## Chapter 1

## 1. Introduction

Basically microstrip element consists of an area of metallization support above the ground plane, named as microstrip patch. The supporting element is called substrate material which is placed between the patch and the ground plane [1]. The microstrip antenna can be fabricated with low cost lithographic technique or by monolithic integrated circuit technique. Using monolithic integrated circuit technique we can fabricate phase shifters, amplifiers and other necessary devices, all on the same substrate by automated process [2]. In majority of the cases the performance characteristics of the antenna depends on the substrate material and its physical parameters. This unit will give the basic picture regarding microstrip antenna configurations, methods of analysis and some feeding techniques.

## 1.1 Introduction to Microstrip Patch Antennas and its parameters

In the microstrip antenna the upper surface of the dielectric substrate supports the printed conducting strip which is suitably contoured while the lower surface of the substrate is backed by a conducting ground plane [3]. Such antenna sometimes called a printed antenna because the fabrication procedure is similar to that of a printed circuit board. Many types of microstrip antennas have been evolved which are variations of the basic structure. Microstrip antennas can be designed as very thin planar printed antennas and they are very useful elements for communication applications [4].
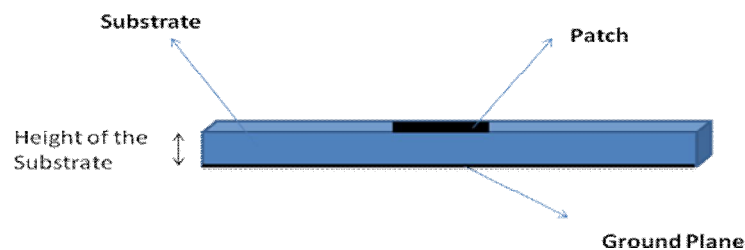


**Fig 1 Basic Structure of Microstrip Patch Antenna**

So many advantages and applications can be mentioned for microstrip patch antennas over conventional antennas. There are several undesirable features we encountered with conventional antennas like they are bulky, conformability problems and difficult

to perform multiband operations so on. The advantages include planar surface, possible integration with circuit elements, small surface, generate with printed circuit technology and can be designed for dual and multiband frequencies [5]. Disadvantages include narrow bandwidth, low RF power handling capability, larger ohmic losses and low efficiency because of surface waves etc. For the last two decades, researchers have been struggling to overcome these problems and they succeeded many times with their novel designs and new findings.

## 1.2  Feed Methods

There are mainly four basic methods for the feeding to these antennas

Probe Coupling Method

Microstrip Line Feeding Method

Aperture Coupled Microstrip Feed Method

Proximity Coupling Method

### 1.2.1   Probe Coupling Method

Coupling of power to the microstrip patch antenna can be done by probe feeding method. The inner conductor of the probe line is connected to patch lower surface through slot in the ground plane and substrate material [6]. To get perfect impedance matching we need to find out the location of the feed point over the antenna element.

$$Coupling \approx \iiint_v E_z J_z \, dv \approx \cos(\pi x_0 / L) \qquad \text{---------} \qquad (1)$$

Design simplicity and input impedance adjustment through feed point positioning, makes this feeding method popular. But there are some limitations also like larger lead for thicker substrate, difficulty in soldering for array elements etc.
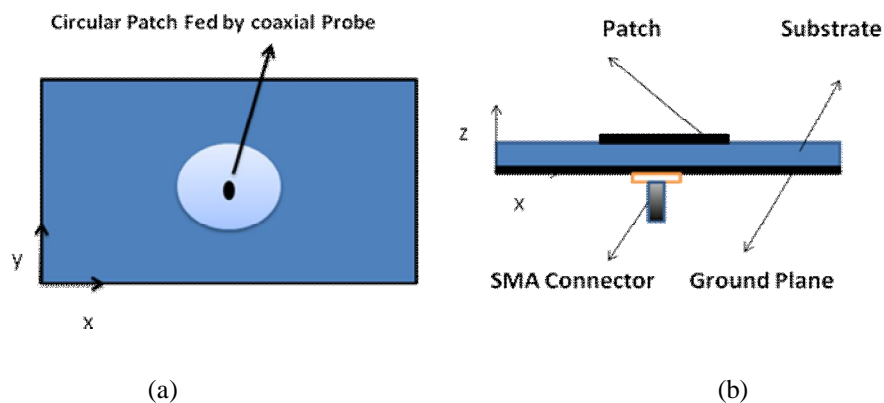


(a)                                              (b)

