Resonant Frequency

Basically an antenna is a form of tuned circuit that constitutes inductance and capacitance. Consequently, it has a resonant frequency. Resonant frequency is a frequency at where the capacitive reactance and inductive reactance cancel-out each other. At this point where reactance cancel-out each other, the RF antenna becomes purely resistive [1]. The resistance is the combination of the loss resistance and the radiation resistance.

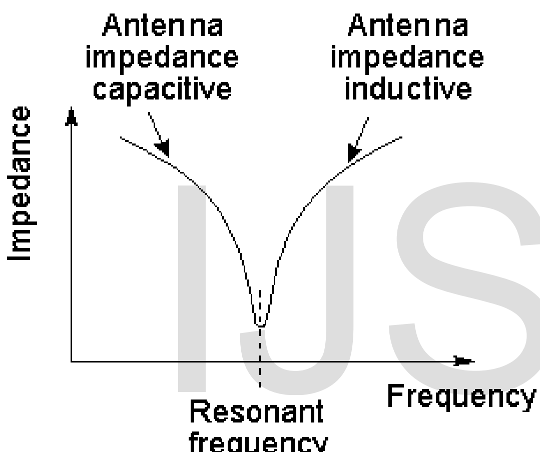


Figure: 1-1:Impedance of RF antenna with frequency

Physical properties and the environmental conditions determine the capacitance and inductance of RF antenna at where it is located. It is observed that larger the antenna elements, the lower the resonant frequency [1]. For example,antennas for UHF terrestrial television has relatively small elements while comparing with VHF broadcast FM has larger elements indicate a lower frequency.

1.3. Bandwidth

An antenna's bandwidth specifies the range of frequencies over which its performance does not suffer due to a poor impedance matching [1].

RF antennas are designed to operate around the resonant point. An Antenna can be operated efficiently over a limited bandwidth. If the antenna is operated outside its operating bandwidth range and the radio transmitter is not adequately protected then damage may occur.

For receiving purpose, the performance of the antenna is less critical in some respects. It can be operated outside its normal bandwidth without any fear of damage. However, it is important to ensure that the performance of the antenna design is optimum for best reception.

1.4.Gain

This parameter is used to measure the degree of directivity of radiation pattern of an Antenna. Antenna gain or power gain may be defined as, 'the ratio of radiation intensity in a given direction to the radiation intensity of an antenna radiated isotropic manners'. Gain is a dimension-less factor related to power and expressed in decibels [1].

Long range and better signal qualities are the advantages of high gain antennas but preferentially radiate in a particular direction. Low gain antenna has shorter range but the orientation of the antenna is relatively inconsequential. Gain is given as under [1].

$$\text{Gain} = \text{Efficiency} \times \text{Directivity}$$

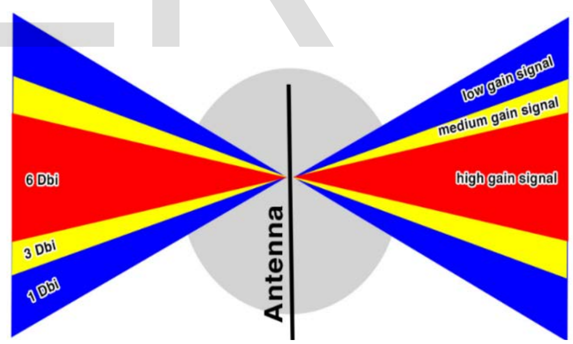


Figure: 1-2:Gain efficiency

1.5.Directivity

It is the ratio of radiation intensity in a given direction at where antenna has strongest emission to the radiation intensity averaged over all directions while the average radiation intensity is equal to the total power radiation by an antenna divided by 4π. The formula for directivity is given by [5];

$$D = U_{max}/U_o = 4\pi U_{max}/P_{rad}$$

Where **D** is the directivity (dimension less), $\mathbf{U_{max}}$ is radiation intensity (maximum) (Watt/solid angle), $\mathbf{U_o}$ is the isotropic radiation intensity (Watt/Solidangle). TheIsotropic antenna is a virtual antenna which radiates equally in all possible directions.

1.6.Radiation Efficiency

Radiation Efficiency is the ability of an antenna that how well an antenna converts accepted power to radiated power. An efficient antenna radiates most of the power received from transmission line.Radiation efficiency is the ratio of Radiation resistance to the sum of radiation resistance and loss resistance. Radiation resistance and loss resistances constitute the resistive part of an antenna. Power transferred from antenna is equalized by the radiation resistance while internal loss of the antenna is incorporated by the loss resistance, [1]

Efficiency = Radiation Resistance / (Radiation Resistance + Loss Resistance)

Radiation Efficiency often expressed as percentage or in dB. For example, an efficiency of 0.8 is 80% or -0.97dB.

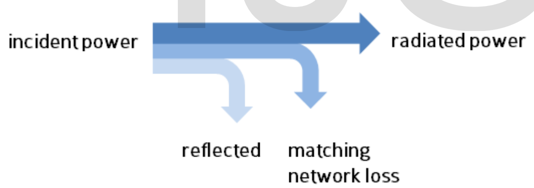


Figure: 1-3: Radiation Efficiency

1.7.Return Loss

The difference between forwarded power and reflected power is known as return losswhile measure of occurrence of electrical losses said to be antenna efficiency. It is represented in dB. Return loss is related to both standing wave ratio (SWR) and reflection coefficient (Γ) [1]. Increasing return loss corresponds to lower SWR. Return loss is a measure of how well devices or lines are matched. High return loss represents good matching. A high return loss results in a lower insertion loss. Return loss will be zero if all the power is reflected.

1.8.VSWR

Voltage Standing Wave Ratio (VSWR) is a measure of numerical description of how much the antenna is matched to transmission line connected to it.It is the ratio between peak amplitude and minimum amplitude of a standing wave along a transmission line [1].
The reflection coefficient **(Γ)** is the ratio of reflected voltage by incident voltage. The relation betweenReflection Coefficient and Impedances is [2],

$$\Gamma = \frac{Z_L - Z_S}{Z_L + Z_S}$$

Where $\mathbf{Z_L}$ is the load impedance, $\mathbf{Z_s}$ is the source impedance. When load is open circuit means $\mathbf{Z_L}$= infinity which lead to$\boldsymbol{\Gamma = 1}$. Similarly the when load is short circuited the $\mathbf{Z_{L=}0}$ leading to$\boldsymbol{\Gamma = -1}$. In case of perfectly matched condition, the load impedance $\mathbf{Z_{L}}$ is equal to the source impedance so that $\mathbf{Z_L=Z_s}$ which lead to $\boldsymbol{\Gamma = 0}$.

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

In case of perfectly matched antenna, $\Gamma = 0$, which lead to VSWR=1.

Closer the value of VSWR to 1, more matched the antenna is;

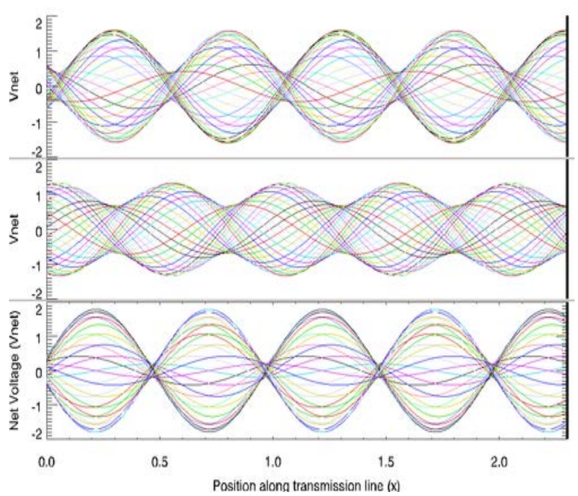


Figure: 1.4: **VSWR**

2. Fundamentals of Micro strip Patch Antenna

2.1. Micro strip Patch Antenna

In its most basic form, a Micro strip patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Figure 2.1. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate [2].

