A Project Report on

# A UWB slotted Microstrip Patch Antenna for 5G application

(A dissertation submitted in partial fulfilment of the requirements of Bachelor of Technology in Electronics & Communication Engineering of the West Bengal University of Technology, West Bengal)

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## Certificate of Approval

This is to certify that the project report on **"A UWB slotted Microstrip Patch Antenna for 5G application "** is a record of bonafide work, carried out by **Rajesh Haldar, Dhrubajyoti Biswas, Sukhamoy Roy, Abhijit Kirtania, Rajdeep Bhattacharjee, Akbar Ansari, Amit Mandal, Suvendu Mondal,** under my guidance and supervision.

In my opinion, the report in its present form is in conformity as specified by Global Institute of Management & Technology and as per regulations of the West Bengal University of Technology. To the best of my knowledge the results presented here are original in nature and worthy of incorporation in project report for the B.Tech. Program in Electronics & Communication in the academic year 2023-24.

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# Abstract

In this digital world of 5G communication system, high speed data and greater bandwidth are the common needs. The goal of this project is to design and analysis the Microstrip Patch Antenna which covers the Ultra-Wide Band in range of 35.492 to 26.649 GHz. This paper presents the design and optimization of a microstrip patch antenna for ultra-wideband applications in the 5G communication system. Initially a conventional rectangular patch antenna was created and after seven steps of modifications to the patch and the ground plane, an ultra-wideband bandwidth patch antenna is achieved .CST studio suite version 2023 is used to simulate the conventional rectangular patch antenna and the effects of each modification on the bandwidth, return loss, and gain of the antenna. The proposed miniaturized antenna shows a bandwidth of 8.855 GHz, a return loss of -30.002 dB at resonant frequency of 27.838 GHz, and acceptable gain of 5.247 dBi.

# Introduction

Ultra-wideband (UWB) antennas are essential components for wireless communication systems that require high speed data transmission and greater bandwidth. UWB antennas can operate over a wide range of frequencies, typically from 3.1 GHz to 10.6 GHz, as defined by the Federal Communications Commission (FCC) . However, with the development of the fifth-generation (5G) communication system, there is a need for UWB antennas that can cover higher frequency bands, such as the 25 to 36 GHz band, which is one of the potential candidates for 5G applications .

Microstrip patch antennas are attractive candidates for UWB applications due to their advantages of low profile, light weight, easy fabrication, and integration with other microwave circuits . However, conventional microstrip patch antennas have inherent drawbacks of narrow bandwidth, low gain, and poor radiation efficiency . Therefore, various techniques have been proposed to enhance the performance of microstrip patch antennas for UWB applications, such as using different feeding methods, substrate materials, patch shapes, and slotting techniques .

The main challenge in designing a microstrip patch antenna for UWB applications is to achieve a wide bandwidth, which is usually limited by the narrow resonant behaviour of the patch. Several methods have been proposed to overcome this limitation, such as using multiple resonators, parasitic elements, metamaterials, defected ground structures, etc. However, these methods often increase the complexity and size of the antenna, and may introduce undesired effects such as spurious radiation, mutual coupling, and dispersion. Therefore, a simple and effective method to enhance the bandwidth of the patch antenna is to introduce slots in the patch and/or the ground plane. The slots can modify the current distribution and the resonant modes of the patch, and create multiple resonances that can be merged into a wide band. The slots can also improve the impedance matching and the radiation characteristics of the antenna. The shape, size, and position of the slots can be optimized to achieve the desired performance.

In this paper, slotting technique is used to design and optimize a microstrip patch antenna for UWB applications in the 5G communication system. Initially a conventional rectangular patch antenna is created at resonant frequency of 27.132 GHz in step one with return loss of-15.38 dB and perform seven steps of modifications to the patch and the ground plane, using different slotting techniques and metal pics. We use a full-wave electromagnetic simulator to analyse the effects of each modification on the bandwidth, return loss, and gain of the antenna. By introducing a four-step staircase slot in the patch, two rectangular slots at two sides of the patch, a H-shape in the ground plane, another slot at both side of the feedline, and a circle in the feedline, results in an UWB antenna with a bandwidth of 8.855 GHz, a return loss of -30.002 dB at 27.838 GHz, and a gain of 5.677 dBi. Compare the performance of the proposed antenna with the conventional rectangular patch antenna and other existing UWB antennas in the literature is done. The proposed antenna can be used for various wireless communication systems that require UWB operation. The design and simulation of the antenna is carried out using CST microwave Studio simulation software. This is a simulation based study.

# Chapter 1

## MICROSTRIP PATCH ANTENNA

### 1.1. Aim

The aim of this paper is to design an inset fed rectangular Microstrip Patch Antenna and study the effect of antenna dimensions Length (L), Width (W) and substrate parameters relative Dielectric constant ($\varepsilon r$), substrate thickness (t) on the Radiation parameters of Bandwidth and Beam-width and optimize a microstrip patch antenna for ultra-wideband applications in the 5G communication system. We use different slotting techniques and metal pics to modify the patch and the ground plane, and analyse the effects on the bandwidth, return loss, and gain of the antenna. We show that we can achieve an ultra-wideband antenna with a bandwidth of 8.855 GHz, a return loss of -30.002 dB at 27.838 GHz, and a gain of 5.677 dBi. We also compare and validate the performance of the proposed antenna with other existing antennas in the literature.

### 1.2. Antenna

An antenna changes radio signals in the air into electricity, or vice versa. Antennas send signals, receive signals, or both. All NETGEAR wireless devices have an antenna, either a visible pole on the outside, or inside where you do not see it. The distance that an antenna sends (transmits) depends on the type, and the amount of power running through it.

### 1.3. Antenna Characteristics

An antenna is a device that is made to efficiently radiate and receive radiated electromagnetic waves. There are several important antenna characteristics that should be considered when choosing an antenna for your application as follows:

- Antenna radiation patterns
- Power Gain
- Gain
- Polarization

### 1.4. Overview of Microstrip Antenna

A microstrip antenna is a type of antenna that is fabricated using photolithographic techniques on a printed circuit board (PCB). It consists of a metallic patch of various shapes on the surface of a dielectric substrate, with a metal foil ground plane on the opposite side of the board. The patch is usually fed by a microstrip line, a coaxial probe, or a coplanar waveguide. The patch radiates due to the fringing fields at the edges of the patch, which form a slot antenna with the ground plane. The radiation pattern of the patch antenna is typically broadside, with a low cross-polarization level. The input impedance of the patch antenna depends on the shape, size, and position of the patch, as well as the substrate material and thickness. The resonant frequency of the patch antenna is determined by the effective length of the patch, which is slightly larger than the physical length due to the fringing effect. The bandwidth of the patch antenna is inversely proportional to the quality factor of the patch, which is affected by the substrate dielectric constant and thickness, as well as the feeding method. The gain and efficiency of the patch antenna are related to the radiation resistance, the ohmic losses, and the surface waves [1].

Microstrip antennas have become very popular in recent decades due to their thin planar profile which can be incorporated into the surfaces of consumer products, aircraft and missiles; their ease of fabrication using printed circuit techniques; the ease of integrating the antenna on the same board with the rest of the circuit, and the possibility of adding active devices such as microwave integrated circuits to the antenna itself to make active antennas [2]. However, microstrip antennas also have some disadvantages, such as low power handling, low bandwidth, low gain, poor efficiency, and susceptibility to interference and multipath effects [3].

The main challenge in designing a microstrip antenna for UWB applications is to achieve a wide bandwidth, which is usually limited by the narrow resonant behaviour of the patch. Several methods have been proposed to overcome this limitation, such as using multiple resonators, parasitic elements, metamaterials, defected ground structures, etc. However, these methods often increase the complexity and size of the antenna, and may introduce undesired effects such as spurious radiation, mutual coupling, and dispersion. Therefore, a simple and effective method to enhance the bandwidth of the patch antenna is to introduce slots in the patch and/or the ground plane. The slots can modify the current distribution and the resonant modes of the patch, and create multiple resonances that can be merged into a wide band. The slots can also improve the impedance matching and the radiation characteristics of the antenna. The shape, size, and position of the slots can be optimized to achieve the desired performance.