**Fig 1.1 Probe Coupling Method a) Top View b) Side View**

### 1.2.2 Microstrip Line feeding Method:

Using microstrip line we can give excitation to the antenna as shown in the figure 1.2. This method is very simple to design and fabricate. But this technique suffers from some limitations. If substrate thickness is increased in the design then the surface waves and the spurious radiation also increases. Because of that the undesired cross polarization radiation arises. Microstrip line feeding can be used in the conditions where performance of the antenna is not a strict matter. The edge-coupled feed can be improved with coplanar wave guide feeding.
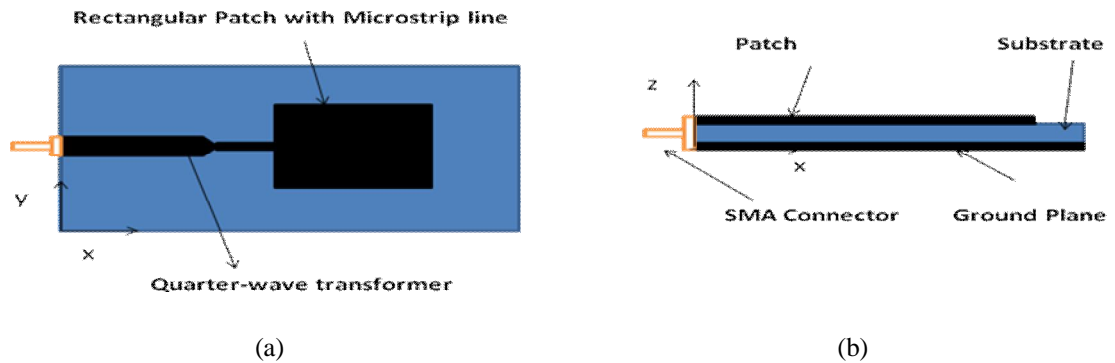


(a)                                          (b)

**Fig 1.2 Geometry of direct microstrip feed microstrip patch antenna a) Top view b) Side view**



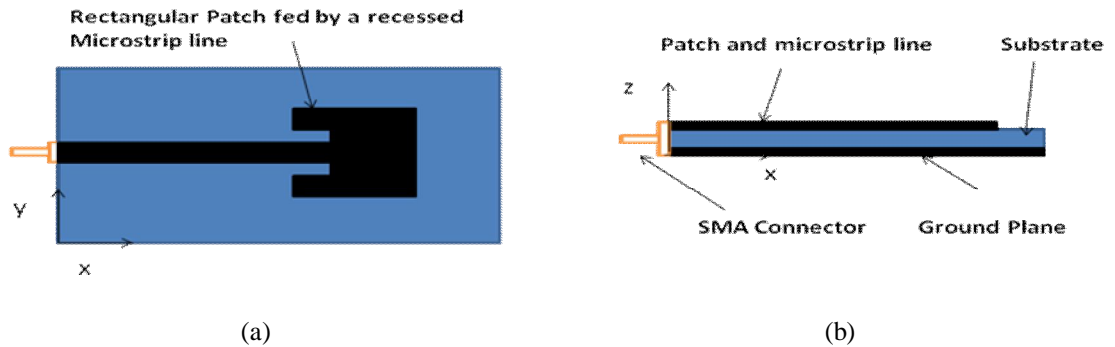(a)                                          (b)

**Fig 1.3 Geometry of recessed microstrip line feed patch antenna a) Top view b) Side view**

### 1.2.3 Proximity Coupled Method:

This method can be employed, where two or multilayer substrate configuration is considered. Generally in this configuration, microstrip line will be placed on lower substrate and the patch element will be placed on the upper substrate. Other name for this feeding is electromagnetically coupled feed. Capacitive nature will appear between feed line and patch in this case. By choosing thin lower substrate layer and

placing patch on top layer will improve the bandwidth and reduce the spurious radiation. Fabrication of this feeding is slightly difficult because of alignment problems in feed and patch at proper location. Peaceful thing is soldering and related problems can be eliminated.
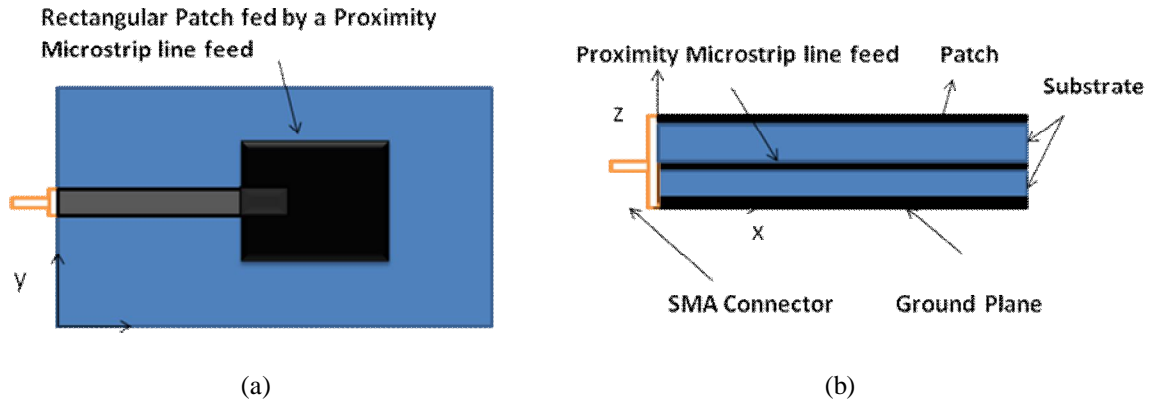