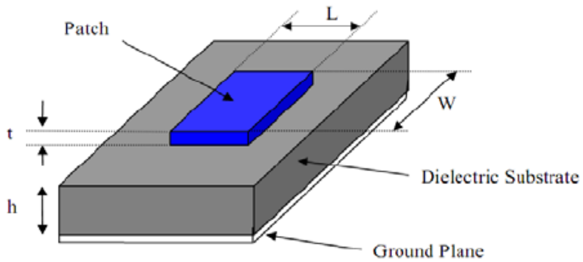


Figure 2.1: Structure of a Micro strip Patch Antenna

In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, elliptical or some other common shape as shown in Figure 2.2. For a rectangular patch, the length L of the patch is usually $0.3333\lambda_o<L<0.5\lambda_o$, where λ_o is the free-space wavelength. The patch is selected to be very thin such that $t<<\lambda_o$ (where t is the patch thickness). The height h of the dielectric substrate is usually $0.003\ \lambda_o \leq h \leq 0.05\lambda_o$. The dielectric constant of the substrate (ε_r) is typically in the range $2.2 \leq \varepsilon_r \leq 12$.

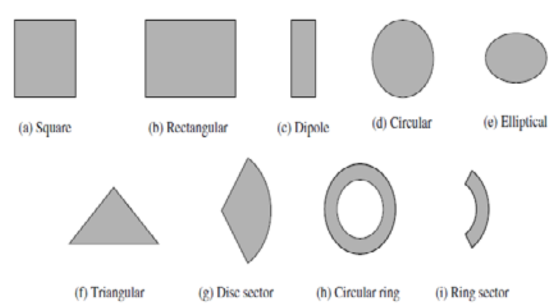


Figure 2.2: Common shapes of micro strip patch elements

Micro strip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. For good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable since this provides better efficiency, larger bandwidth and better radiation [3]. However, such a configuration leads to a larger antenna size. In order to design a compact Micro strip patch antenna, higher dielectric constants must be used which are less efficient and result in narrower bandwidth. Hence a compromise must be reached between antenna dimensions and antenna performance.

2.2. Advantages and dis-advantages

Micro-strip patch antennas are increasing in popularity for use in wireless applications due to their low-profile structure. Therefore they are extremely compatible for embedded antennas in handheld wireless devices such as cellular phones, pagers etc [3]The telemetry and communication antennas on missiles need to be thin and conformal and are often Micros-trip patch antennas. Another area where they have been used successfully is in Satellite communication. Some of their principal advantages are given below:

- Light weight and low volume.
- Low profile planar configuration which can be easily made conformal to host surface.
- Low fabrication cost, hence can be manufactured in large quantities.
- Supports both, linear as well as circular polarization.
- Can be easily integrated with microwave integrated circuits (MICs).
- Capable of dual and triple frequency operations.
- Mechanically robust when mounted on rigid surfaces.

Micro strip patch antennas suffer from a number of disadvantages as compared toconventional antennas. Some of their major disadvantages discussed are given below [4]:

- Narrow bandwidth
- Low efficiency
- Low Gain
- Extraneous radiation from feeds and junctions
- Poor end fire radiator except tapered slot antennas
- Low power handling capacity.
- Surface wave excitation

Micro strip patch antennas have a very high antenna quality factor (Q) [4]. Q represents thelosses associated with the antenna and a large Q leads to narrow bandwidth and low efficiency. Q can be reduced by increasing the thickness of the dielectric substrate. But as the thickness increases, an increasing fraction of the total power delivered by the source goes into a surface wave. This surface wave contribution can be counted as an unwanted power loss since it is ultimately scattered at the dielectric bends and causes degradation of the antenna characteristics. However, surface waves can be minimized by use of photonic bandgap structures as discussed by Qian et al [4]. Other problems such as lower gain and lower power handling capacity can be overcome by using an array configuration for the elements.

2.3. Feed Techniques

Micro strip patch antennas can be fed by a variety of methods. These methods can be classified into two categories- contacting and non-contacting. In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as a micro strip line. In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the micro strip line and the radiating patch [4]. The four most popular feed techniques used are the micro strip line, coaxial probe (both contacting schemes), aperture coupling and proximity coupling (both non-contacting schemes).

2.3.1. Micro-strip Line Feed

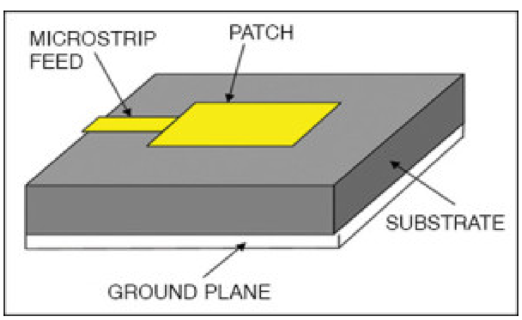


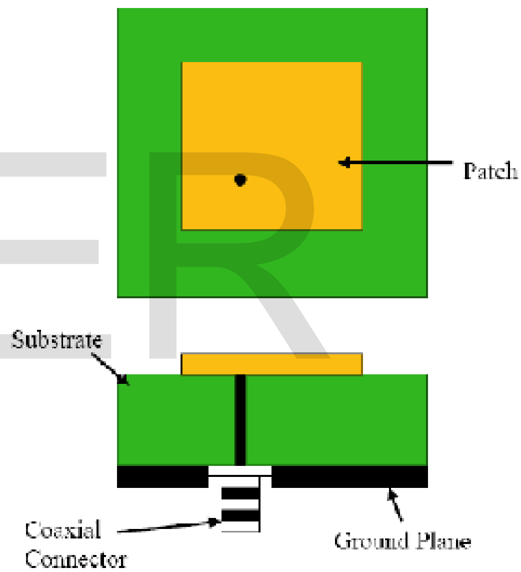
Figure 2.3: Micro strip Line Feed

In this type of feed technique, a conducting strip is connected directly to the edge of the micro strip patch as shown in Figure 2.3. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure.

The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. This is achieved by properly controlling the inset position. Hence this is an easy feeding scheme, since it provides ease of fabrication and simplicity in modeling as well as impedance matching. However as the thickness of the dielectric substrate being used, increases, surface waves and spurious feed radiation also increases, which hampers the bandwidth of the antenna [4]. The feed radiation also leads to undesired cross polarized radiation.

2.3.2. Coaxial Feed

The Coaxial feed or probe feed is a very common technique used for feeding Micro strip patch antennas [3]. As seen from Figure 2.4, the inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is



connected to the ground plane.

Figure 2.4: Probe fed Rectangular Micro strip Patch Antenna

The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance. This feed method is easy to fabricate and has low spurious radiation. However, its major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates ($h > 0.02\lambda_o$). Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems [4].

It is seen above that for a thick dielectric substrate, which provides broad bandwidth, the micro strip line feed and the coaxial feed suffer from numerous disadvantages. The non-contacting feed techniques which have been discussed below, solve these problems.

2.3.3. Aperture Coupled Feed

In this type of feed technique, the radiating patch and the micro strip feed line are separated by the ground plane as shown in Figure 3.5. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane [4].

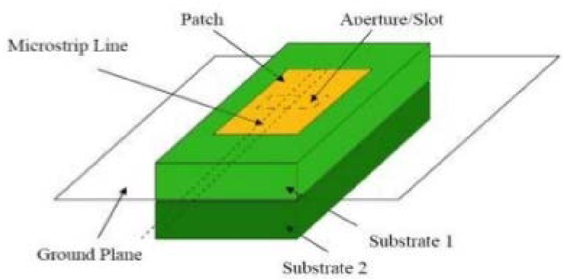


Figure 2.5: Aperture-coupled feed

The coupling aperture is usually centered under the patch, leading to lower cross-polarization due to symmetry of the configuration. The amount of coupling from the feed line to the patch is determined by the shape, size and location of the aperture. Since the ground plane separates the patch and the feed line, spurious radiation is minimized. Generally, a high dielectric material is used for the bottom substrate and a thick, low dielectric constant material is used for the top substrate to optimize radiation from the patch [5]. The major disadvantage of this feed technique is that it is difficult to fabricate due to multiple layers, which also increases the antenna thickness. This feeding scheme also provides narrow bandwidth.

