Theory of Microstrip Antenna in Wireless Systems

Mahesh Chander Mishra
R.R Government Automatous College, Alwar, India

Abstract:

It is mentioned in the beginning of this paper that microstrip antennas have distinct advantages and becoming more popular due their compactness and suitability for modern devices. To analyze the microstrip antenna and essential parameters, feeding techniques, method of analysis, and simulation software available for building the platform to propose new/modified planar antennas.

Introduction

The beginning of the communication can be traced back to 1844 when Morse successfully transmitted a massage over a single wire. Similarly, the age of wireless communication started with German scientist Heinrich Hertz experiment in the year 1888 [Sobol Harold 1984]. Since then the Communication has gone through a long journey of successes and failures and have become quite mature to satisfy users need. The revolution in both wired and wireless communication systems have unprecedented impact on the world society, today it is difficult to imagine life without communication.

Communication systems are generally classified as narrow band and wideband systems. Wideband communication systems are further categorized as (i) broadband and (ii) ultra-wideband (UWB). Difference between them is in terms of impedance bandwidth. Narrowband is one which can provide a bandwidth of 10% or less; broadband can provide a bandwidth of more than 10% but less than 25% and ultrawideband (UWB) provide bandwidth more than 25%. Example of narrow band communication systems are - GSM (Global System for Mobile communication, 890960 MHz), PCS (Personal Communication System, 1.85--1.99 GHz), DCS (Digital Communication System, 1.71--1.88 GHz), UMTS (Universal Mobile Telecommunication System, 1.92--2.17 GHz), WiMAX (Worldwide Interoperability for Wireless Access, 2.5--2.7 GHz and 3.3--3.69 GHz), ISM (Industrial, Scientific and Medicine, 2.4--2.484 GHz), WLAN (Wireless Local Area Networks, 5.15--5.825 GHz), downlink of satellite communication (X-band 7.25--7.75 GHz). Unlicensed Ultra-wideband lies in 3.1--10.6 GHz frequency range.

The wireless systems are always of greater interest to research community due to their inherent advantages such as modest infrastructure investment (no wire), easy deployment, end user mobility support, remote area connectivity and cost effective. Apart from other electronics, most integral and vital part of any wireless communication system is antenna and are used at both ends – Transmitter and Receiver. Similarly, receiver side antenna is first stage and receives signal from free space.

Conversion of electric energy into electromagnetic energy is performed by antenna and vice-versa. Formally, an antenna has been defined as "*a metallic conductor electrically connected through a transmission line to the receiver or transmitter*" or "*a structure associated with transition region between free space wave and guided wave or vice versa*" [Balanis2005].

The field of antenna is nearly as old as the communication and work in this field is so vast, it is difficult to summarize here. The Hertz [Schantz H.G. 2012] was the pioneer in the field of antenna and provided a comprehensive theoretical framework for understanding radio waves. The research community worked very hard in this field to provide better antennas to support radio communication and various types of antennas are designed and developed. Antennas can be broadly classified as: array, wire, aperture, reflector, microstrip and lens antennas. The work in this thesis is focused on microstrip antennas.

Microstrip antennas are low cost, small size, low profile and associate with other circuit components easily as compared to other antennas. Basic microstrip configuration is very similar to a Printed Circuit Board (PCB). It constitutes a lowloss thin substrate, both sides coated with copper layer. Printed configuration is etched out on one side of the microstrip board and copper layer is used as a ground plane. Early developments attracted some potential research groups and studies on theoretical analysis of different patch geometries and experimental verifications were carried out. Parallel trend also developed very quickly and some research groups tried to implement antennas such as wire, aperture, array etc. in planar form. They are commonly referred to as printed antennas.

Planar antennas include microstrip and printed antennas. Due to microstrip patches, operations and characteristics of such antennas are somewhat different from other types of antennas. With the developments in mobile and wireless communications, urge of modern application was for compact size antennas and planar antenna has been found suitable candidates [Lee and Chen 1997, Wong 2003, Guha and Antar 2011]. Omnipresence of planer antenna is visualized in communication systems such as broadcasting, cell phones, handheld devices, radar, satellite communications, ad-hoc networks as well as in wireless and Bluetooth enabled devices etc.