(a)                                                   (b)

**Fig 1.4 Geometry of proximity coupled microstrip feed patch antenna a) Top View b) Side view**



(a)                                                   (b)
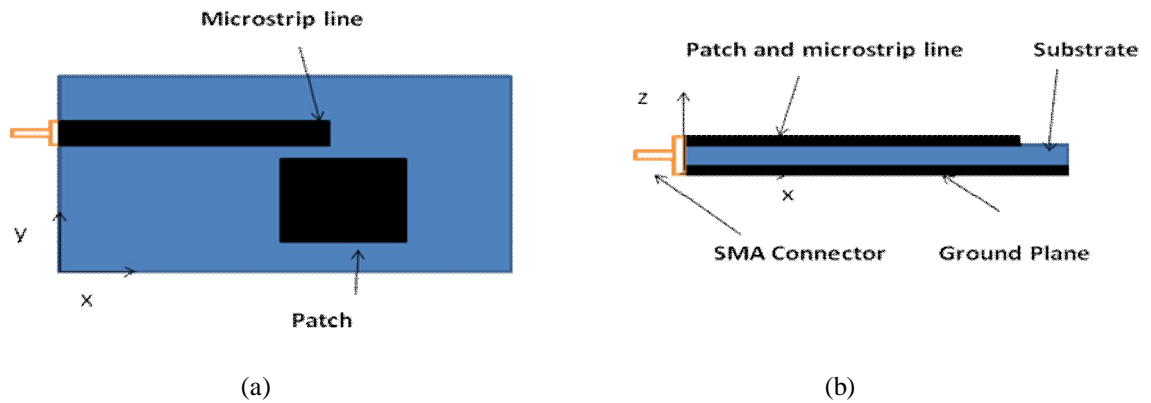
**Fig 1.5 Geometry of patch antenna fed by an adjacent microstrip line a) Top view b) Side view**

### 1.2.4   Aperture Coupled Feed Method:

This method employs ground plane between two substrates. A slot will be placed on the ground plane and feed line will be placed on lower substrate. This will be electromagnetically connected to patch on the upper substrate through the ground plane slot. One should take care about substrate parameters and they have to choose in a way that feed optimization and independent radiation functioning can exist. The coupling slot should be nearly cantered so that the patch magnetic field will be maximum. Coupling amplitude can be calculated by

$$Coupling \approx \iiint_v \bar{M}.\bar{H}\ dv \approx \sin(\pi x_0 / L) \ \text{--------} \qquad\qquad (2)$$



(a)                                                                                      (b)
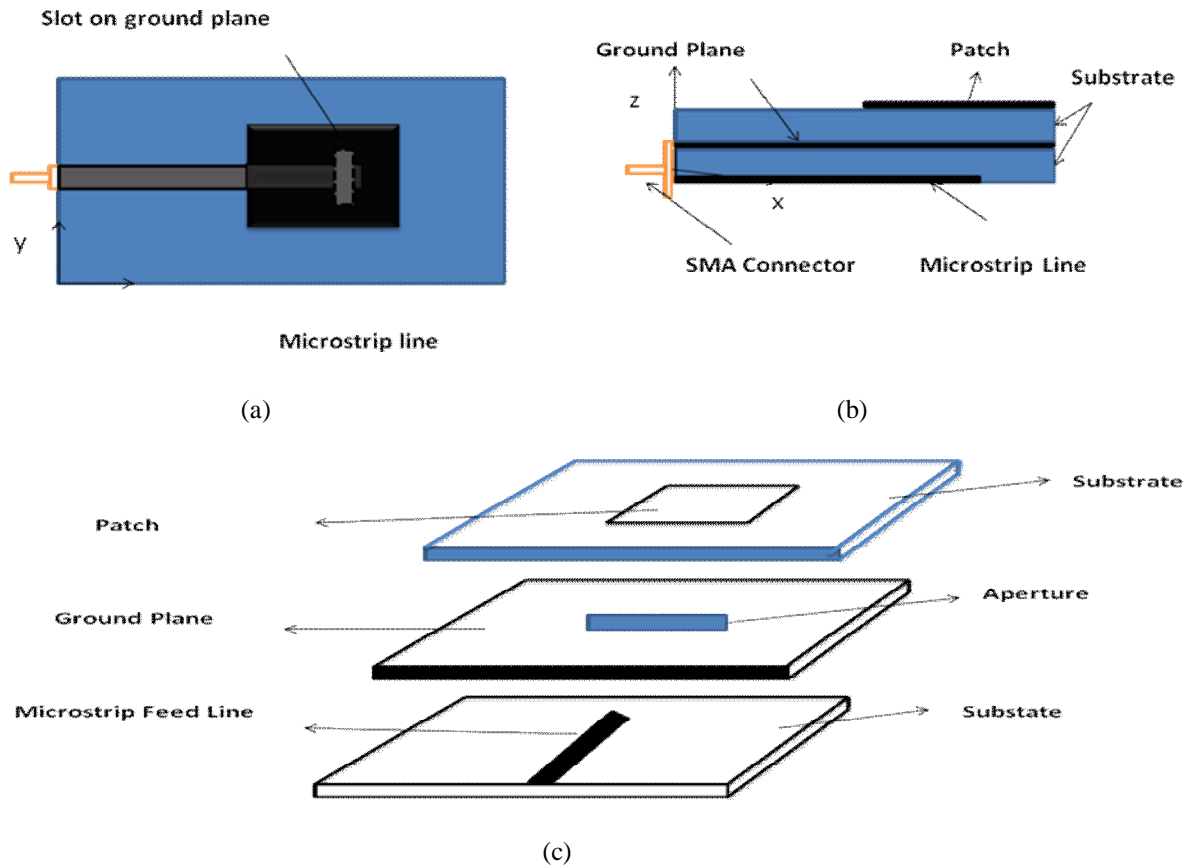