2.3.4. Proximity Coupled Feed

In this type of feed technique, the radiating patch and the micro strip feed line are separated by the ground plane as shown in Figure 3.5. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane [6].

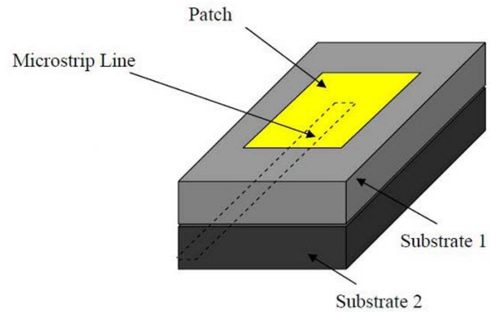


Figure 2.6: Proximity-coupled Feed

Matching can be achieved by controlling the length of the feed line and the width-to-line ratio of the patch. The major disadvantage of this feed scheme is that it is difficult to fabricate because of the two dielectric layers which need proper alignment. Also, there is an increase in the overall thickness of the antenna.

Characteristics	Micro strip Line Feed	Coaxial Feed	Aperture coupled Feed	Proximity coupled Feed
Spurious feed radiation	More	More	Less	Minimum
Reliability	Better	Poor due to soldering	Good	Good
Ease of fabrication	Easy	Soldering and drilling needed	Alignment required	Alignment required
Impedance Matching	Easy	Easy	Easy	Easy
Bandwidth (achieved with impedance matching)	2-5%	2-5%	2-5%	13%

Table 2.1: Characteristics of different feed techniques [4].

2.4. Methods of Analysis

The most popular models for the analysis of Micro strip patch antennas are the transmission line model, cavity model, and full wave model [5] (which include primarily integral equations/Moment Method). The transmission line model is the simplest of all and it gives good physical insight but it is less accurate. The cavity model is more accurate and gives good physical insight but is complex in nature. The full wave models are extremely accurate, versatile and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements and coupling. These give less insight as compared to the two models mentioned above and are far more complex in nature.

2.4.1. Transmission Line Model

This model represents the micro strip antenna by two slots of width *W* and height *h*, separated by a transmission line of length L. The micro strip is essentially a nonhomogeneous line of two dielectrics, typically the substrate and air.

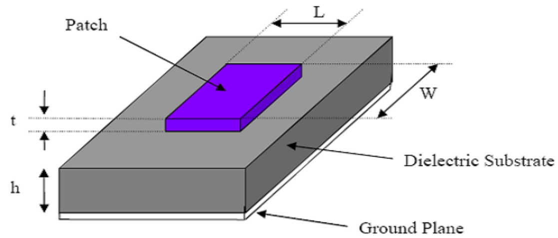


Figure 2.7: Micro strip Line

Hence, as seen from Figure 3.8, most of the electric field lines reside in the substrate and parts of some lines in air. As a result, this transmission line cannot support pure transverse-electric-magnetic (TEM) mode of transmission, since the phase velocities would be different in the air and the substrate.

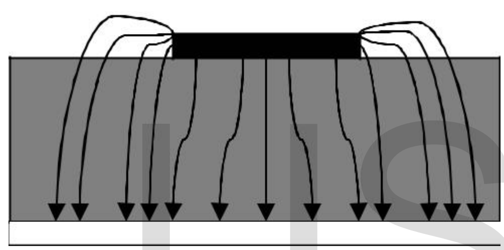


Figure 2.8: Electric Field Lines

Instead, the dominant mode of propagation would be the quasi-TEM mode. Hence, an effective dielectric constant (ε_{reff}) must be obtained in order to account for the fringing and the wave propagation in the line. The value of ε_{reff} is slightly less thenε_r because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in the air as shown in Figure 3.8 above. The expression for ε_{reff} is given by Balanis [1] as:

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

Where ε_{reff} = Effective dielectric constant

ε_r = Dielectric constant of substrate

h = Height of dielectric substrate

W = Width of the patch

Consider Figure 2.9 below, which shows a rectangular micro strip patch antenna of length *L*, width *W* resting on a substrate of height *h* . The co-ordinate axis is selected such that the length is along the *x* direction, width is along the *y* direction and the height is along the *z* direction.

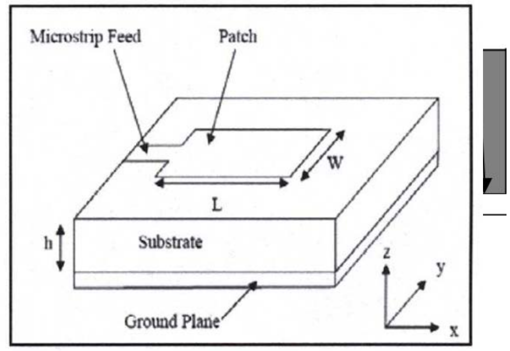


Figure 2.9: Micro strip Patch Antenna

In order to operate in the fundamental TM_{10} mode, the length of the patch must be slightly less than λ / 2 where λ is the wavelength in the dielectric medium and is equal to [7]

$$\lambda_o / \sqrt{\varepsilon_{reff}}$$

Where,$\lambda_o$is the free space wavelength. TheTM_{10}mode implies that the field varieson λ / 2 cycle along the length, and there is no variation along the width of the patch [7]. In the Figure 3.10 shown below, the micro strip patch antenna is represented by two slots, separated by a transmission line of length L and open circuited at both the ends. Along the width of the patch, the voltage is maximum and current is minimum due to the open ends. The fields at the edges can be resolved into normal and tangential components with respect to the ground plane.

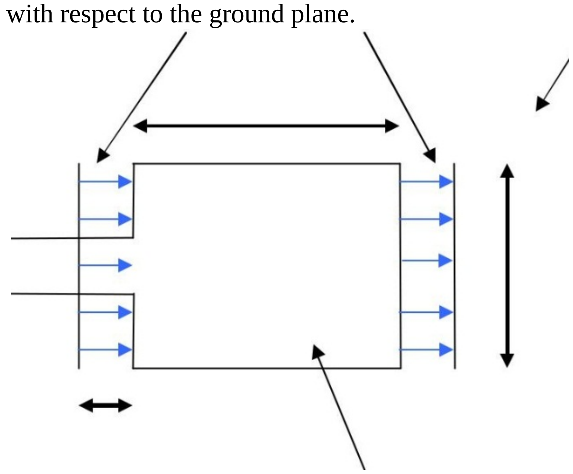


Figure 2.10: Top View of Antenna

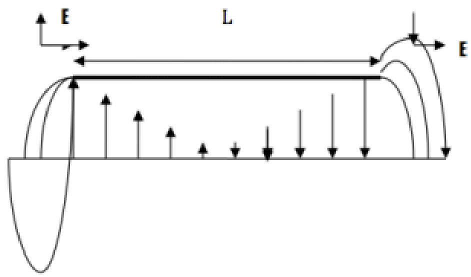


Figure 2.11: Side View of Antenna

It is seen from Figure 3.11 that the normal components of the electric field at the two edges along the width are in opposite directions and thus out of phase since the patch is $\lambda / 2$ long and hence they cancel each other in the broadside direction. The tangential components (seen in Figure 3.11), which are in phase, means that the resulting fields combine to give maximum radiated field normal to the surface of the structure. Hence the edges along the width can be represented as two radiating slots, which are $\lambda / 2$ apart and excited in phase and radiating in the half space above the ground plane. The fringing fields along the width can be modeled as radiating slots and electrically the patch of the micro strip antenna looks greater than its physical dimensions.

2.4.2. Cavity Model

Although the transmission line model discussed in the previous section is easy to use, it has some inherent disadvantages. Specifically, it is useful for patches of rectangular design and it ignores field variations along the radiating edges [8]. These disadvantages can be overcome by using the cavity model. A brief overview of this model is given below.

In this model, the interior region of the dielectric substrate is modeled as a cavity bounded by electric walls on the top and bottom. The basis for this assumption is the following observations for thin substrates ($h<<\lambda$) [10].