## 1.5. Microstrip Patch Antenna

Microstrip antennas are attractive due to their light weight, conformability and low cost. These antennas can be integrated with printed strip-line feed networks and active devices. This is a relatively new area of antenna engineering. The radiation properties of micro strip structures have been known since the mid 1950's. The application of this type of antennas started in early 1970's when conformal antennas were required for missiles. Rectangular and circular micro strip resonant patches have been used extensively in a variety of array configurations. A major contributing factor for recent advances of microstrip antennas is the current revolution in electronic circuit miniaturization brought about by developments in large scale integration. As conventional antennas are often bulky and costly part of an electronic system, micro strip antennas based on photolithographic technology are seen as an engineering breakthrough. In its most fundamental form, a Microstrip 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 1.1. 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.

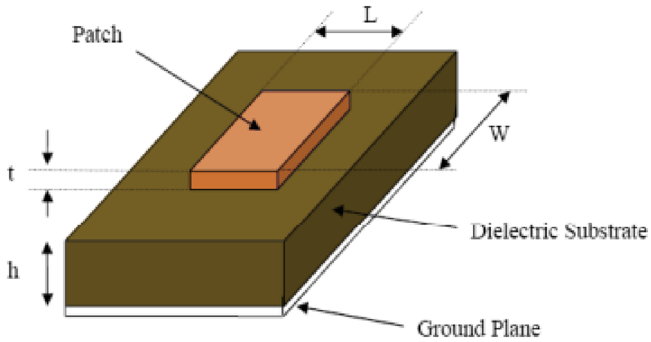



**Figure 1.1** Structure of a Microstrip Patch Antenna

In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, and elliptical or some other common shape as shown in Figure 1.2. For a rectangular patch, the length L of the patch is usually $0.3333\lambda o < L < 0.5\ \lambda o$, where $\lambda o$ 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 ($\varepsilon r$) is typically in the range $2.2 \leq \varepsilon r \leq 12$.

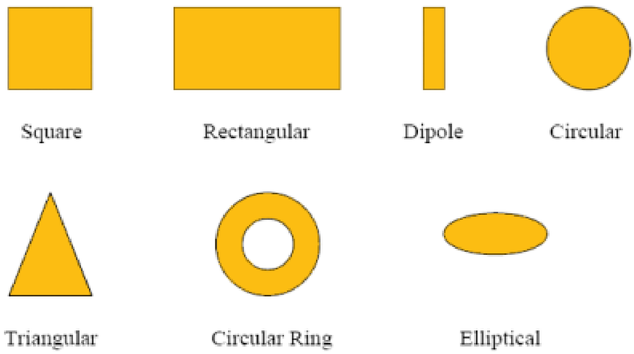



**Figure 1.2** Common shapes of microstrip patch elements

Microstrip 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. However, such a configuration leads to a larger antenna size. In order to design a compact Microstrip patch antenna, substrates with higher dielectric constants must be used which are less efficient and result in narrower bandwidth. Hence a trade-off must be realized between the antenna dimensions and antenna performance.

## 1.6. Advantages and Disadvantages

Microstrip 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. The telemetry and communication antennas on missiles need to be thin and conformal and are often in the form of Microstrip patch antennas. Another area where they have been used successfully is in Satellite communication. Some of their principal advantages discussed by Kumar and Ray are given below:

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

Microstrip patch antennas suffer from more drawbacks as compared to conventional antennas.

Some of their major disadvantages are given below:

- Narrow bandwidth
- Low efficiency
- Low Gain
- Low power handling capacity.
- Surface wave excitation

- Extraneous radiation from feeds and junctions
- Poor end fire radiator except tapered slot antennas

Microstrip patch antennas have a very high antenna quality factor (Q). It represents the losses associated with the antenna where a large Q leads to narrow bandwidth and low efficiency. Q can be decreased 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.

# Chapter 2

## FEED TECHNIQUE AND BANDWIDTH

### 2.1. Feed Techniques

Microstrip 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 microstrip line. In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch. The four most popular feed techniques used are the microstrip line, coaxial probe (both contacting schemes), aperture coupling and proximity coupling (both non-contacting schemes).

### 2.1.1. Microstrip Line Feed

In this type of feed technique, a conducting strip is connected directly to the edge of the Microstrip patch as shown in Figure 2.1. 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.

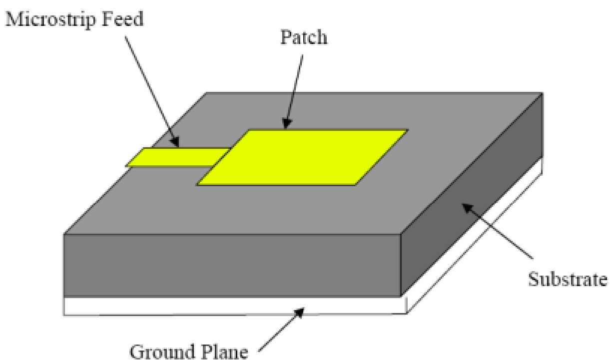



**Figure 2.1** Microstrip Line Feed

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. The feed radiation also leads to undesired cross polarized radiation.

### 2.1.2. Coaxial Feed

The Coaxial feed or probe feed is a very common technique used for feeding Microstrip patch antennas. As seen from Figure 2.2, 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.

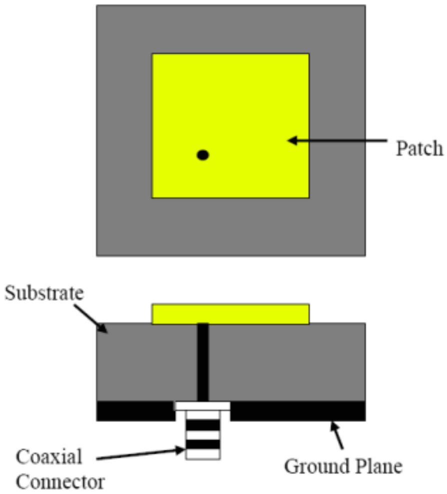



**Figure 2.2** Probe fed Rectangular Microstrip Patch Antenna

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, a major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and then 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. It is seen above that for a thick dielectric substrate, which provides broad bandwidth, the microstrip line feed and the coaxial feed suffer from numerous disadvantages. The non-contacting feed techniques which have been discussed below, solve these issues.

### 2.1.3. Aperture Coupled Feed

In this type of feed technique, the radiating patch and the microstrip feed line are separated by the ground plane as shown in Figure 2.3. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane.

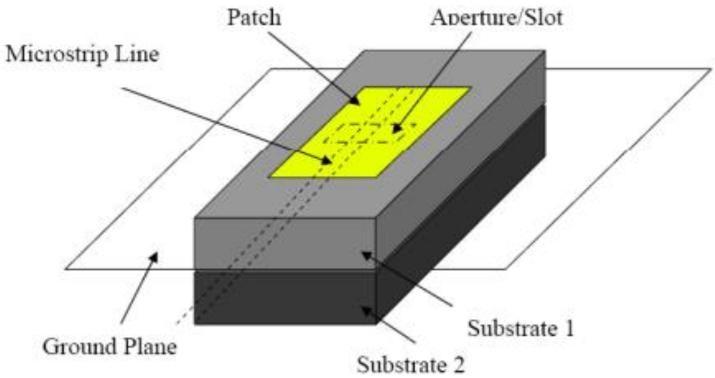



**Figure 2.3** Aperture-coupled feed

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 bottom substrate and a thick, low dielectric constant material is used for the top substrate to optimize radiation from the patch. 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.

### 2.1.4. Proximity Coupled Feed

This type of feed technique is also called as the electromagnetic coupling scheme. As shown in Figure 2.4, two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (as high as 13%), due to overall increase in the thickness of the microstrip patch antenna. This scheme also provides choices between two different dielectric media, one for the patch and one for the feed line to optimize the individual performances.

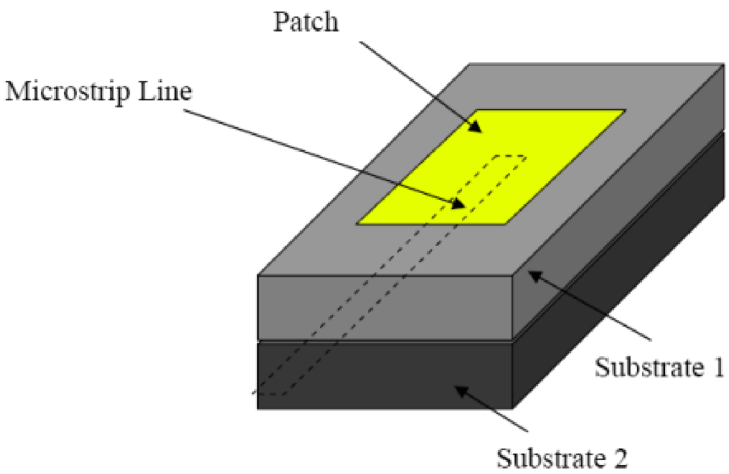



**Figure 2.4** Proximity-coupled Feed

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.