(c)

**Fig 1.6 Geometry of an aperture coupled feed microstrip patch antenna a) Top view b) Side view c) Pictorial view**

## 1.2.5 Summary of Advantages and Disadvantages of Feeding Methods

Table 1 summarizes the advantages and disadvantages of the four feeding methods discussed above.

| | Advantages | Disadvantages |
|---|---|---|
| **Proximity Coupled** | ▪ No direct contact between feed and patch<br>▪ Can have large effective thickness for patch substrate and much thinner feed substrate | ▪ Multilayer fabrication required. |
| **Microstrip Line** | ▪ Monolithic<br>▪ Easy to fabricate<br>▪ Easy to match by controlling<br>▪ Insert position<br>▪ Easy to match<br>▪ Low spurious radiation | ▪ Spurious radiation from feed line, especially for thick substrate when line width is significant |
| **Coaxial Feed** | ▪ Easy to match<br>▪ Low spurious radiation | ▪ Large inductance for thick substrate<br>▪ Soldering required |

| | ■ Use of two substrates avoids deleterious effect of a high-dielectric constant substrate on the bandwidth and efficiency | ■ Multilayer fabrication required |
|---|---|---|
| **Aperture Coupled** | ■ No direct contract between feed and patch avoiding large probe reactance or width microstrip line | ■ Higher back lobe radiation |
| | ■ No radiation from the feed and active devices since a ground plane separates them from the radiating patch | |

**Table 1.1 The comparisons between the four common feeding methods for microstrip patch antenna**

## 1.3 Methods of analysis of Microstrip Patch Antenna

The most popular methods 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.

### 1.3.1   Transmission Line Model

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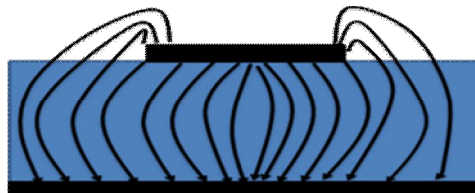


**Fig 1.7 Electric Field Lines**

As seen from the Fig 1.7, most of the electric field lines lies 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 phase velocities would be different in the air and the substrate. Instead, the dominant mode of propagation would be the quasi-TEM mode [7]. Hence an effective dielectric constant ($\varepsilon_{\text{reff}}$) must be obtained in order to account for the fringing and the wave propagation in the line. The value of $\varepsilon_{\text{reff}}$ is slightly less than $\varepsilon_r$ because the fringing

fields around the periphery of the patch are not confined in the dielectric substrate but are also spreads in the air. The expression for $\varepsilon_{reff}$ is given by

$$\varepsilon_{reff} = (\varepsilon_{reff+1})/2 + (\varepsilon_{reff-1})/2 \ [1+12h/w]^{-1/2} \qquad\qquad \text{------} \qquad\qquad (3)$$

Where $\varepsilon_{reff}$ = Effective dielectric constant

$\varepsilon_r$ = Dielectric constant of substrate

h = Height of the dielectric substrate

w = Width of the patch

### 1.3.2 Cavity model

In the cavity model, the region between the patch and the ground plane is treated as a cavity that is surrounded by magnetic walls round the periphery and by electric walls from the top and bottom sides. Since thin substrates are used, the field inside the cavity is uniform along the thickness of the substrate. The fields underneath the patch for regular shapes such as rectangular, circular, triangular, and sectoral can be expressed as a summation of the various resonant modes of the two-dimensional resonator.