Recent developments in planar antennas for wireless systems have been studied and design techniques for achieving high performances for such antennas

MICROSTRIP ANTENNAS

In the recent years, cellular, wireless and satellite communication systems have grown manifolds. Reduction in the size of integrated circuits has resulted in reduction in the physical dimensions of electronic equipment's and mobile communication devices. This reduction has fuelled strong demand for broadband and wideband planar antennas catering to various wireless communication applications. Researchers have termed planar antennas as microstrip patch as well.

[Deschamps1953] proposed the first planar antenna as microstrip radiators. However, until early 1970'sresearch outcome was not stated in literature. The first practical microstrip patch antenna was developed by [Munson 1974, Howell 1975].

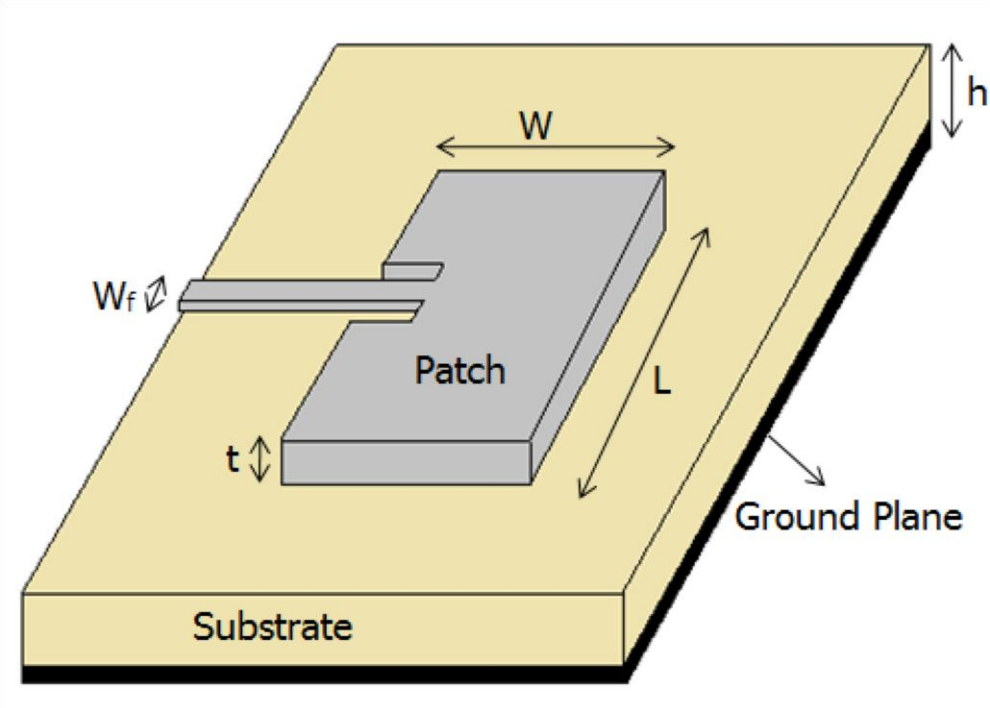

Fig. 1. Basic configuration of a microstrip antenna

Fig. 1. shows basic configuration used for microstrip patch antenna. Microstrip antenna comprises of a ground plane on one side and radiating patch on the other side of a dielectric substrate. Their radiation characteristics are similar to dipole antenna in spite of, different geometrical shape, because patch and ground plane behaves like two different poles. The patch which is normally consists of gold or copper, can have any regular or any other shapes. Regular shapes like- triangular, rectangular, and circular, cone, elliptical

etc. are used to simplify prediction of analysis and performance related to microstrip antennas [Garg et al. 2001].