## 2.2. Methods of Analysis

The preferred models for the analysis of Microstrip patch antennas are the transmission line model, cavity model, and full wave model (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.

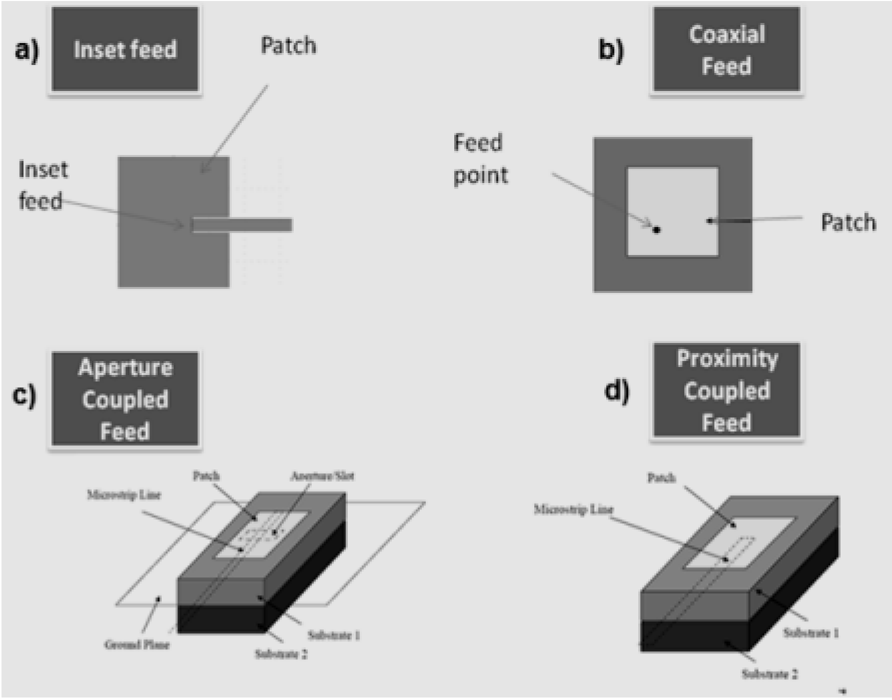



Figure 2.5: Comparison of different feed techniques

| characteristics | Microstrip 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 | 2-5% | 2-5% | 21% | 13% |

**Table 2.1** Comparison of different feed techniques

## 2.3. Transmission Line Model

This model represents the microstrip antenna by two slots of width W and height h, separated by a transmission line of length L. The microstrip is essentially a non homogeneous line of two dielectrics, normally the substrate and air.

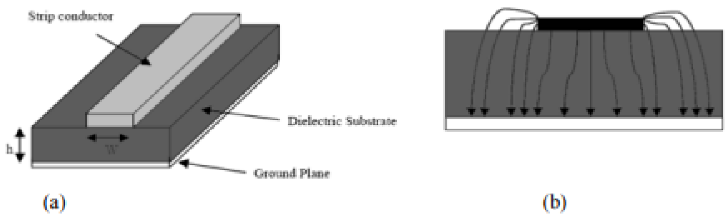



Figure 2.6 (a) Microstrip Line (b) Electric Field Lines

Hence, as shown in Figure.2.6 (b), most of the electric field lines lies in the substrate and parts of some lines are in air. As a result, this transmission line do not support pure transverse electromagnetic mode of transmission, since the phase velocities would be different in the air and the substrate. Instead, the dominant mode of propagation would be the quasi-TEM mode. Hence, an effective dielectric constant (εreff) must be obtained in order to account for the fringing and the wave propagation in the line. The value of εreff is little less than εr because the fringing fields around the edge of the patch are not confined in the dielectric substrate but are also spread in the air as shown in Figure above. The expression for εreff can be given as:

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

Where,
εreff = Effective dielectric constant
εr = Dielectric constant of substrate
H = Height of dielectric substrate
W = Width of the patch

Consider Figure 2.7, which shows a rectangular microstrip patch antenna of length L, width W lying on a substrate of height h. The co-ordinate axis is selected in such a way that the length is along the x axis direction, width is along the y axis direction and the height is along the z axis direction.

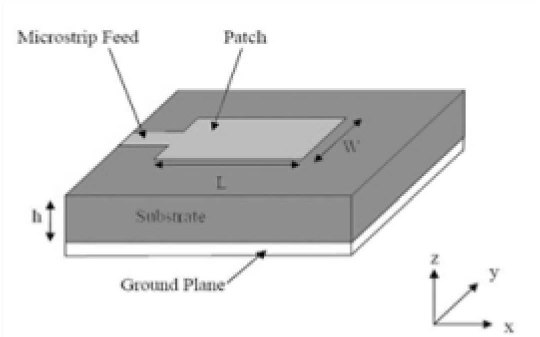



**Figure 2.7** Microstrip Patch Antenna

In order to operate in the TM10 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 λo/√εreff where λo is the free space wavelength. The TM10 mode implies that the field varies one λ/2 cycle along the length, and there is no difference along the width of the patch. In the Figure 2.7, the microstrip patch antenna is shown by two slots and 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.

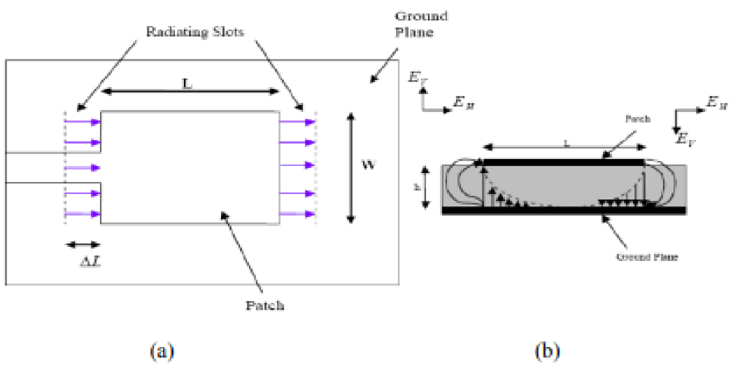



**Figure 2.8** (a) Top View of Antenna (b) Side View of Antenna

It is shown in Figure 2.8.b 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 λ/2 long and hence they nullify each other in the broadside direction. The tangential components 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 λ /2 apart and excited in phase and radiating in the half space above the ground plane.

The fringing fields along the width can be modelled as radiating slots and electrically the patch of the microstrip antenna looks greater than its physical dimensions. The dimensions of the patch along its length have now been extended on each end by a distance ΔL, which is given empirically as:

$$\Delta L = 0.412h\frac{(\varepsilon_{\mathrm{reff}} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{\mathrm{reff}} - 0.258)(\frac{W}{h} + 0.8)}$$

The effective length of the patch Leff now becomes:

$$\mathrm{L_{eff}} = L + 2\Delta L$$

For a given resonance frequency fo, the effective length is given by as:

$$\mathrm{L_{eff}} = \frac{c}{2f_0\sqrt{\varepsilon_{\mathrm{reff}}}}$$

For a rectangular Microstrip patch antenna, the resonance frequency for any TMmn mode is given by as:

$$f_0 = \frac{c}{2f_0\sqrt{\varepsilon_{\mathrm{reff}}}}[(\frac{m}{L})^2 + (\frac{n}{W})^2]^{1/2}$$

Where m and n are modes along L and W respectively for efficient radiation, the width W is given as;

$$W = \frac{c}{2f_0\sqrt{\frac{(\varepsilon_r + 1)}{2}}}$$

## 2.4. Properties of a Basic Microstrip Patch

A microstrip or patch antenna is a low profile antenna that has a number of advantages over other antennas it is lightweight, low cost, and easy to integrate with accompanying electronics. While the antenna can be 3D in structure (wrapped around an object, for example), the elements are usually flat; Hence their other name, planar antennas. Note that a planar antenna is not always a patch antenna.