The fringing fields around the periphery are taken care of by extending the patch boundary outward so that the effective dimensions are larger than the physical dimensions of the patch. The effect of the radiation from the antenna and the conductor loss are accounted for by adding these losses to the loss tangent of the dielectric substrate. The far field and radiated power are computed from the equivalent magnetic current around the periphery [8].

An alternate way of incorporating the radiation effect in the cavity model is by introducing an impedance boundary condition at the walls of the cavity. The fringing fields and the radiated power are not included inside the cavity but are localized at the edges of the cavity. However, the solution for the far field, with admittance walls is difficult to evaluate.

### 1.3.3 Multiport Network Model

The Multiport Network Model (MNM) for analyzing the microstrip antenna is an extension of the cavity model. In this method, the electromagnetic fields underneath

the patch and outside the patch are modelled separately. The patch is analyzed as a two-dimensional planar network, with a multiple number of ports located around the periphery [9]. The multiport impedance matrix of the patch is obtained from its two-dimensional Green's function. The fringing fields along the periphery and the radiated fields are incorporated by adding an equivalent edge admittance network. The segmentation method is then used to find the overall impedance matrix. The radiated fields are obtained from the voltage distribution around the periphery [10].

The above three analytical methods offer both simplicity and physical insight. In the latter two methods, the radiation from the microstrip antenna is calculated from the equivalent magnetic current distribution around the periphery of the radiating patch, which is obtained from the corresponding voltage distribution. Thus, the microstrip antenna analysis problem reduces to that of finding the edge voltage distribution for a given excitation and for a specified mode. These methods are accurate for regular patch geometries. For complex geometries, the numerical techniques described below are employed.

### 1.3.4   Method of Moments

In the Method of Moments (MoM) the surface currents are used to model the microstrip patch and polarization currents in the dielectric slab are used to model the fields in the dielectric slab [11]. An integral equation is formulated for the unknown currents on the microstrip patches, feed lines and their images in the ground plane. The integral equations are transformed into algebraic equations that can be easily solved using a computer. This method takes into account the fringing fields outside the physical boundary of the two-dimensional patch, thus providing a more exact solution.

### 1.3.5   Finite Element Method

The Finite Element Method (FEM), unlike the MoM, is suitable for volumetric configurations. In this method, the region of interest is divided into a number of finite surfaces or volume elements depending upon the planar or volumetric structures to be analyzed. These discredited units, generally referred to as finite elements, can be any well-defined geometrical shapes such as triangular elements for planar configurations and tetrahedral and prismatic elements for three-dimensional

configurations, which are suitable even for curved geometry [12]. It involves the integration of certain basic functions over the entire conducting patch, which is divided into a number of subsections. The problem of solving wave equations with inhomogeneous boundary conditions is taken by decomposing it into two boundary value problems, one with Laplace's equation with an inhomogeneous boundary and the other corresponding to an inhomogeneous wave equation with a homogenous boundary condition.

### 1.3.6   Spectral Domain Technique

In the Spectral Domain Technique (SDT), a two-dimensional Fourier transform along the two orthogonal directions of the patch in the plane of substrate is employed. Boundary conditions are applied in Fourier transform plane. The current distribution on the conducting patch is expanded in terms of chosen basis functions and the resulting matrix equation is solved to evaluate the electric current distribution on the conducting patch and the equivalent magnetic current distribution on the surrounding substrate surface. The various parameters of the antennas are then evaluated.

### 1.3.7   Finite Difference Time Domain Method

The Finite Difference Time Domain (FDTD) method is well-suited for microstrip antennas, as it can conveniently model numerous structural in-homogeneities encountered in these configurations. It can also predict the response of the microstrip antenna over the wide bandwidth with a single simulation. In this technique, spatial as well as time grid for the electric and magnetic fields are generated over which the solution is required. The spatial discretizations along three Cartesian coordinates are taken to be same. The E-cell edges are aligned with the boundary of the configuration and H-fields are assumed to be located at the centre of each E-cell. Each cell contains information about material characteristics. The cells containing the sources are excited with a suitable excitation function, which propagates along the structure. The discretized time variations of the fields are determined at desired locations. Using a line integral of the electric field, the voltage across the two locations can be obtained. The current is computed by a loop integral of the magnetic

field surrounding the conductor, where the Fourier transform yields a frequency response.

The above numerical techniques, which are based on the electric current distribution on the patch conductor and the ground plane, give results for any arbitrarily shaped antenna with good accuracy, but they are time consuming. These methods can be used to plot current distributions on patches but otherwise provide little of the physical insight required for antenna design.

## 1.4 Measurement of Antenna Characteristics

The antennas, in general, are characterised by parameters like gain, input impedance, directivity, radiation pattern, effective area and polarization properties. The experimental procedure to find the parameters of the antenna is discussed in the following sections. The S parameters can be determined with Vector Network Analyzer and radiation patterns can be computed through the antenna measurement setup in connection with Network analyzer. The cables and connectors have its losses associated at higher frequency bands. The measuring instrument should be calibrated before using it. There are many calibration procedures are available in network analyzer. Single port, full two port and TRL calibration methods are generally used. Return loss, VSWR and input impedance can be measured using single port calibration method.