Substrate dielectric constant should be less. Various types of substrates having a large range of dielectric constant and loss tangent values have been developed and presented in [Carver and Mink 1981]. Microstrip patch antennas are printed over an infinite grounded dielectric substrate with small thickness and loss tangent. Feed lines and radiating patch photo etched commonly on dielectric substrate. For superior performance of a patch antenna, patch thickness (t) must be of several order smaller to the free space wavelength ($t << \lambda_o$). The height h of the dielectric must be within the range $0.3333\lambda_o \leq h \leq 0.05\lambda_o$ and ε_r substrate dielectric constant need to be in the range $2.2 \leq \varepsilon_r \leq 12$ [Balanis 2005]. Thick substrates with lower dielectric constant are desirable good antenna performance, large bandwidth, better efficiency, however, at the cost of large size of element [Pozar 1992, Balanis 2005]. Microstrip patch may be used in application employing broad frequency range ~ 100 MHz to ~ 100 GHz due to its inherent advantages [Garg et al. 2001].

Advantages of Microstrip Antennas

Microstrip antennas provide a lot of advantages over conventional antennas.

Some of advantages over conventional antennas offer by microstrip antennas are [Garg et al. 2001]:

- Low volume , Light weight and thin profile configurations
- Possibility of circular and linear polarization using simple feed
- Low fabrication cost
- cavity backing is not required
- Easy integration with microwave integrated circuits
- Facilitates simultaneous fabrication of matching networks and feed line with antenna design.

Limitations of Microstrip Antennas

In comparison to conventional antennas, microstrip has certain limitations [Garg et al. 2001]:

- Lower gain
- Narrow bandwidth
- In the feed structure of arrays large ohmic loss
- Excitation of surface waves
- Extraneous radiation from feeds and junctions
- Radiation mostly into half space
- Lower power handling capability
- Utilization of high dielectric constant substrate leads narrow bandwidth and poor efficiency.
- Require quality substrate and good temperature tolerance

BASIC ANTENNA PARAMETERS

Antenna plays a significant role in performance of wireless communication, as they are responsible for transmission and reception of electromagnetic signals to facilitate communication between two end devices. The performance of any antenna is determined across some parameters. In this section we have introduced some basic antenna parameters such as: *reflection coefficient*, *S11*, *VSWR*, *bandwidth*, *directivity* and *gain*, *radiation pattern*, *half power beam width* and *polarization*.

Reflection Coefficient (Γ) and S11

Microwave transmission line impedance is called the Characteristic Impedance (Z_0) and microwave device impedance is called the arbitrary load impedance (Z_L). Due to mismatch between Z_0 and Z_L, electric and magnetic fields in the transmission line and in the device do not match. This causes reflection of some of the microwave power at the connection resulting in reflected waves co-existing with incident waves.

Reflection Coefficient, Γ, is a measure of this reflection. It is derived by normalizing the reflected voltage amplitude V_0^{-} to the incident wave amplitude V_0^{+} and it is defined mathematically:

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{V_0^-}{V_0^+} \quad (1.1$$

In an antenna system, the S11 is defined as a *"parameter that indicates the amount of power lost to the load and does not return as a reflection"*. Mathematically, S11 is defined as:

$$S11 = -20\log|\Gamma| \quad (dB) \quad (1$$

This suggests that ratio P_R/P_T should be expressed in dB. It should be as small as possible. The S11 should be negative number and large as possible.

When matching between the microwave transmission line and the microwave device such as antenna is perfect, reflection coefficient Γ is zero. No power would be reflected back by making S11 equal to infinity. All the incident power is reflected back when S11= 0 dB, Γ= 1. In practical uses, acceptable value of reflection coefficient Γ = 1/3 and the S11 becomes equal to -9.54 dB. Due to this reason, bandwidth calculations S11 = -10 dB is considered.

Voltage Standing Wave Ratio (VSWR)

At any point in transmission line, total electric field is equal to the sum of reflected and incident field. Total electric field has maxima and minima as the incident and reflected fields go in and out of phase. This variation in the field is called standing wave pattern. This is characterized by VSWR.