The figure 2.9 shows a patch antenna in its basic form: a flat plate on a ground plane. The center conductor of a coax serves as the feed probe to couple electromagnetic energy in and/or out of the patch. The electric field distribution of a rectangular patch in its fundamental mode is also shown.

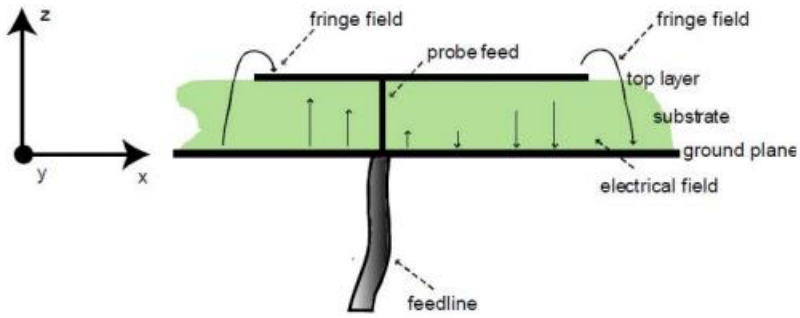



**Figure 2.9** Basic Microstrip patch antenna with probe feeding

The electric field is zero at the center of the patch, maximum (positive) at one side, and minimum (negative) on the opposite side. It should be mentioned that the minimum and maximum continuously change side according to the instantaneous phase of the applied signal. The electric field does not stop abruptly at the patch's periphery as in a cavity rather; the fields extend the outer periphery to some degree. These field extensions are known as fringing fields and cause the patch to radiate. Some popular analytic modeling techniques for patch antennas are based on this leaky cavity concept. Therefore, the fundamental mode of a rectangular patch is often denoted using cavity theory as the TM10 mode.

Since this notation frequently causes confusion, we will briefly explain it. TM stands for transversal magnetic field distribution. This means that only three field components are considered instead of six. The field components of interest are: the electric field in the z direction and the magnetic field components in x and y direction using a Cartesian coordinate system, where the x and y axes is parallel with the ground plane and the z axis is perpendicular.

In general, the modes are designated as TMnmz. The z value is mostly omitted since the electric field variation is considered negligible in the z axis.

Hence TMnm remains with n and m the field variations in x and y direction. The field variation in the y direction (impedance width direction) is negligible; thus m is 0. And the field has one minimum to maximum variation in the x direction (resonance length direction); Thus n is 1 in the case of the fundamental. Hence the notation TM10

## 2.5. Dimensions

The resonant length determines the resonant frequency and is about l/2 for a rectangular patch excited in its fundamental mode. The patch is, in fact, electrically a bit larger than its physical dimensions due to the fringing fields. The deviation between electrical and physical size is mainly dependent on the PC board thickness and dielectric constant.

A better approximation for the resonant length is:

$$L \approx 0.49\, \lambda_d = 0.49\, \frac{\lambda_0}{\sqrt{\varepsilon_r}}$$

This formula includes a first order correction for the edge extension due to the fringing fields, with:

· L = resonant length
· λd = wavelength in PC board
· λo = wavelength in free space
· εr = dielectric constant of the PC board material.

Other parameters that will influence the resonant frequency:

- Ground plane size
- Metal (copper) thickness
- Patch (impedance) width

## 2.6. Antenna Gain

Antenna gain relates the intensity of an antenna in a given direction to the intensity that would be produced by a hypothetical ideal antenna that radiates equally in all directions or is tropically and has no losses. Since the radiation intensity from a lossless isotropic antenna equals the power into the antenna divided by a solid angle of $4\pi$ steradians, we can write the following equation:

$$Gain = 4\pi(\frac{Radiation\ Intensity}{Antenna\ Input\ power})$$

$$Gain = 4\pi(\frac{U(\theta, \emptyset)}{Pin})$$

The gain of a rectangular microstrip patch antenna with air dielectric can be very roughly estimated as follows. Since the length of the patch, half a wavelength, is about the same as the length of a resonant dipole, we get about 2 dB of gain from the gain relative to the vertical axis of the patch. If the patch is square, the pattern in the horizontal plane will be directional, somewhat as if the patch were a pair of dipoles separated by a half-wave; this counts for about another (2-3) dB. Finally, the addition of the ground plane cuts off most or all radiation behindthe antenna, reducing the power averaged over all directions by a factor of 2 (and thus increasing the gain by 3 dB). Adding this all up, we get about 7-9 dB for a square patch, in good agreement with more sophisticated approaches.

## 2.7. Methods to Enhance Gain in Microstrip Patch Antenna

Most compact microstrip antenna designs show decreased antenna gain owing to the antenna size reduction. To overcome this disadvantage and obtain an enhanced antenna gain, several designs for gain-enhanced compact microstrip antennas with the loading of a high permittivity dielectric supers rate or the inclusion of an amplifier-type active circuitry have been demonstrated. Use of a high-permittivity super's rate loading technique gives an increase in antenna gain of about 10 dB with a smaller radiating patch. An amplifier-type active microstrip antenna as a transmitting antenna with enhanced gain and bandwidth has also been implemented.

## 2.8. Polarization

The plane wherein the electric field varies is also known as the polarization plane. The basic patch covered until now is linearly polarized since the electric field only varies in one direction. This polarization can be either vertical or horizontal depending on the orientation of the patch. A transmit antenna needs a receiving antenna with the same polarization for optimum operation. The patch mentioned yields horizontal polarization, as shown. When the antenna is rotated 90°, the current flows in the vertical plane, and is then vertically polarized.

A large number of applications, including satellite communication, have trouble with linear polarization because the orientation of the antennas is variable or unknown. Luckily, there is another kind of polarization circular polarization. In a circular polarized antenna, the electric field varies in two orthogonal planes (x and y direction) with the same magnitude and a 90° phase difference. The result is the simultaneous excitation of two modes, i.e. the TM10 mode (mode in the x direction) and the TM01 (mode in the y direction). One of the modes is excited with a 90° phase delay with respect to the other mode. A circular polarized antenna can either be Right-hand circular polarized (RHCP) or left-hand circular polarized (LHCP). The antenna is RHCP when the phases are 0° and 90° for the antenna in the figure below when it radiates towards the reader, and it is LHCP when the phases are 0° and 90°.

## 2.9. Bandwidth

Another important parameter of any antenna is the bandwidth it covers. Only impedance bandwidth is specified most of the time. However, it is important to realize that several definitions of bandwidth exists impedance bandwidth, gain bandwidth, polarization bandwidth, and efficiency bandwidth. Gain and efficiency are often combined as gain bandwidth.

### 2.9.1. Impedance bandwidth/return loss bandwidth

This is the frequency range wherein the structure has a usable bandwidth compared to certain impedance, usually 50 Ω. The impedance bandwidth depends on a large number of parameters related to the patch antenna element itself (e.g., quality factor) and the type of feed used. The plot below shows the return loss of a patch antenna and indicates the return loss bandwidth at the desired S11/VSWR (S11 wanted/VSWR wanted). The bandwidth is typically limited to a few percent. This is the major disadvantage of basic patch antennas.

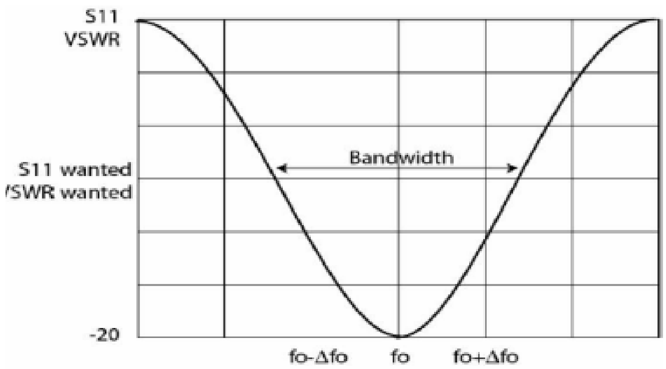



**Figure 2.10** VSWR Bandwidth Calculation

Important note: Different definitions of impedance bandwidth are used, such as:

VSWR = 2:1 and other values, S11 values other than –10 dB, the maximum real impedance divided by the square root of two [Z(Re)/√2, bandwidth], etc. This tends to turn selecting the right antenna for a specific application into quite a burden.

### 2.9.2. Gain/gain bandwidth

This is the frequency range wherein the antenna meets a certain gain/gain requirement
(e.g., 1 dB gain flatness).