### 1.4.1   Return loss and VSWR

The reflection coefficient at the antenna input is the ratio of the reflected voltage to the incident voltage and is same as the $S_{11}$ when the antenna is connected at the port 1 of the network analyzer. It is the measure of the impedance mismatch between the antenna and the source line. The degree of mismatch is usually described in terms of Return loss or VSWR. The return loss (RL) is the ratio of the reflected power to the incident power, expressed in dB as

$$RL = -20\log(|\Gamma|) = -20\log(|S_{11}|) = -|S_{11}|(dB) \qquad \text{------} \qquad (4)$$

The frequency corresponding to return loss minimum is taken as resonant frequency of the antenna. The range of frequencies for which the return loss value is less than -

10 dB points is usually treated as bandwidth of the antenna. The bandwidth of the antenna can be expressed as percent of bandwidth

$$\% \ Bandwidth = \frac{Bandwidth}{Center \ frequecny} * 100 \qquad \text{------} \qquad (5)$$

The voltage standing wave ratio (VSWR) is the ratio of the voltage maximum to the minimum of the standing wave existing on the antenna input terminals. VSWR equals to 2 gives a return loss of approximately equals to 10 dB and it is set as the reasonable limits for a matched antenna.

### 1.4.2   Q factor

It represents the antenna loss factor and it is given by

$$\frac{1}{Q_t} = \frac{1}{Q_r} + \frac{1}{Q_c} + \frac{1}{Q_d} + \frac{1}{Q_{sw}} \qquad \text{--------} \qquad (6)$$

Where $Q_t$ represents total Q factor of the patch antenna, $Q_r$ is Q factor due to the radiation losses, $Q_c$ is due to conduction losses and $Q_d$ is due to dielectric losses. For thin substrates losses due to the surface wave $Q_{sw}$ are very small and can be neglected, thus

$$\frac{1}{Q_t} = \left[ \frac{1}{Q_r} + \frac{1}{Q_c} + \frac{1}{Q_d} \right]^{-1} \qquad \text{-------} \qquad (7)$$

Approximate formulas for individual Q factors are given by

$$Q_d = \frac{1}{\tan \delta} \qquad \text{-------} \qquad (8)$$

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

$$Q_c = h \sqrt{\mu_0 \mu f_r \sigma_c} \qquad \text{-------} \qquad (9)$$

Where $\sigma_c$ is conductivity of the metal

$$Q_r = \frac{\pi}{4 G_r Z_0} \qquad \text{-------} \qquad (10)$$

Where $G_r$ is the radiation conductance and $Z_0$ is the characteristic impedance of the patch.

### 1.4.3   Efficiency

The radiation efficiency of the antenna can be defined as the ratio of the radiated power to the input power. It can be expressed in terms of Q factor, which for a microstrip patch antenna is

$$e = \frac{Q_t}{Q_{rad}} \qquad \text{-------} \qquad\qquad (11)$$

### 1.4.4   Antenna gain and Directivity

Antenna gain is the ratio of the intensity of an antenna's radiation in the direction of strongest to that of a reference antenna, when both the antennas are fed by the same input power. If the reference is an isotropic antenna, the gain is often expressed in units of dBi. The gain of the antenna is a passive phenomenon – power is not added by the antenna, but redistributed to provide more radiated power in certain directions than would be transmitted by an isotropic antenna.

The directive gain of antenna is given by $G_n = eD$, where 'e' is efficiency and 'D' is directivity.

$D = \frac{(4k_0 W)^2}{\pi \eta_0 G_r}$, where $\eta_0$ is impedance of free space and $k_0$ is the wave number in the dielectric and it is given by $k_0 = w\sqrt{\mu_0 \varepsilon_r}$ . It illustrates that directivity is not sensitive to substrate thickness and resonant frequency and gain increases with patch width and resonant frequency.

### 1.4.5   Radiation Pattern

The radiation pattern represents the spatial distribution of electromagnetic field radiated by the antenna. The pattern will be taken in two planes, namely E-plane and H-plane. E-plane is the plane containing electric field vector and the direction of maximum radiation and H-plane is the plane containing the magnetic field vector and the direction of maximum. By placing antenna in the receiving mode inside the

anechoic chamber, E-plane and H-plane radiation patterns will be taken using antenna measurement setup and network analyzer.

The radiation pattern of the antenna at multiple frequency points can be measured with single rotation of the test antenna positioner and measurement software. Positioner will stop at each angle and $S_{21}$ measurement will be taken at different frequency points in the operating band. This thing will be repeated till it reaches to stop angle. The measured data will be stored for the further processing to plot the graphs.