- Since the substrate is thin, the fields in the interior region do not vary much in the *z* direction, i.e. normal to the patch.
- The electric field is z directed only, and the magnetic field has only the transverse components H x and H y in the region bounded by the patch metallization and the ground plane. This observation provides for the electric walls at the top and the bottom [9].

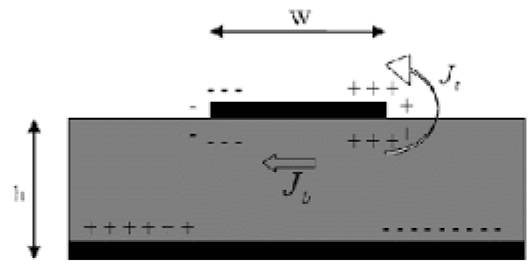


Figure 2.12: Charge distribution and current density creation on the micro strip patch

Consider Figure 2.12 shown above. When the micro strip patch is provided power, a charge distribution is seen on the upper and lower surfaces of the patch and at the bottom of the ground plane. This charge distribution is controlled by two mechanisms-an attractive mechanism and a repulsive mechanism as discussed by Suvidya [11]. The attractive mechanism is between the opposite charges on the bottom side of the patch and the ground plane, which helps in keeping the charge concentration intact at the bottom of the patch. The repulsive mechanism is between the like charges on the bottom surface of the patch, which causes pushing of some charges from the bottom, to the top of the patch. As a result of this charge movement, currents flow at the top and bottom surface of the patch. The cavity model assumes that the height to width ratio (i.e. height of substrate and width of the patch) is very small and as a result of this the attractive mechanism dominates and causes most of the charge concentration and the current to be below the patch surface. Much less current would flow on the top surface of the patch and as the height to width ratio further decreases, the current on the top surface of the patch would be almost equal to zero, which would not allow the creation of any tangential magnetic field components to the patch edges. Hence, the four sidewalls could be modeled as perfectly magnetic conducting surfaces. This implies that the magnetic fields and the electric field distribution beneath the patch would not be disturbed. However, in practice, a finite width to height ratio would be there and this would not make the tangential magnetic fields to be completely zero, but they being very small, the side walls could be approximated to be perfectly magnetic conducting [11].

Since the walls of the cavity, as well as the material within it are lossless, the cavity would not radiate and its input impedance would be purely reactive. Hence, in order to account for radiation and a loss mechanism, one must introduce a radiation resistance R_r and a loss resistance R_L . A loss cavity would now represent an antenna and the loss is taken into account by the effective loss tangent δ_{eff} which is given as:

$$\delta_{eff}=1/Q_T$$

$Q_T$is the total antenna quality factor and has been expressed by [11] in the form:

$$\frac{1}{Q_T}=\frac{1}{Q_d}+\frac{1}{Q_c}+\frac{1}{Q_r}$$

- $Q_d$represents the quality factor of the dielectric and is given as :

$$Q_d=\frac{\omega_r W_T}{P_d}=\frac{1}{\tan\delta}$$

where ω_r is the angular resonant frequency.

W_T is the total energy stored in the patch at resonance.

P_d is the dielectric loss.

$\tan\delta$ is the loss tangent of the dielectric.

- $Q_c$represents the quality factor of the conductor and is given as :

$$Q_c=\frac{\omega_r W_T}{P_c}=\frac{h}{\Delta}$$

where P_c is the conductor loss.

Δ is the skin depth of the conductor.

h is the height of the substrate.

- $Q_r$represents the quality factor for radiation and is given as:

$$Q_r=\frac{\omega_r W_T}{P_r}$$

where P_r is the power radiated from the patch.

Substituting equations (3.8), (3.9), (3.10) and (3.11) in equation (3.7), we get

$$\delta_{eff}=\tan\delta+\frac{\Delta}{h}+\frac{P_r}{\omega W_T}$$

Thus, equation (3.12) describes the total effective loss tangent for the micro strip patch antenna.

2.4.3. Full Wave Solutions-Method of Moments

One of the methods, that provide the full wave analysis for the micro strip patch antenna, is the Method of Moments. In this method, the surface currents are used to model the micro strip patch and the volume polarization currents are used to model the fields in the dielectric slab. It has been shown by H. Errifi and A. Badri [13] how an integral equation is obtained for these unknown currents and using the Method of Moments, these electric field integral equations are converted into matrix equations which can then be solved by various techniques of algebra to provide the result. A brief overview of the Moment Method described by Vikram and Sanjeev [14] is given below.

The basic form of the equation to be solved by the Method of Moment is:

$F(g)=h$ (3.13)

Where,F is a known linear operator, g is an unknown function, and h is the source or excitation function. The aim here is to find g , when F and h are known. The unknown functioncan be expanded as a linear combination of N terms to give:

$$g=\sum_{n=1}^{N} a_n g_n=a_1 g_1+a_2 g_2+\ldots\ldots+a_N g_N$$

wherea_n is an unknown constant and g_n is a known function usually called a basis or expansion function. Substituting equation (3.14) in (3.13) and using the linearity property of the operator F, we can write:

$$\sum_{n=1}^{N} a_n F(g_n) = h$$

The basic functions g_n must be selected in such a way, that each $F(g_n)$ in the above equation can be calculated. The unknown constants a_n cannot be determined directly because there are N unknowns, but only one equation. One method of finding these constants is the method of weighted residuals. In this method, a set of trial solutions is established with one or more variable parameters. The residuals are a measure of the difference between the trial solution and the true solution. The variable parameters are selected in a way which guarantees a best fit of the trial functions based on the minimization of the residuals.

From the antenna theory point of view, we can write the Electric field integral equation as:

$$E = f_e(J) \qquad (3.18)$$

Where, E is the known incident electric field.

J is the unknown induced current.

f_e is the linear operator.

The first step in the moment method solution process would be to expand J as a finite sum of basis function given as [14]:

$$J = \sum^{M} J_i b_i$$

where b_i is the ith basis function and J_i is an unknown coefficient. The second step involves the defining of a set of M linearly independent weighting functions, w_j. Taking the inner product on both sides and substituting equation (3.19) in equation (3.18) we get:

$$\langle w_j, E\rangle = \sum_{i=1}^{M} \langle w_j, f_e(J_i, b_i)\rangle$$

Where, j= 1,2,.....M

Writing in Matrix form as,

$$[Z_{ij}][J] = [E_j]$$

Where, $Z_{ij}=\langle w_j, f_e(b_i)\rangle$

$E_j=\langle w_j, H\rangle$

J is the current vector containing the unknown quantities.

The vector E contains the known incident field quantities and the terms of the Z matrix are functions of geometry. The unknown coefficients of the induced current are the terms of thevector. Using any of the algebraic schemes mentioned earlier, these equations can be solved to give the current and then the other parameters such as the scattered electric and magnetic fields can be calculated directly from the induced currents.

2.5. Literature review and state of the art

A triangular slot is introduced at the upper edge of the patch to reduce the resonant frequency. A small piece of triangular patch is added within the area of the triangular slot to improve the gain bandwidth performance of the antenna. The antenna size has been reduced by 46.2% when compared to a conventional square micro strip patch antenna with a maximum of 160MHz bandwidth and ¡27:36 dB return loss [5]. The characteristics of the designed structure are investigated by using MoM based electromagnetic solver, IE3D. The simple configuration and low profile nature of the proposed antenna leads to easy fabrication and make it suitable for the applications in Wireless communication system. Mainly it is developed to operate in the WiMax frequency range of 3.2 to 3.8 GHz.

A novel particle swarm optimization method based on IE3D was used to design an inset feed linearly polarized rectangular micro strip patch antenna with four element array. The length of the antenna is nearly half wavelength in the dielectric; it's a very critical parameter, which governs the resonant frequency of the antenna. In view of design, selection of the patch width and length are the major parameters along with the feed line depth [6]. Desired patch antenna design was simulated by IE3D simulator program. Initially antenna was set as a single patch and after evaluating the outcomes of antenna features; operation frequency, radiation patterns, reflected loss, efficiency and antenna gain, antenna was transformed to a 2x1 linear array. Finally, Antenna was analyzed the 4x1 linear antenna array to increase directivity, gain, efficiency and have better radiation patterns.
A rectangular micro strip patch array antenna at 2.4 GHz for wireless communications is designed and simulated by using Ansof/Ansys that provides a radiation pattern along a wide angle of beam and achieves a gain of 11.6 dBi and also made a comparison among the different substrates which

shows different results based on same parameters [7].