### 2.9.3. Efficiency bandwidth

This is the frequency range wherein the antenna has reasonable (application dependent) radiation/total efficiency.

### 2.9.4. Polarization bandwidth

This is the frequency range wherein the antenna maintains its polarization.

### 2.9.5. Axial ratio bandwidth

This bandwidth is related to the polarization bandwidth and this number expresses the quality of the circular polarization of an antenna.

# Chapter 3

## RECTANGULAR PATCH ANTENNA

### 3.1. Introduction

Microstrip antennas are among the most widely used types of antennas in the microwave frequency range, and they are often used in the millimeter-wave frequency range as well [1, 2, 3]. (Below approximately 1 GHz, the size of a microstrip antenna is usually too large to be practical, and other types of antennas such as wire antennas dominate). Also called patch antennas, microstrip patch antennas consist of a metallic patch of metal that is on top of a grounded dielectric substrate of thickness h, with relative permittivity and permeability εr and μr as shown in Figure 3.1 (usually μr=1). The metallic patch may be of various shapes, with rectangular and circular being the most common, as shown in Figure 3.1.

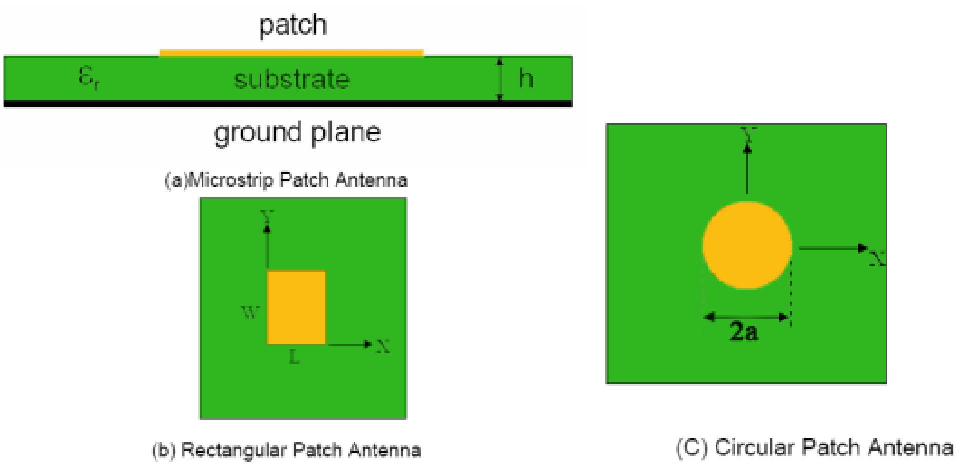



**Figure 3.1** Rectangular & Circular Patch Antenna

Most of the discussion in this section will be limited to the rectangular patch, although the basic principles are the same for the circular patch. (Many of the CAD formulas presented will apply approximately for the circular patch if the circular patch is modeled as a square patch of the same area.) Various methods may be used to feed the patch, as discussed below. One advantage of the microstrip antenna is that it is usually low profile, in the sense that the substrate is fairly thin. If the substrate is thin enough, the antenna actually becomes “conformal,” meaning that the substrate can be bent to conform to a curved surface (e.g., a cylindrical structure). A typical Substrate thickness is about 0.02 λ0. The metallic patch is usually fabricated by a photolithographic etching process or a mechanical milling process, making the construction relatively easy and inexpensive (the cost is mainly that of the substrate material). Other advantages include the fact that the microstrip antenna is usually lightweight (for thin substrates) and durable.

Disadvantages of the microstrip antenna include the fact that it is usually narrowband, with bandwidths of a few percent being typical. Some methods for enhancing bandwidth are discussed later, however. Also, the radiation efficiency of the patch antenna tends to be lower than some other types of antennas, with efficiencies between 70% and 90% being typical.

## 3.2. Basic Principles of Operation

The metallic patch essentially creates a resonant cavity, where the patch is the top of the cavity, the ground plane is the bottom of the cavity, and the edges of the patch form the sides of the cavity. The edges of the patch act approximately as an open-circuit boundary condition. Hence, the patch acts approximately as a cavity with perfect electric conductor on the top and bottom surfaces, and a perfect "magnetic conductor" on the sides. This point of view is very useful in analyzing the patch antenna, as well as in understanding its behavior. Inside the patch cavity the electric field is essentially z directed and independent of the z coordinate. Hence, the patch cavity modes are described by a double index (m, n). For the (m, n) cavity mode of the rectangular patch the electric field has the form.

$$E_z(x, y) = A_{mn} \cos\left(\frac{m\pi x}{L}\right) cos\left(\frac{n\pi x}{W}\right)$$

Where L is the patch length and W is the patch width. The patch is usually operated in the (1, 0) mode, so that L is the resonant dimension, and the field is essentially constant in the y direction. The surface current on the bottom of the metal patch is then x directed, and is given by,

$$E_z(x, y) = A_{mn} \cos\left(\frac{m\pi x}{L}\right) cos\left(\frac{n\pi x}{W}\right)$$

For this mode the patch may be regarded as a wide microstrip line of width W, having a resonant length L that is approximately one-half wavelength in the dielectric. The current is maximum at the centre of the patch, x = L/2, while the electric field is maximum at the two "radiating" edges, x = 0 and x = L. The width W is usually chosen to be larger than the length (W =1.5 L is typical) to maximize the bandwidth, since the bandwidth is proportional to the width. (The width should be kept less than twice the length, however, to avoid excitation of the (0, 2) mode.)

At first glance, it might appear that the microstrip antenna will not be an effective radiator when the substrate is electrically thin, since the patch current in (2) will be effectively shorted by the close proximity to the ground plane. If the modal amplitude A10 were constant, the strength of the radiated field would in fact be proportional to h. However, the Q of the cavity increases as h decreases (the radiation Q is inversely proportional to h). Hence, the amplitude A10 of the modal field at resonance is inversely proportional to h. Hence, the strength of the radiated field from a resonant patch is essentially independent of h, if losses are ignored. The resonant input resistance will likewise be nearly independent of h. This explains why a patch antenna can be an effective radiator even for very thin substrates, although the bandwidth will be small.

## 3.3. Resonant Frequency

The resonance frequency for the (1, 0) mode is given by

$$\mathrm{f}_0 = \frac{c}{2L_e\sqrt{\varepsilon_r}}$$

Where c is the speed of light in vacuum. To account for the fringing of the cavity fields at the edges of the patch, the length, the effective length Le is chosen as Le= L + 2ΔL

The Hammers tad formula for the fringing extension is

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{\mathrm{eff}} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{\mathrm{eff}} - 0.258)(\frac{W}{h} + 0.8)}$$

Where,

$$\varepsilon_{\mathrm{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[1 + \frac{12\,h}{w}]^{-1/2}$$

# Chapter 4

## PROPOSED DESIGN OF PATCH ANTENNA

### 4.1. Proposed Design

The condition for patch designing is $h_t \ll \lambda_0$. The range is normally $0.03\lambda_0 \leq h \leq 0.05\lambda_0$ 0.003 for top $h$ of the dielectric substrate [4]. The variety of relative permittivity of the substrate $(\epsilon_r)$ is within $2.2 \leq \epsilon_r \leq 12$. For designing a microstrip patch antenna, selection of frequency and substrate fabric performs very crucial role. In this work, the resonance frequency or centre frequency is selected as 27.842 GHz that is inside 5G bands with lower bound frequency as 25 GHz and upper bound frequency as 36 GHz.

The substrate is chosen as FR-4 with dielectric regular 4.3 and loss tangent is 0.025. The dielectric of the substrate controls the bandwidth and gain values of the antenna. Loss Tangent can be expressed as the quantity of the electromagnetic wave passing through a dielectric is absorbed or misplaced within the dielectric. So, substances with low loss tangent were taken into consideration. Also high efficiency and greater bandwidth results in compromise in relative permittivity of substrate. Moreover, low relative permittivity of the dielectric has elevated fringing effects. Hence, authors have chosen lower dielectric material in this work as it offers extra bandwidth and higher performance with compromise in the fringing field [5]. The top of the substrate $h$ also governs the bandwidth as increment in substrate height, floor wave and spurious feed radiation will increase (i.e. undesired radiation and can couple to different components) which restrict the bandwidth [6].