VSWR is defined as "*the ratio of maximum voltage to the minimum voltage along the line*". It expresses match between the microwave device such as antenna and microwave transmission line. Mathematically,

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} = \frac{1+S_{11}}{1-S_{11}} = \frac{V_{max}}{V_{min}}$$

The match is perfect when VSWR is 1 to 1, in this case complete energy transferred to the antenna to be radiated. VSWR value of two is acceptable for practical applications.

Radiation Pattern

It is defined as "*the graphical or mathematical representation of the antenna as a function of space coordinates*". It is a three dimensional quantity involving variation in field or power as function of spherical coordinates [Balanis 2005]. Radiation pattern of a generic antenna is shown in Fig. 2. The pattern has one main lobe with minor lobes in other directions.

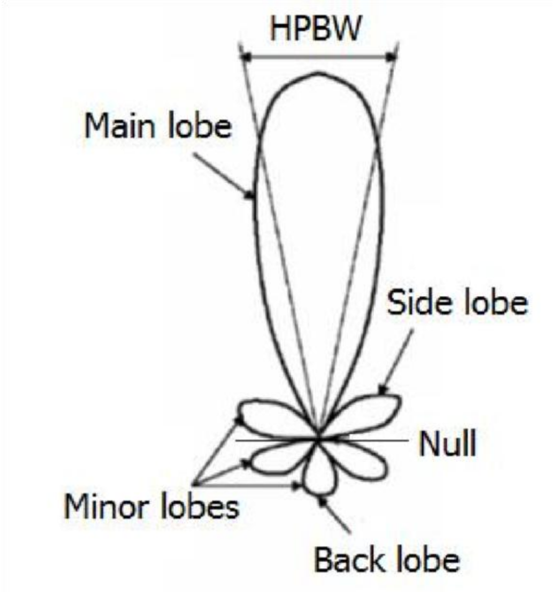

Fig. 1.Radiation pattern of the generic antenna

Direction of maximum radiation is defined by major lobe. In Fig. 2, except the major lobes all other considered as minor lobes [Kraus and Marhefka 2003]. Other than intended direction side lobe is a radiation lobe for radiation in any direction. A back lobe axis makes an angle of 180^0 with respect to antenna beam. Side lobes and back lobe are undesirable because they represent noise sources for receiving antennas and wasted energy in transmitting antennas. In the practical applications side lobe level of -

20 dB or lesser is not desirable [Balanis 2005].

FNBW (First Null Beam Width) and HPBW (Half Power Beam Width)

Pattern beamwidth is defined as "*the angular separation between two identical points on opposite sides of the pattern maxima*". There are a number of beamwidth, in antenna pattern. Half power beam width mostly used. As per [Balanis 2005], the half power beam width is defined as "*the angle between the two directions in which the radiation intensity is half of the maximum intensity of the beam and plane containing the direction of the maximum of the beam*". Another important beamwidth is the first null beamwidth. It is defined as angular separation among first nulls of the radiation pattern.

Directivity and Gain

Directivity of antenna described as "*the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions. The average radiation intensity is equal to the total power radiated by the antenna divided by 4π*". Parameter gain closely related to directivity and performance of antenna is described by it. Gain is realized or actual quantity. Due to ohmic losses in antenna gain of antenna is less than the directivity. Gain of antenna is defined as "*the ratio of the intensity, in a particular direction, to the radiation intensity that would be obtained if the power accepted by antenna were radiated isotropically*". Directive gain is a measure of radiated power concentration in a specific direction [Balanis 2005].

Bandwidth

It is defined as "*the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard*" [Balanis 2005]. It can be measure as frequency range on either side of a center frequency. In this range of frequency antenna characteristics such as *pattern, input impedance, beamwidth, side lobe level, polarization, gain, radiation efficiency*, and *beam direction* are within an adequate value of those available at center frequency. In other words, bandwidth can be defined as *"the frequency range over which it is matched with that of the feed line within specified limits"*. For acceptable operation, ratio of upper frequencies to lower is also defined as bandwidth of broadband antenna. The impedance bandwidth or bandwidth over the center frequency f_c defined as percentage of $f_2 - f_1$ (frequency difference) corresponding -10 dB reflection coefficient.

$$BW_{Broadband}(\%) = \left[\frac{f_2 - f_1}{f_c}\right] * 100; \quad where\ f_2$$

Impedance bandwidth depends on parameters related to the patch antenna element and the type of feed used.