A dual band rectangular micro strip patch antenna along with the innovative meta material structure is proposed at a height of 3.2mm from the ground plane, which consists of a rectangular geometry incorporated with c shaped structure. Antenna is designed to resonate at 2.478GHz and 2.919 GHz frequency. The impedance bandwidth of the patch antenna along with the meta material structure at 2.478 GHz is improved by 20.4 MHz and return loss is reduced by 20.128dB. At 2.919GHz the impedance bandwidth is improved by 25.4MHz and return loss is reduced by 19.564dB [8]. For verifying that the proposed meta material structure possesses Negative values of Permeability and Permittivity within the operating frequency ranges, Nicolson-Ross-Weir method (NRW) has been employed. For simulation purpose CST-MWS Software has been used.

A micro strip patch antenna is composed of a trace of copper or any other metal of any geometry on one side of a standard printed circuit board (PCB) substrate with other side grounded. This antenna is using coaxial, strip line, aperture-coupling or proximity-coupling methods. The patch antennas are very useful because of their; low weight, ability to conform to any geometrical shape, easy integration with HMICs and MMICs, and low cost fabrication [9]. The current research focus is on the reconfigurable antennas. These can provide wide bandwidth performance; multi-band functionality; the frequencies and bandwidths can be reconfigured as well. The micro strip antennas are widely used in military, industrial and commercial sectors. Review of bandwidth enhancement techniques, multi-band and wideband reconfigurable antenna designs are presented.

E shaped micro strip patch antenna is designed using FR4-epoxy and epoxy-kevlar material. The permittivity of FR4-epoxy and epoxy-kevlar is 4.4 and 3.6 respectively. The return loss, radiation pattern & gain of the proposed antenna show that it has promising characteristics for various wireless communication applications [10]. The effects of changing the permittivity of the substrate is also studied. It is analyzed that how antenna performance varies while changing the value of dielectric constant. The proposed antenna is coaxially fed. The design is being simulated using HFSS (High Frequency Structure Simulator) software.

Circularly polarized antenna reduce the effect of multipath reflections, enhances weather penetration and allows for any orientation to the communication system. A single fed circularly polarized micro strip patch antenna that operates at 2.4 GHz. Compact symmetric slit square micro strip patch antennas are proposed for circularly polarized (CP) radiation [11]. A symmetric slit on a patch radiator is used for circularly polarized radiation with a compact size. Two slit shapes embedded along the four diagonal directions on the patch radiators are realized for compact circularly polarized.

A rectangular micro strip patch antenna design is consist of three layer substrate for ultra wide band (UWB) wireless communications system. The UWB antenna simply consists of a rectangular patch with micro strip line feeding and on three layer substrate. Where used substrate permittivity is 2.2, 2.33 and 4.4, that is placed on the ground plane. The rectangular micro strip patch antenna is simulated which covers the range of 6.9 to 8.7 GHz. Results are derived from the study of graph of return loss, input impedance, 2D radiation pattern and 3D radiation pattern [12].

A rectangular micro strip patch array antenna design and simulate by using HFSS software "An soft-High Frequency Structure Simulator" and compare the performance of 2 elements, 4 elements, 8 elements, and 16 elements patch arrays with that of a single patch for the same operating frequency [13]. Also comparisons are made between the performance of series, corporate and series-corporate feed network in terms of return loss, gain, and directivity and radiation pattern. Enhancement in gain, directivity and better return loss performance can be obtained by the use of RT-DURROID substrate because Low dielectric constant substrates are generally preferred for maximum radiation. Quarter wave transformer and power divider are used to feed the elements. These arrays are designed to operate at a frequency of 10 GHz. Goal is to obtain a high directivity with better gain and reduced losses, to be especially used for X band applications such as satellite communication, radar, medical applications, and other wireless systems.

A survey is conducted on commonly used techniques and design used in micro strip antenna papers which has been used for designing of an efficient, low profile, small, compatible, affordable micro strip antenna, mainly used to designed reconfigurable, multiband and wideband antennas, after that a initiator patch design is given with dimensions on which technique will be applied for the analysis of different parameter of antenna [14]. A novel ultra-wideband printed monopole antenna is used in wireless communication devices [15]. In wireless communications, dual or multiband antenna has been playing a key role for wireless service needs application. Micro strip patch antenna design with form of substrate, feed techniques and slots for UWB based system applications.

A 3x3 antenna array of rectangular topology is designed to operate at Ku Band [16]. The antenna has been designed as arrays of patches, where number of elements, spacing and feeding currents have been optimized to fulfill the requirements of low side lobe level and good cross polarization. The operating frequency of array is from 12 to 18 GHz. The antenna array has been designed and simulated on FR4 Substrate with dielectric constant of 4.4. The design is analyzed by FEM based HFSS 14.0 by which return loss, 3D polar plot, Directivity, VSWR and Gain of the antenna are computed. The software simulated results are shows that the proposed antenna array provides good performance in terms of return loss, VSWR and Gain.

Four rectangular micro strip antennas have been studied and analyzed. A rectangular patch which has six parallel slits of 5mmx37mm and then variation in length and width of those slits. Results are analyzed on two configurations, single layer and multilayer [17]. With single layer rectangular micro strip patch antennas dual band broadband antenna is obtained which has a maximum bandwidth of 15.13% with a gain of 4.7dBi with multilayer configuration.A multi frequency dual band broadband antenna (in comparison to single layer configuration) has four resonant frequencies and has maximum bandwidths of 27.08% with a gain of 5.69dBi. All four antennas are simulated in IE3D simulation software, and all Antennas are designed on FR4 substrate.

The difficult of antenna design increases when the number of operating frequency band increase and for miniaturization, the antenna must also be small enough to be placed inside the system. Line feed method is used to exited the patch antenna [18]. Antenna is operating at a resonant frequency of 2.45GHz, dielectric substrate (Rogers RT5870) with relative permittivity (=2.33) and thickness of 0.787mm, for applications such as IEEE 802.11 Wi-Fi, IEEE 802.15.1 Bluetooth, IEEE 802.15.4 Zig Bee, wireless USB, microwave oven, codeless phone etc. The simulation results of designed antennas indicate that the antenna fulfills the excellent requirements and characteristics for various frequency bands and showing the good radiation patterns and characteristics in the interested WLAN communication.

By employing the trial and error method to optimize the size and position of the PROSs, the reflection coefficient less than -10 dB at the Global Positioning System (GPS), Global System for Mobile communications (GSM), Wireless-Fidelity (Wi-Fi) and Worldwide Interoperability for Microwave Access (WiMAX) bands, can be achieved. To evaluate performance of the proposed structure, three antennas say Ant I (triple-band antenna), Ant II(triple-band antenna) and Ant III (four-band antenna) are designed [19].

The proposed antenna contains a substrate layer (FR-4 loss) with a dielectric constant of 4.4 and there is a circular patch on the upper layer of the substrate. The coaxial probe feed is used to excite the desired antenna which reduces the spurious radiation and hence obtained good efficiency. By using cavity model 20% excess bandwidth can be achieved while maintaining the lower size of the antenna [20]. An "E" shaped slot is introduced in the radiating patch to obtain dual band resonance frequency with maximum current distribution on the surface. Finally the simulated results using Computer Simulation Technology (CST) microwave studio 2009 in this design is compared with manual computation results which are found to be suitable for WLAN applications.

A rectangular microstrip patch antenna with EBG structure has been designed for wireless application and WIMAX. The patch antenna along with the Electromagnetic Band Gap structure is designed to resonate at 2.9 GHz [21]. Simulations and analysis has been carried out to verify the performance of Electromagnetic Band Gap structures in patch antenna. All the simulation work is done by using HFSS. It is observed that return loss and bandwidth have increased but the gain, directivity and efficiency shows good agreement.