The height for the substrate materials $(h)$ for the rectangular microstrip patch antenna is 0.95 mm. There are several methods for feeding the patch antennas. In this paper, microstrip line feed [7] is used for feeding the rectangular microstrip patch antenna which is very efficient in term of impedance matching. We have considered

$$Z_o = 50\ Ohm$$

The length and width of the antenna may be determined out through the usage of the subsequent equations [8]:

$$W = \frac{c}{2f}\sqrt{\frac{2}{\epsilon_r+1}} \qquad (1)$$

Where $c$speed of light is, $f$ is the frequency, $\epsilon_r$ is relative permittivity of substrate

$$L = L_{eff} - L \qquad (2)$$

Where $L_{eff}$ is the effective length of the patch can be expressed as

$$L_{eff} = \frac{c}{2f\sqrt{\epsilon_{eff}}} \qquad (3)$$

Where $\epsilon_{eff}$ is the effective relative permittivity given as follows

$$\epsilon_{eff} = \frac{\epsilon_r+1}{W} + \frac{\epsilon_r-1}{W}(1+\frac{12h}{W})^{-\frac{1}{2}} \qquad (4)$$

And $L$ is the length extension given as follows:

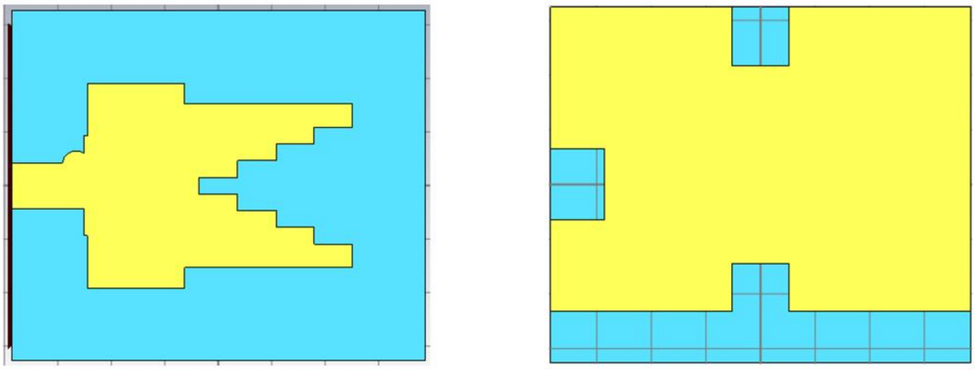
$$L = 0.412h\frac{(\epsilon_{eff}+0.3)(\frac{W}{h}+0.264)}{(\epsilon_{eff}-0.258)(\frac{W}{h}+0.8)} \qquad (5)$$

The corresponding length $L_g$ and width $W_g$ of the substrate and height of the substrate $h$ roughly indicate the dimension (length × width × height) of the patch antenna. These values are found out from the given equations.

$$L_g = L + 6h \qquad (6)$$

$$W_g = W + 6h \qquad (7)$$

By using the above equations, the dimensions of the a conventional inset feed rectangular patch microstrip antenna had been designed at resonant frequency of 27.842 GHz $h = 0.95$, $\epsilon_r = 4.3$. The thickness of the metal patch is taken as 0.0355mm. Next, the structure is further modified by introducing a four-step staircase slot in the patch, two rectangular slots at two sides of the patch, a rectangular slot in the ground plane, two more rectangular slots in the ground plane, two rectangular metal pics at beside of the feedline, and a circle in the feedline, to improve the performance (i.e. return loss, VSWR, gain etc.) of the patch antenna. Moreover, the schematic of rectangular slotted microstrip patch antenna is shown in Fig.4.1. For more clarity.



(a) front side of microstrip patch antenna (b) back side of microstrip patch antenna

Fig.-4.1 Proposed Design of Patch Antenna

## 4.2. Designing steps of the presented antenna

We propose an ultra-wideband (UWB) microstrip patch antenna with improved performance. The design process and the antenna geometry are shown in Fig. 4.2.

<u>The design steps are as follows:</u>

- **Step 1:** a conventional rectangular microstrip patch antenna with copper as the metal and microstrip line feed technique is designed, as shown in Fig. 4.2 (a). The antenna has a single resonant frequency at 27.114 GHz.

- **Step 2:** a four-step staircase slot on the patch, as shown in Fig. 4.2 (b). The slot shifts the resonant frequency to a higher value and creates a dual-band behaviour with two resonant frequencies at 27.668 GHz and 32.973 GHz.

- **Step 3:** In this step, two slot on both side of the patch, as shown in Fig. 4.2 (c). The slot enhances the radiation performance of the antenna and improves the return loss and bandwidth of the dual-band behaviour at 28.312 GHz and 34.138 GHz.

- **Step 4:** Next, ground plane is modified with a rectangular slot, as shown in Fig. 4.2 (d). The slot improves the impedance matching of the antenna and changes the resonant frequencies slightly to 28.417 GHz and 34.529 GHz.

- **Step 5:** An H-shaped slot is introduced in the ground plane as shown in Fig. 4.2 (e). The slot lowers the resonant frequency of the antenna and maintains the dual-band behaviour at 28.038 GHz and 34.359 GHz.

- **Step 6:** Two metal pieces at the junction of the feed line on both side of the patch is cut away, as shown in Fig. 4.2 (f). The metal pieces enhance the bandwidth of the antenna and achieve a wideband behaviour from 26.512 GHz to 32.999 GHz.

- **Step 7:** Finally, the introduction of a circular metal disc at the junction of the feed line of the patch, as shown in Fig. 4.2 (g) increases the gain of the antenna and achieves an ultra-wideband of 8.588 GHz behaviour from 26.65 GHz to 34.503 GHz, with a return loss of -30.002 dB at 27.838 GHz and a gain of 5.677 dBi.

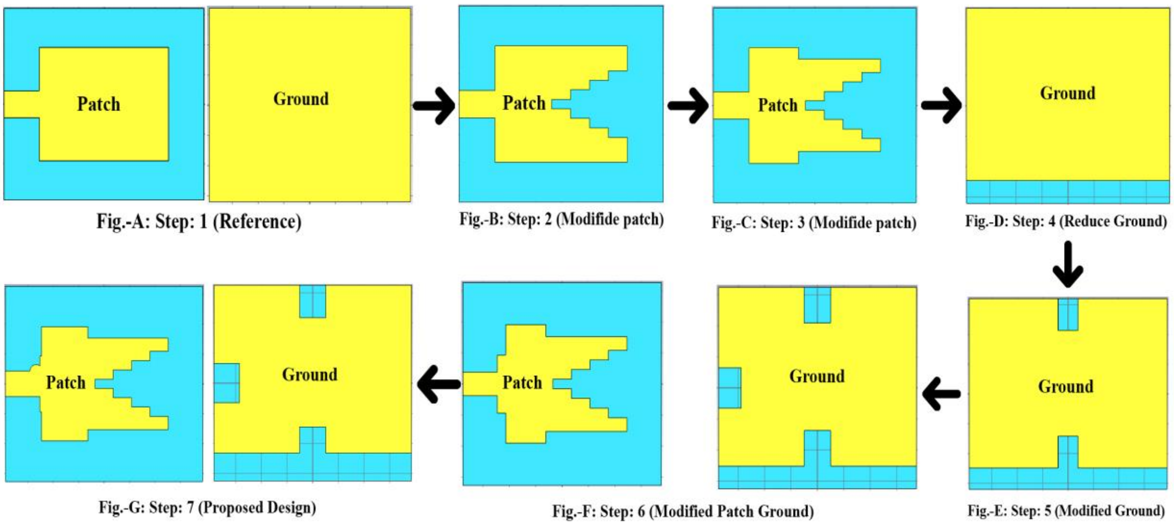



**Fig. 4.2 Step by step evolution of the presented antenna.**

## 4.3. Result and Discussion

All the patch antennas were designed and implemented the usage of CST studio suite [5]. Initially, conventional rectangular microstrip patch antenna is designed and VSWR, return loss, gain were observed. Next, the conventional antenna is modified by inserting a rectangular slot in the upper metallic patch which provides an extra enhancement in the bandwidth and satisfactory value for return loss, VSWR. Now, different results corresponding to the conventional and proposed slotted microstrip patch antenna are discussed below.

### 4.3.1. Structure of the antenna

Perspective observations of the conventional and slotted rectangular microstrip patch antenna (with microstrip line feed) are shown in Fig. 4.3 and fig. 4.4.