Polarization

In radiated wave polarization is defined as "*the property of an electromagnetic wave describing the time varying direction and relative magnitude of the electric field vector*" [Balanis 2005]. Whereas, polarization of the wave transmitted (radiated) by the antenna is defined as the polarization of an antenna. Polarization plane is known as the plane where the electric field varies. Three types of polarization generally occur:

- Linear polarization
- Elliptical polarization
- Circular polarization

In general, an antenna will radiate an elliptical polarization characterized, can be analysed by parameters: *tilt angle, sense of rotation* and *axial ratio* (AR). The axial ratio is defined as the ratio of major axis to minor of polarization ellipse. Polarization becomes linear with axial ratio is infinite or zero. Perfect circular polarization (CP) obtained with axial ratio unity, tilt angle is not applicable. Circularly polarized waves produce when two orthogonal field components radiated in phase quadrature but equal amplitude [Kraus and Marhefka 2003].

FEEDING TECHNIQUES FOR MICROSTRIP ANTENNAS

Most common feeding methods to feed microstrip antennas are:

- Coaxial feed line
- Proximity coupled feed
- Microstrip feed line
- Aperture coupled feed
- Coplanar waveguide feed

These methods influence the polarization characteristics and input impedance. These techniques further be simplified as: direct contacting (microstrip, coaxial) and non-contacting (aperture and proximity coupled) methods. In first case, radiating patch fed by RF power directly using microstrip line. In second case, for transferring power between radiating patch and microstrip line EM field is used [Carver and Mink 1981, James and Hall 1989, Pozar 1992, Waterhouse 2003, Balanis 2005].

Microstrip Feed Line

One of the original excitation methods is used for patch antenna is microstrip feed technique, shown in Fig. 1.3 [Munson 1974, Waterhouse 2003]. Microstrip feed line is a conductive line having width lesser in

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comparison to the patch. Microstrip feed line is simple to match, easy to fabricate, and model. In this type of feed, surface wave and spurious feed radiation increase with increasing the surface thickness limiting the bandwidth (typically 2-5%). Here, W_f is the width of microstrip feed line with patch of width W and length L.

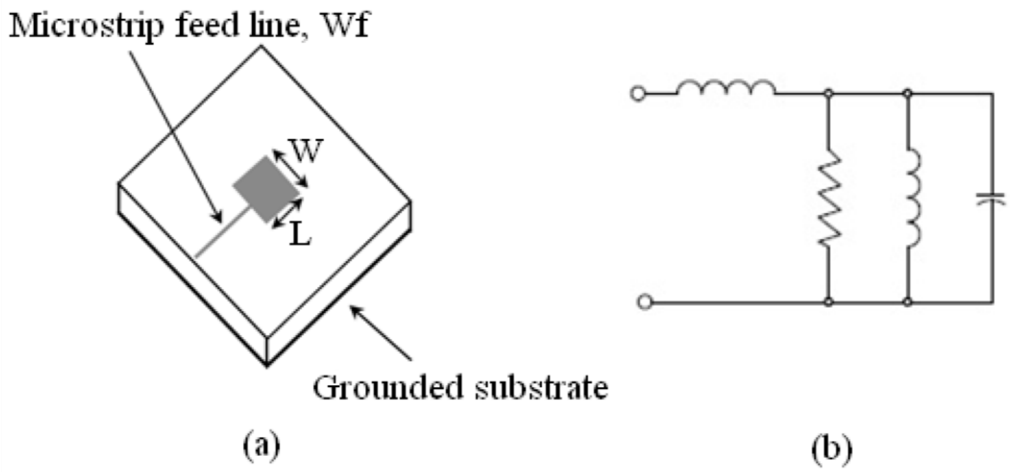

Fig. 3 (a) Microstrip feed line patch antenna, (b) its equivalent circuit diagram

Fig. 3 (b) shows the equivalent circuit of the microstrip feed line patch antenna, parallel RLC network represents the resonant patch and series inductor representing feed inductance of the microstrip feed line. Patch is excited through the coupling of J_z feed current to the E_z field of dominant patch mode and is defined as:

$$coupling \sim \int_v E_z J_z dv \sim cos\frac{\pi s}{L}$$

where L is resonant length of patch and s define as offset of feed point from edge of patch (s = 0 or L) [Pozar 1992].