Antenna size is a major factor that limits device miniaturization. To decrease the size, antenna design is based on micro strip and can be embedded into the RFID tag [22]. The increasing demand for higher data rates continues in wireless technology enabling wireless data, voice, and video applications at multi gigabit speeds has recently been attracting much interest in both academic and industry. Simulation is done by using the software Advanced Design System (ADS). The antenna is designed at 2.45GHz and a bandwidth of 110MHz is obtained. By changing the parameters like air gap, width of the patch and length of the patch using the same technique have been also simulated and provided a bandwidth of 250MHz which resonate at 2.4GHz.

The performance analysis of bandwidth enhancement of a monopole patch antenna with V-shaped slot for car-to-car and WLAN communications, omnidirectional wideband E-shaped cylindrical patch antennas, design of wideband/dual-band E-shaped patch antennas with the transmission line mode theory, patch size reduction of rectangular micro strip antennas by means of a cuboid ridge and micro strip rectangular patch antenna for S and X Band applications [23].

Micro strip patch antennas are used because of its low profile, small size, weight, cost, Performance, Ease of installation. These are also used in Satellite applications, space craft, aircraft, wireless applications such as WLAN, WiMAX, Wi-Fi and etc. The rectangular patch antenna is designed for C band application such as Wi-Fi and can be operated at the frequency of 5.4GHz [24]. The substrate material of the antenna is Rogers RT/ Duroid 5880(tm) and it has the relative permittivity of 2.2. Simulation is done by using HFSS 13.0 simulation software.

3. *Antenna Design*

The proposed antenna is designed in figure 4.1 which comprises of two patches;

- Lower rectangular patch (ground element)
- Upper Rectangular Patch (parasitic element)

The lower rectangular patch as a ground element and the upper rectangular patch as a parasitic element which is stacked by separating with an air gap. The circle at the center of the top view shows the feed point of the micro strip patch antenna. The below figure 4.1 shows the top view and side view of the designed micro strip patch antenna.

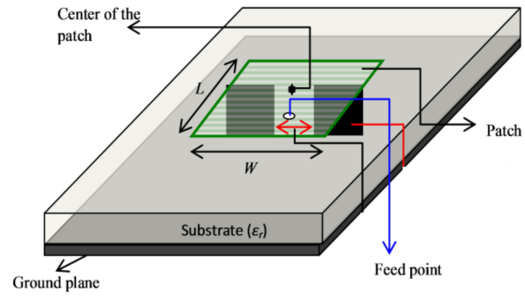


Figure 3.1: Micro Strip Patch Antenna Design

Various factors to be considered in the design include the following [16];

- Operating Frequency
- Bandwidth
- Equations for antenna design
- Substrate's Dielectric Constant
- Dielectric Substrate thickness
- Miscellaneous other parameters

3.1. Operating Frequency

The resonant frequency is controlled by the length (L) of the patch. There is a need to select the right frequency. Generally in the field of mobile communications, the frequency range used is from 1800 MHz to 1900 MHz. It is therefore considered appropriate to select the frequency which will fall between these ranges [16].

Mobile Systems Frequency Range
= 1800 – 1900 MHz
Selected Resonant Frequency
= 1.8 GHz

Similarly in wireless communication systems the frequency range is from 2300 MHz to 2500 MHz. Hence as selected above, the designed antenna should operate in this range.

Wireless Communication Systems Frequency Range = 2300 – 2500 MHz
Selected Resonant Frequency
= 2.450 GHz

Where,

L	=	Length of the Patch
W	=	Width of the Patch
fr	=	Resonant Frequency
εr	=	Permittivity of the Substrate
ξreff	=	Effective dielectric constant
h	=	Height

We know that when we increase the permittivity of the substrate to say four times, the length decreases by a factor of two. Hence in the antenna designs, the researchers generally use higher values of εr.

3.2. Bandwidth

Height "h" of the substrate controls the bandwidth. If the height is increased, as a result the bandwidth increases thus resulting in efficiency increase of the antenna. However it should be noted that when the height of the substrate is increased, it will result in the induction of the surface waves (travelling inside the substrate) and may get coupled with the other components thus affecting the antenna performance.

3.3. *Equations for antenna design*

The following equations will be used for our calculations. These relate to calculating the values/dimensions for the "Basic Single Layer Micro Strip Antenna" [19].

Dimension	Equation
Effective Permittivity	εref=εr+12+εr-12*11+12*hw ΔLh=0.412ξreff+0.3Wh+0.264ξr eff-0.258Wh+0.8
Patch Width	W=Co2fr2ξr+1 Where Co is the velocity of light
Effective Length	Leff=L+2ΔL
Patch Length	L=c2frξreff-2ΔLE

Table 3.1: Equations/Formulas

Low permittivity (4.4) is selected which is FR4 having the loss tangent value (dissipation factor) of 0.02 i.e. laminate base materials from which printed circuit boards (multilayer) are constructed. "FR" stands for "Flame Retardant" & woven glass reinforced epoxy resin is indicated by Manish Kansal [21].

Test/Specification	FR4 Laminate Typical Values
Thermal Stress, Solder bath 288 deg. C	>60
Dimensional Stability, E-2/150	<0.04% Warp/fill
	<1.00% Bow/Twist
Flammability, Classification UL94	V0
Water Absorption E-1/105	0.10%
Peel Strength After Thermal Stress	11 lb./in After 10s/288 Deg. C
Flexural Strength	100,000 lbf/in² Lengthwise
	75,000 lbf/in² Crosswise
Resistivity After Damp Heat Volume	10 ^8 M ohms cm
Resistivity After Damp Heat Surface	10 ^8 M ohms
Dielectric Breakdown. Parallel to laminate	>60KV
Dielectric Constant @ 1MHz	4.7
Dissipation Factor @ 1MHz	0.014
Q-Resonance @ 1 MHz	>75
Q-Resonance @ 50 MHz	>95
Arc Resistance	125 s
Glass Transition Temperature	135 Deg. C
Temperature Index	130 Deg. C
A Few Other Relevant Facts from other Sources	
Specific Gravity	1.8-1.9
Rockwell Hardness (M scale)	110
Coefficient of Thermal Expansion	11 microns/m/Deg.C Lengthwise
	15 microns/m/Deg.C Crosswise
Thermal Conductivity	2.2-2.5 cal/h. cm Deg C

Table 3.2: Data sheet (FR)

Following are some of the other parameter values used;

Loss Tangent (dissipation factor)
= 0.02
Copper Cladding (substrate thickness)
= 35µm
Connector SMA (Sub Miniature version A)
= 50 Ω
Note: The method used is of coaxial probe.

Dielectric Constant (ξr)
= 4.4

It should be noted that our main objective is also to reduce the size of the antenna. We are using a higher value of the dielectric constant because it will lead to reduced dimensions of the proposed antenna by Hazel Thomas [19].

3.4. Dielectric Substrate thickness

Thickness of dielectric substrate (h)
= 1.60 mm
Frequency (fr)
= 2.450 GHz
Dielectric Constant (ξr)
= 4.4

3.5. Miscellaneous other parameters

In our design we have used the following two radiating elements;

- Driven Patch
- Parasitic Patch

L1 - length of the driven patch
W1 - width of the driven patch
L2 - Length of the parasitic patch
W2 - Width of the parasitic patch
X1 - Width of the notch in driven patch
Y1 - height of the notch in driven patch
X2 - Width of the notch in parasitic patch
Y2 - height of the notch in parasitic patch
Let’s now look at the design & dimensions of the first antenna, Patch Antenna-1 (the one simulated by J. Vanitha – N. Augustia).