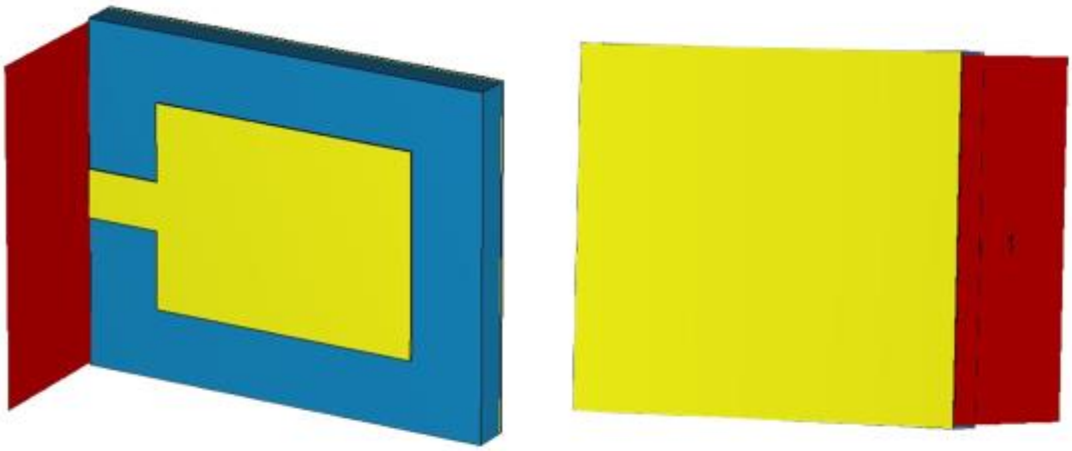


**Fig. 4.3 Perspective observation of conventional rectangular patch antenna (using CST Studio)**

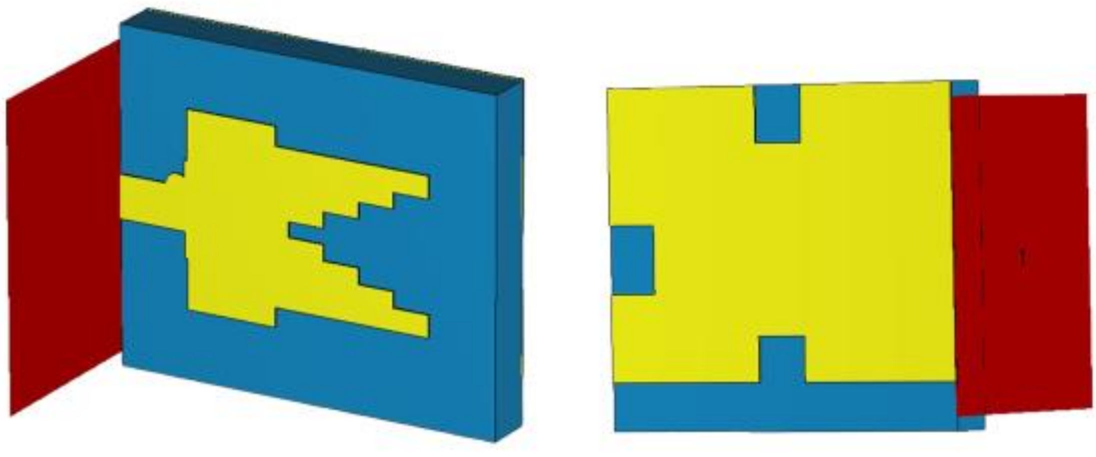


**Fig. 4.4 Perspective observation of proposed rectangular patch antenna (using CST Studio)**

### 4.3.2. Return Loss

Return Loss is expressed by parameter S11 that indicates the amount of power reflect back to the transmitter from an antenna. Return loss should be at least -10 dB to be said as good. Bandwidth is generally laid out in phrases of a return loss. As shown in the Fig. 4.5 return loss is -15.349 dB and bandwidth are 1.911 GHz for microstrip line feed conventional rectangular patch antenna. With insertion of the rectangular slot in the patch antenna, there is an additional enhancement in performance compare to the conventional rectangular microstrip patch antenna. The difference between higher and lower operating frequency is as much as 8.588 GHz i.e., bandwidth 8.588 GHz which is satisfy the characteristic of 5G system and also provides better return loss of -30.002 dB. Corresponding return loss graph for proposed slotted patch antenna is shown in Fig. 4.6.

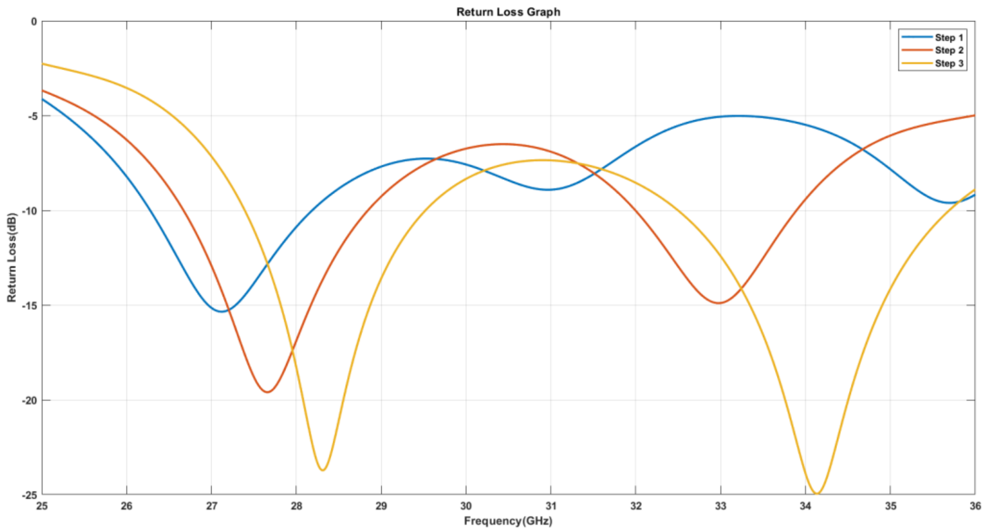



Fig. 4.5: Return Loss for antenna configuration step 1 to step 3

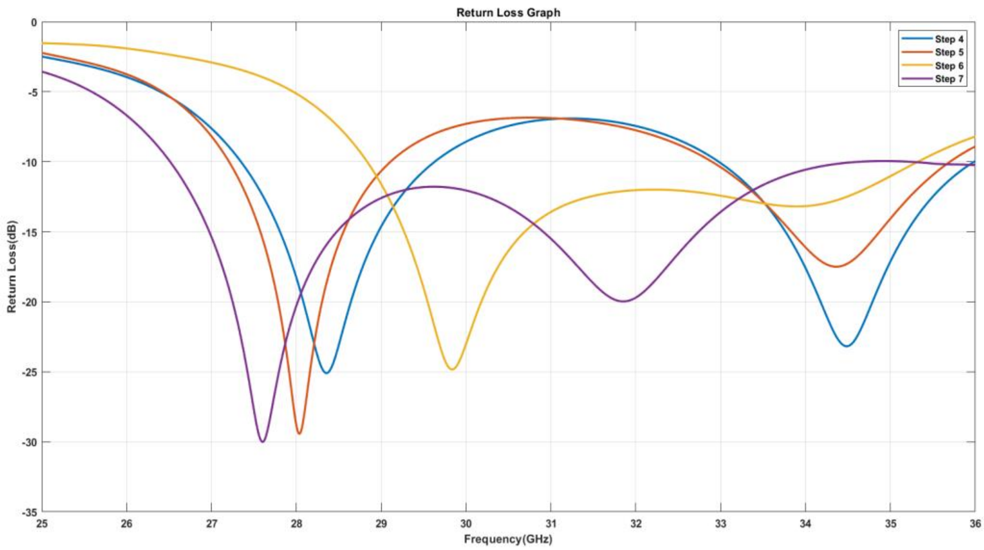



Fig. 4.6: Return Loss for antenna configuration step 4 to step 7

### 4.3.3. Voltage Standing Wave Ratio

The best values of VSWR have to lie between 1 and 2 [10] for a patch antenna. Higher values of VSWR indicates extra mismatch in impedance. The proposed conventional antenna gives VSWR value of 1.411 at 27.118 GHz. The same antenna with slot gives a VSWR value of 1.065 which is good for radiation properties of the antenna. So, the proposed slotted antenna has better VSWR over the conventional one. Fig. 4.7 and Fig. 4.8 show the VSWR plot for conventional and slotted rectangular patch antenna respectively.