These types of direct contacting methods are used for simplicity. The methods, however, suffers from bandwidth and feed radiation trade-off. For increasing bandwidth an increase in substrate thickness is required, causing increase in spurious feed radiation and increased surface wave power and feed inductance.

Coaxial Feed Line

A new excitation method proposed in mid-1970s was probe feeding or coaxial feed [Munson 1974]. As shown in Fig. 4 (a), a probe is connected to patch connector through ground plane. Feeding pin or probe commonly works as middle conductor of a coaxial line. Fig. 4 (b) shows the equivalent circuit of the coaxial feed line patch antenna, parallel RLC network representing the resonant patch and series inductor represents feed inductance of the coaxial feed line.

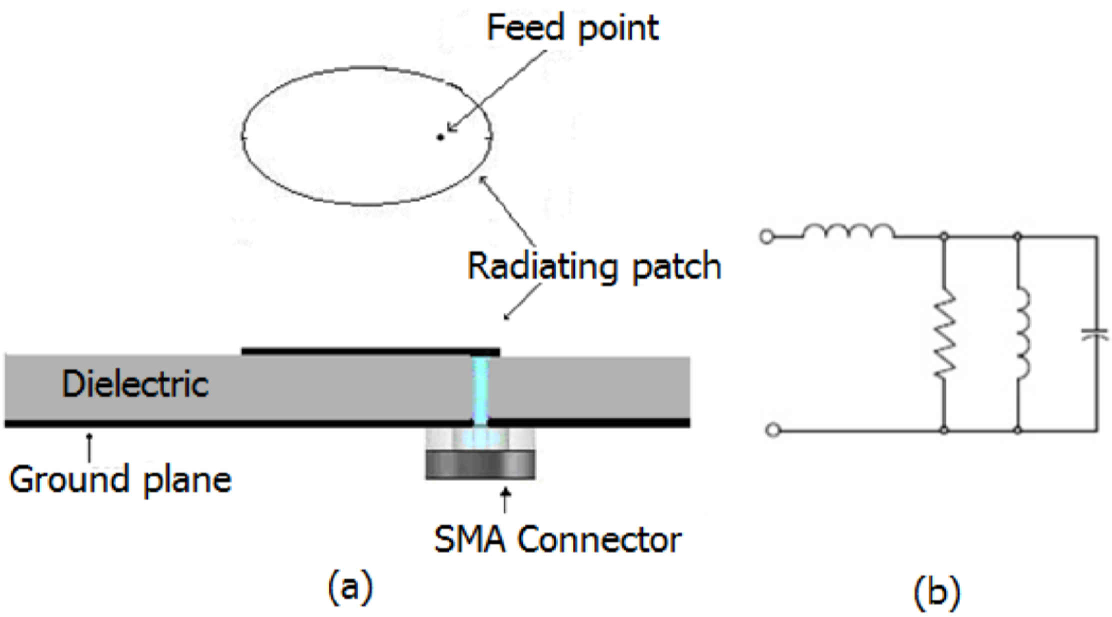

Fig..4 (a) Coaxial feed line patch antenna, (b) its equivalent circuit diagram

Impedance control is obtained by probe position. This type of feeding is known as direct contact type, because of direct contact available between the patch and feed line. Due to direct contacting patch is isolated from feeding circuitry. This minimizes spurious radiation and makes coaxial feed techniques more efficient**.**

Proximity Coupled Feed

A schematic diagram of proximity coupled fed (also known as electromagnetic coupling) is shown in Fig. 5 (a) [Waterhouse 2003, Pozar and Kaufman 1987]. Microstrip antenna contains a microstrip feed line situated at grounded substrate. Above grounded substrate another dielectric laminate with a patch etched on top. These two dielectric layers not separated by any ground plane. Power from feed network is coupled to patch electromagnetically. For bandwidth improvement in proximity coupling, patch exists on a relatively thick substrate whereas feed line is on effectively thinner substrate. This reduces spurious radiation and coupling. Fig. 5 (b) shows the equivalent circuit of the proximity coupled feed patch antenna, which includes a capacitor in series with the parallel RLC resonator representing a patch.