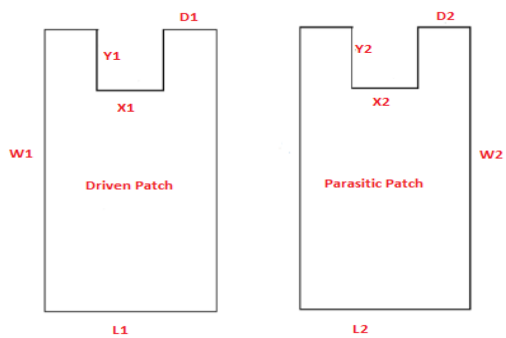


Figure 3.2: Patch dimensions of the micro strip patch antenna 01

	Parameter	Value (mm)
L1	Length of the driven patch	26
W1	Width of the driven patch	37.26
L2	Length of the parasitic patch	25.8
W2	Width of the parasitic patch	37.06
D1	Dimension	10.2
X1	Width of the notch in driven patch	5
Y1	Height of the notch in driven patch	4.86
D2	Dimension	10.1
X2	Width of the notch in parasitic patch	5.3
Y2	Height of the notch in parasitic patch	4.96

Table 3-3: The patch dimensions and other parameters of antenna 01

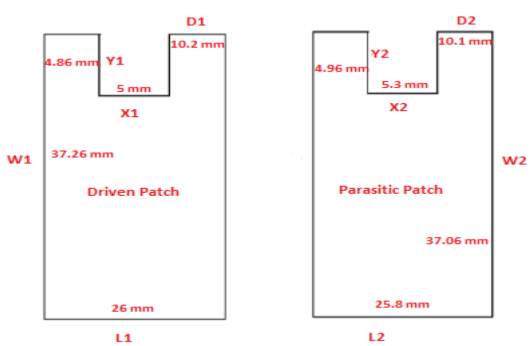


Figure 3.3: Patch Antenna -01, Dimensions

As we can note, the geometrical dimension of lower patch is 26 mm x 37.06 mm and that of the upper patch is 25.8 mm x 37.26 mm. The height of the antenna was increased by the researchers which; is a must for increasing the bandwidth.

In order to improve the bandwidth we designed a structure with two radiating elements, a driven patch and a parasitic patch. The driven patch is excited by using a coaxial feed. The coaxial feed used is 50omhs coaxial feed. The field thus generated by the driven patch is coupled with the parasitic patch to improve the overall bandwidth, directivity, gain and overall efficiency of the structure.

Our main aim is to improve the bandwidth further by designing and simulating a new antenna and by changing its various parameters to get a better bandwidth. For this we have to use the same substrate (stacked notch method) to come up with a second antenna (Antenna-2) and see if we can further improve the bandwidth.

Figure 3.4: Patch dimensions of the micro strip patch antenna 02

The air gap results in lowering the effective. The feeding method for this permittivity and also contributes to increase in the height of antenna which is essential to increase the bandwidth. After obtaining desired results we worked to improve the bandwidth further using the same substrate and same stacked notch method. We came up with another one different structure to achieve more bandwidth. The details of the first structure are shown in Table3.3 with reference to Figure 3.4The geometrical dimensions of the lower patch are 26.00mm X 37.06mm and of the upper patch are 25.80mm X 37.26mm. A rectangular notch is introduced in both the patches of different dimensions.

	Parameter	Value (mm)
L1	Length of the driven patch	27.01
W1	Width of the driven patch	36.34
L2	Length of the parasitic patch	31.27
W2	Width of the parasitic patch	35.90
D1	Dimension	10.2
X1	Width of the notch in driven patch	5
Y1	Height of the notch in driven patch	4.86
D2	Dimension	10.1
X2	Width of the notch in parasitic patch	6.38
Y2	Height of the notch in parasitic patch	5.92

Table 3.4: The patch dimensions and other parameters of antenna 02

Figure: 3.5: Patch Antenna-02, Dimensions

The slot results in meandering of surface currents thus, their paths are lengthened, while patch dimensions are fixed, and fundamental resonant frequency is decreased. Equally, with fixed operating frequency, a large amount of size reduction can be obtained.

The Figure 3.5 shows the patch dimensions of the micro strip patch antenna 2. While looking at the design of the second micro strip antenna (250 megahertz) various parameters have been changed. The 10 mm air gap is kept constant without any change. The thickness of both the patches substrate (FR4) is same i.e. 1.6mm. Following observations were made based on the changes in the design;

Resonating Frequency = 2.4 GHz
Bandwidth = 250 megahertz
(2.32 gigahertz to 2.57 gigahertz)
Gain = 5.989dB
Directivity = 7.943 dB
Efficiency = 77.012 %

4. *Design and Analysis*

4.1. Design Analysis

So we have with us the previously designed and simulated micro strip patch antenna (110 MHz). As we can see that in the micro strip antenna 1;

- Rectangular Notch was introduced (in both patches)
- Both the patches had different dimensions
- Feed point was in between the two patches (driven & parasitic)
- Geometric dimensions
    - o Lower Patch (LI x W2) = 26 mm x 37.06 mm
    - o Upper Patch (L2 x W1) = 25.8 mm x 37.26 mm
- Size of the antenna (L1 x W1) = 26 mm x 37.26 mm
- Antenna frequency = 2.45 GHz
- Bandwidth (obtained) = 110 MHz

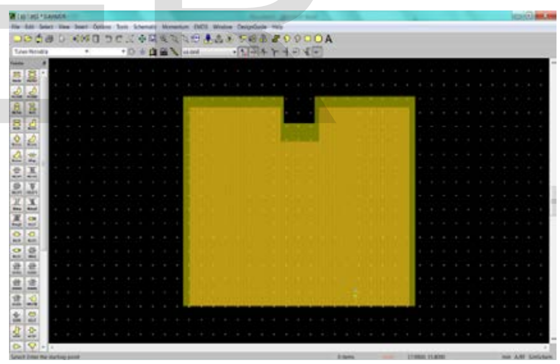


Figure 4.1: Micro Strip Patch Antenna

The total size of the antenna is 26mm x 37.26mm. It has two patches. The upper patch and lower patch are stacked together with a large air gap which is used to reduce the effect of the dielectric loss of the antenna material. The length and width of the lower patch is 26 mm and 37.06 mm respectively. The length and width of the upper patch is 25.8 mm and 37.26mm respectively. The antenna is designed at 2.45GHz and a bandwidth of 110MHz is obtained.

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The second proposed/developed antenna is shown below.

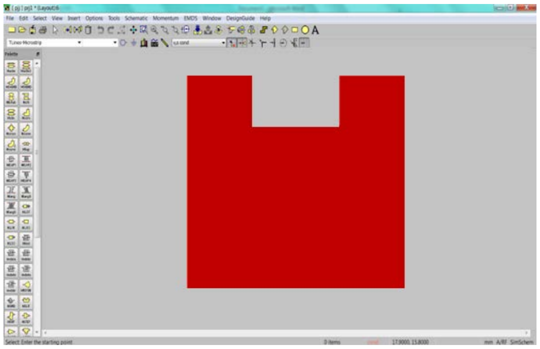

Figure 4.2: Micro Strip Patch Antenna 02

4.2. Return Loss

Return loss (dB) is defined as that the difference in dB between power sent towards antenna under test (AUT) and power reflected. The requirement for reflection coefficient for wireless devices is to be less than or equal to 10dB. The simulated return loss for the designed antenna 1 and antenna 2 is shown in Figure 6 and 7. At the operating frequency the return loss is less than 10dB. A frequency range of 0.1-3GHz is selected and 100 frequency points are selected over this range to obtain accurate results. The center frequency is selected as the one at which the return loss is minimum.

Selected Frequency Range = 0.10 to 3.0 GHz
Frequency points (for accuracy) = 100

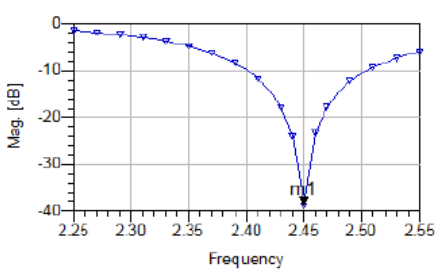

Figure 4.3: Return Loss Antenna-01

Noted values at "m1" are;
Frequency = 2.45 GHz
Return Loss = 38.875 dB

Now let's have a look at the return loss of the second antenna.