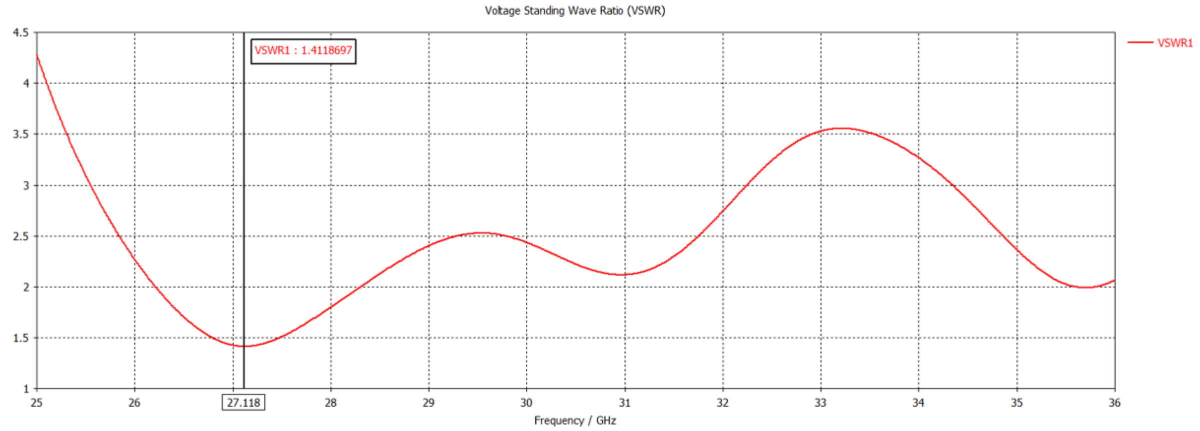



**Fig. 4.7: Plot of VSWR of conventional rectangular patch antenna**

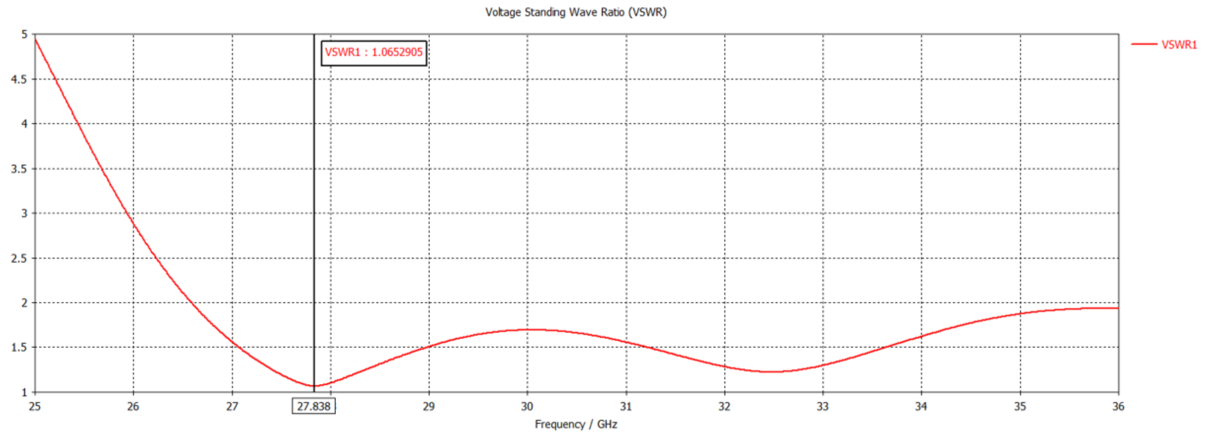



**Fig. 4.8: Plot of VSWR of slotted rectangular patch antenna**

### 4.3.4. Radiation Pattern

The Fig. 4.9 shows 1D result of broadband of slotted rectangular patch antenna with gain of 5.247 dB which is good for 5G applications. Therefore, it can be concluded that slotted patch antenna provides increment in directivity and gain.

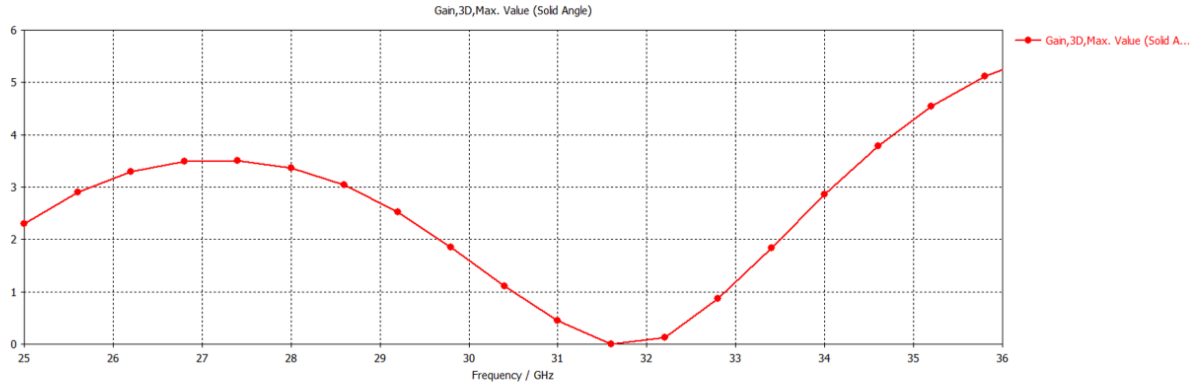



**Fig. 4.9: 1D result of broadband of slotted rectangular patch antenna**

The outcomes of each configuration of the proposed microstrip patch antenna are tabulated in table 1.

| Antenna Evolution Steps | Obtained frequency bands(GHz) | Peak Gain(dBi) | Antenna Evolution Steps | Obtained frequency bands(GHz) | Peak Gain(dBi) |
|---|---|---|---|---|---|
| Step 1 | 26.319-28.264 | 3.97 | Step 4 | 25.837-27.555, 32.871-35.533 | 3.55 |
| Step 2 | 26.711-28.877, 31.978-33.928 | 4.66 | Step 5 | 27.433-29.608, 32.712-35.796 | 3.57 |
| Step3 | 27.447-29.557, 32.568-35.707 | 3.39 | Step 6 | 28.834-35.320 | 3.8 |
| Step 7 | 26.649-35.492 | 5.24 | | | |

# Conclusion

In this paper, we have presented the design and optimization of a microstrip patch antenna for ultra-wideband applications in the 5G communication system. We have used different slotting techniques and metal pics to modify the patch and the ground plane of a basic rectangular patch antenna. We have used a full-wave electromagnetic simulator to analyse the effects of each modification on the bandwidth, return loss, and gain of the antenna. We have shown that by introducing a four-step staircase slot in the patch, two rectangular slots at two sides of the patch, a rectangular slot in the ground plane, two more rectangular slots in the ground plane, two rectangular metal pics at beside of the feedline, and a circle in the feedline, we can achieve an ultra-wideband antenna with a bandwidth of 8.855 GHz, a return loss of -30.002 dB at 27.838 GHz, and a gain of 5.677 dBi. We have compared the performance of the proposed antenna with the conventional rectangular patch antenna and other existing ultra-wideband antennas in the literature. We have found that the proposed antenna has a simple slotted rectangular patch structure, a compact size, a low cost, and a good performance. The proposed antenna can be used for various wireless communication systems that require ultra-wideband operation. The design and simulation of the antenna is carried out using CST microwave Studio simulation software.

# Future Plan

Although fabrication has not been done at this stage, a simple microstrip patch antenna was first used to study and its resonant frequency and bandwidth were observed. The design and simulation of the antenna is carried out using CST microwave Studio simulation software. This is a simulation based study.

As a future work, a Frequency Selective Surface (FSS) will be proposed to improve the antenna gain and return losses of a patch antenna and also plan to fabricate and test the proposed antenna in a laboratory environment and compare the measured results with the simulated ones.

We also plan to study the radiation pattern, polarization, and impedance characteristics of the antenna in different frequency bands. We also plan to compare the proposed antenna with other existing ultra-wideband antennas in the literature in terms of size, complexity, cost, and performance.

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