### 1.4.6   Physical Measurements

Once antenna is fabricated with specific design on a particular substrate material, we need to measure the parameters of the antenna like return loss, VSWR, phase, input impedance and radiation characteristics using Network Analyzer and antenna measurement setup. These devices are included with digital processors and plotting equipment so that the output can be obtained in the form of graph or data. There are mainly two types of network analyzers are available, scalar and vector network analyzers. Scalar network analyzer measures only the magnitudes of transmission and reflection coefficients, whereas vector network analyzer measures both magnitude and phase of the above said parameters. A vector network analyzer consists of microwave source, signal processor, calibration kit and display unit in general.
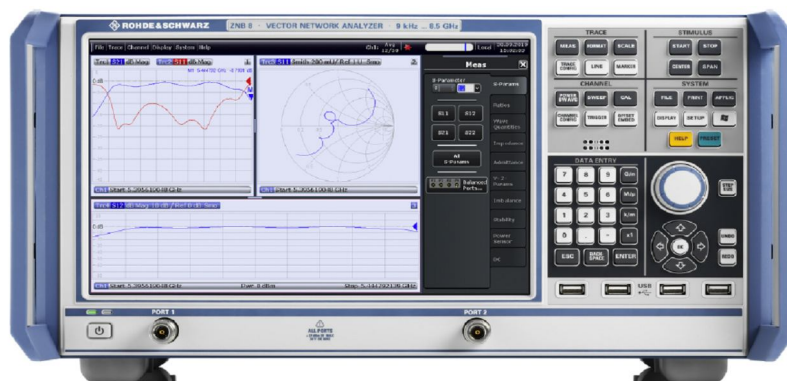


**Fig 1.8 R&S ZNB 20 VNA**

### 1.4.7 Anechoic Chamber

The Anechoic chamber is a room used to measure the antenna characteristics accurately. The room comprises microwave absorbers fixed on the walls, roof and floor to avoid EM reflections. High quality low foam impregnated with dielectrically magnetically lossy medium is used to make the microwave absorber. The tapered shapes of the absorber provide good impedance match for the microwave power impinging upon it. Aluminium sheets are used to shield the chamber from electromagnetic interference from surroundings.

### 1.4.8 Turn table assembly for far field radiation pattern measurement

A turntable assembly consists of a microcontroller based antenna positioner, interfaced with the PC for the radiation pattern measurement. The antenna under test (AUT) is mounted over the turntable assembly and a linearly polarized; wideband standard horn antenna is used as the transmitter for the radiation pattern measurement. The main lobe tracking for gain measurement as well as the polarization pattern measurement is carried out through this setup. The programmed graphical user interface (GUI) manages the antenna characterization by synchronizing each component in the system.
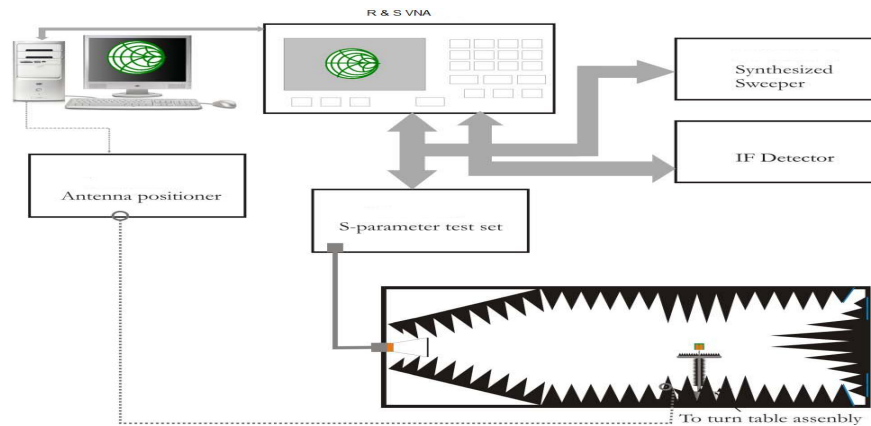


**Fig 1.9 Antenna Measurement setup**

### 1.4.9 Ansys HFSS (High Frequency Structural Simulator)

Ansys HFSS is one of the globally accepted commercial Finite Element Method (FEM) solver for electromagnetic structures. The optimization tool available with HFSS is very useful for antenna engineers to optimize the antenna parameters very

accurately. There are many kinds of boundary schemes available in HFSS. Radiation and PEC boundaries are widely used in this work. The vector as well as scalar representation of E, H and J values of the device under simulation gives a good insight in to the problem under simulation.

## 1.5  Motivation for the work:

The antenna technology has undergone remarkable achievements during past two decades. Antenna designers require a wide range of substrate materials availability with stable electrical, mechanical properties over the various ambient operating conditions. Along with favourable properties and parameters that are required for the perfect design of antennas, the cost of the material also should be less. In recent years, many varieties of antennas have been proposed and investigated on different substrate materials, depending on the applications.