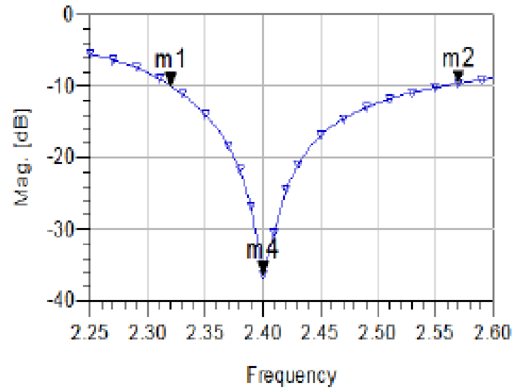

Figure 4.4: Return Loss Antenna-02

At "m1"

Frequency = 2.32 GHz
Return Loss = 9.981 dB

At "m2"
Frequency = 2.57 GHz
Return Loss = 9.602 dB

At "m4"
Frequency = 2.4 GHz
Return Loss = 36.301 dB

Here we observe that the return loss is maximum at 2.4 GHz. We are changing frequencies to come up with less loss and improved bandwidth. The change of parameters has resulted in an improved design.

4.3. Radiation Pattern

Since a micro-strip patch antenna radiates normal to its patch surface, the elevation pattern for φ = 0 and φ = 90 degrees would be important. Figure 8 below shows the gain, radiated power and effective area of the simulated antenna at the operating frequency 2.45GHz. The maximum gain is obtained in the broadside direction and this is measured to be 5.79dB and 6.735dB.

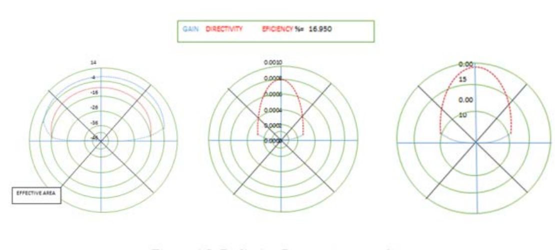

Figure 4.5: Radiation Pattern Antenna-01

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In case of first antenna;

Operating Frequency = 2.45 GHz
Maximum Gain = 5.79 dB & 6.735 dB
Efficiency = 16.95 %

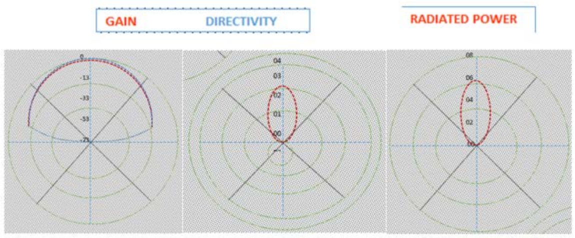


Figure 4.6: Radiation Pattern Antenna-02

In the case of second antenna;
Air Gap = 10 mm
Substrate Thickness (both patches) = 1.6 mm
Resonating Frequency = 2.4 GHz
Gain = 5.989 dB
Directivity = 7.943 dB
Efficiency = 77.0712 %
Bandwidth = 250MHz (2.32 GHz to 2.57 GHz)

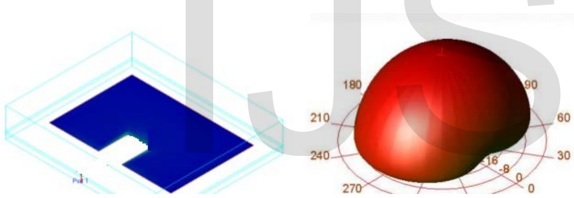


Figure 4.7: 3D View proposed antenna-02

Parameter	Simulated Results (Antenna 1)	Simulated Results (Antenna 2)
Resonating Frequency	2.45 GHz	2.45 GHz
Bandwidth	110 MHz	250 MHz
Gain	5.79 dB	5.989 dB
Frequency Range	2.4 – 2.51 GHz	2.32 – 2.57 GHz
Diversity	7.82 dB	7.943 dB
Efficiency	62.63 %	77.012 %

Table 4.1: shows the comparative analysis of both the antennas

Following are the research findings based on the simulated results;

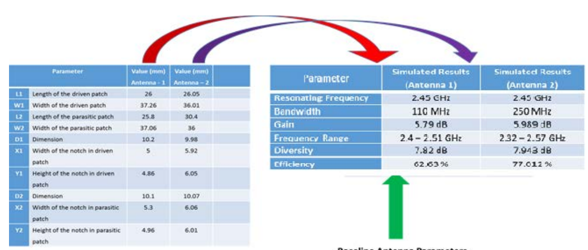
- Design and performance analysis of different structures of the micro strip patch antennas was done.
- Broadband characteristics were studied
- Improvement in the bandwidth is the prime outcome of this research work.
- Stacked/Notched technique was used.
- Efficiency improvement achieved.
- Gain improvement.
- Directivity improvement.
- The above achievements have been made without increasing the thickness of the structure.
- It is also noted that the stacking (in addition to the proposed air gap) has led to the reduction of the effective permittivity which has further leading to the increasing height of the antenna, thus improving the bandwidth.

4.4. Baseline Comparison

Following are the research findings based on the simulated results;

- Design and performance analysis of different structures of the micro strip patch antennas was done.
- Broadband characteristics were studied
- Improvement in the bandwidth is the prime outcome of this research work.
- Stacked/Notched technique was used.
- Efficiency improvement achieved.
- Gain improvement.
- Directivity improvement.
- The above achievements have been made without increasing the thickness of the structure.
- It is also noted that the stacking (in addition to the proposed air gap) has led to the reduction of the effective permittivity which has further leading to the increasing height of the antenna, thus improving the bandwidth.

The baseline comparison is shown below.



	Parameter	Value (mm) Antenna - 1	Value (mm) Antenna – 2
L1	Length of the driven patch	26	26.05
W1	Width of the driven patch	37.26	36.01
L2	Length of the parasitic patch	25.8	30.4
W2	Width of the parasitic patch	37.06	36
D1	Dimension	10.2	9.98
X1	Width of the notch in driven patch	5	5.92
Y1	Height of the notch in driven patch	4.86	6.05
D2	Dimension	10.1	10.07
X2	Width of the notch in parasitic patch	5.3	6.06
Y2	Height of the notch in parasitic patch	4.96	6.01

Parameter	Simulated Results (Antenna 1)	Simulated Results (Antenna 2)
Resonating Frequency	2.45 GHz	2.45 GHz
Bandwidth	110 MHz	250 MHz
Gain	5.79 dB	5.989 dB
Frequency Range	2.4 – 2.51 GHz	2.32 – 2.57 GHz
Diversity	7.82 dB	7.943 dB
Efficiency	62.63 %	77.012 %

Figure 4.8: Comparison with the baseline antenna

Conclusions

In the proposed work the design and performance of micro strip patch antenna of two different structures have been proposed which provide broadband characteristics. The significant improvement in the bandwidth is the main achievement of this proposed work. The stacked-notch technique is used to achieve this wideband. This technique also provides improved efficiency, along with gain and directivity as compared to a simple micro strip patch antenna.

Micro-strip patch antenna is designed and simulate on resonant frequency of 2.4 GHz by using HFSS simulating tool. Simulation is performed to obtain the higher bandwidth by varying patch width, patch length and air gap of micro-strips. Several parametric analyses at resonant frequencies of 2.4 GHz have been performed to get optimized results in terms of enhanced bandwidth.

The designed antenna presents much improved impedance bandwidth. Bandwidth efficiency of Antenna-2 is 250 MHz while for Antenna-1 is 110 MHz which is more than double the bandwidth efficiency of Antenna-1.

The improved gain of Antenna-2 is 5.989 GHz while the gain of Antenna-1 is 5.79 GHz. Similarly, the diversity is improved for Antenna-2 which is 7.943 dB while Antenna-1 has 7.82 dB.
Antenna-2 is much better in terms of efficiency which is 77.012%. In case of Antenna-1, the efficiency is only 62.63%.

The designed antenna presents much improved impedance bandwidth and directivity and larger gain. These improved parameters are achieved without much increase in the thickness of the structure. The stacking along with air gap reduces the effective permittivity while adding to the height of antenna, improves the bandwidth. The notch resulting in increased current path also adds to improvement in bandwidth.

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