The dimensions of the microstrip antenna depend on the substrate material and the antenna performance mostly depends on dielectric constant and loss tangent of that material. The dielectric constant determines the speed at which a signal travels along a transmission line, and in microwave circuitry also affects the geometry of etched features on the board. The speed can be fine tuned by the designers with proper selection of materials with different dielectric constants. Another important factor is the dissipation factor, which will contribute to the amount of signals power that is dissipated as it travels along a transmission line.

The main purpose of the thesis is to investigate the performance characteristics of compact and wideband antennas with respect to different substrate materials. Several novel designs on commercially available microwave substrates are proposed that could be successfully implemented in consumer electronics applications. In this work seven materials are selected with dielectric constants ranging from 2.2 to 9.2. The dielectric materials that are used in this work with their dielectric constants and loss tangents are tabulated in Table 1.2.

**Table 1.2 Substrate Materials used in this work**

| Substrate | RT-duroid 5880 | Arlon AD-250 | Ultralam 3850 | Polyester | Plexiglass | FR4 | Alumina |
|---|---|---|---|---|---|---|---|
| $\varepsilon_r$ | 2.2 | 2.5 | 2.9 | 3.2 | 3.4 | 4.4 | 9.2 |
| Tan δ | 0.0009 | 0.0015 | 0.0025 | 0.003 | 0.001 | 0.02 | 0.008 |

When one decides to design an antenna using a different dielectric substrate, the time consuming design process has to be fully repeated. In such situations, the designers are interested in having simple design formulas that provide a very good approximation to the final design when sophisticated EM analysis and design software packages are applied. This thesis addresses this issue and provides simple design formulas with respect to the resonant frequency and wavelength, which are suitable for the antenna design. In this thesis, four types of models are considered to study their behaviour with change in substrate permittivity.

## 1.6   Thesis organization

Chapter 1 gives the introduction of the thesis. This chapter furnishes the basic information about microstrip patch antennas theory along with different feeding techniques and their advantages and disadvantages. Methods of analysis of microstrip antenna and the antenna basic parameters for its performance evaluation are outlined. Measurements in the frequency domain such as return loss, VSWR, gain and radiation patterns are explained. The motivation of the work and thesis organization is also included in this chapter.

Chapter 2 presents the detailed literature review about compact microstrip antennas. Past work regarding wideband antennas with bandwidth enhancement methods are discussed.

Chapter 3 focused on substrate material selection and its importance in the design of microstrip antennas. Problems associated with surface waves and basic criteria for substrate selection are clearly paraphrased. Design considerations and specifications of basic rectangular patch antenna with design equations are presented. Design considerations for compact and wideband antennas are discussed. Then a detailed literature review about compact and wideband antennas are conducted.

Chapter 4 centres on the brief introduction about wideband and Ultra wideband antennas. Different compact and wideband antennas are designed and a common approach is followed for the antenna development. The proposed antenna designs are simulated and their resonant modes are identified. The antennas are CPW-fed for easy fabrication and better integration with microwave monolithic circuits. For

bandwidth enhancement tapered step ground technique is adopted and detailed discussions regarding the antenna parameters are presented. Surface current distributions on the antenna at the resonant modes and their corresponding radiation patterns are analyzed in detail. The results of the analysis along with the parametric studies have enabled to deduce their design equations and design methodologies on different substrates for the desired operating frequency.

Chapter 5 concentrates on serrated microstrip antennas design and their analysis with change in substrate permittivity. Six models of serrated aperture patch antennas with coaxial feeding and two models with coplanar waveguide feeding are designed. In the case of coaxial fed serrated models dual, triple and multi-bands are achieved and for CPW fed models, wide bandwidths are attained. Frequency domain performance parameters are investigated both numerically and experimentally and presented the comparative analysis.

Chapter 6 imparts on the liquid crystal and liquid crystal polymer antennas for tuneable and conformal applications. Dielectric anisotropy of liquid crystal substrate material in the microstrip antenna with small biasing voltage is presented in this chapter. For conformal applications a flexible liquid crystal polymer dielectric substrate material based wideband antenna models are discussed and their results are analyzed in this chapter.

Chapter 7 contributes on two models of multilayered stacked patch antennas. A combination of U-slot and E-Slot patches on two layers of dielectric substrate materials in stacked configuration is presented. Multiband characteristics are achieved with this stacked configuration and its parametric analysis with change is substrate permittivity is also presented in this chapter. Another model of rotated stacked patch is proposed with circular polarization. Four patch elements in $30^0$ orientations to each other are arranged on four dielectric substrates. Wideband characteristics and circular polarization is attained from this design. The antenna parameters analysis with change in substrate permittivity is also presented in this chapter.

Chapter 8 lends the conclusion by compiling the overall work and its results along with a brief description on the scope of research work.