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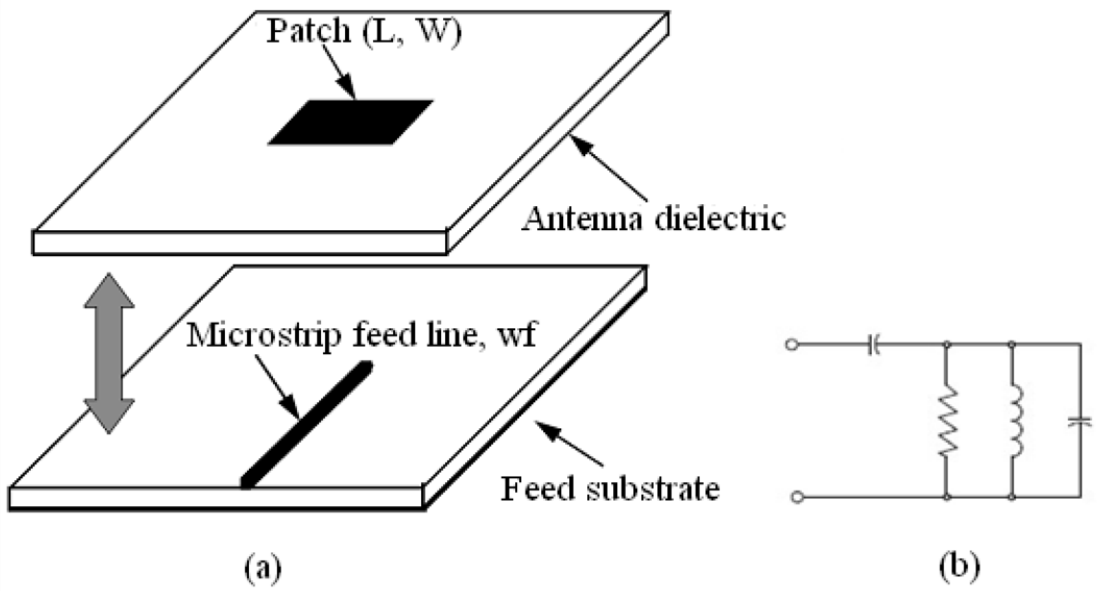

Fig. 5 (a) Proximity coupled feed patch antenna, (b) its equivalent circuit diagram

By controlling width-to-line ratio of patch and length of feed line matching can be achieved. Fabrication of proximity coupled is challenging because proper alignment requires between two dielectric layers.

Aperture Coupled Feed

In this technique, microstrip feed line and radiating patch separated by ground plane [Pozar 1985]. Schematic diagram of aperture coupled feed is shown in Fig. 6 (a) [Waterhouse 2003]. In ground plane, feed line and patch are coupled through an aperture or a slot. Coupling amount from patch to feed line can be obtained by knowing location, size and shape of aperture. Aperture coupled patch provides comparable gain and bandwidth characteristics as those were exhibited by direct fed type patch. However, enhancing the impedance bandwidth of such antennas is very easy. Coupling can occur via equivalent electric or magnetic currents in the slot and is defined mathematically as:

$$coupling \sim \int_v M_y H_y dv \sim sin\frac{\pi s}{L}$$

Where M_y is equivalent magnetic current in the aperture and H_y is dominant field of patch. The relation shows that the maximum coupling occurs when $s = L/2$, i.e., when the aperture is at centre below the patch where the magnetic field is maximum.

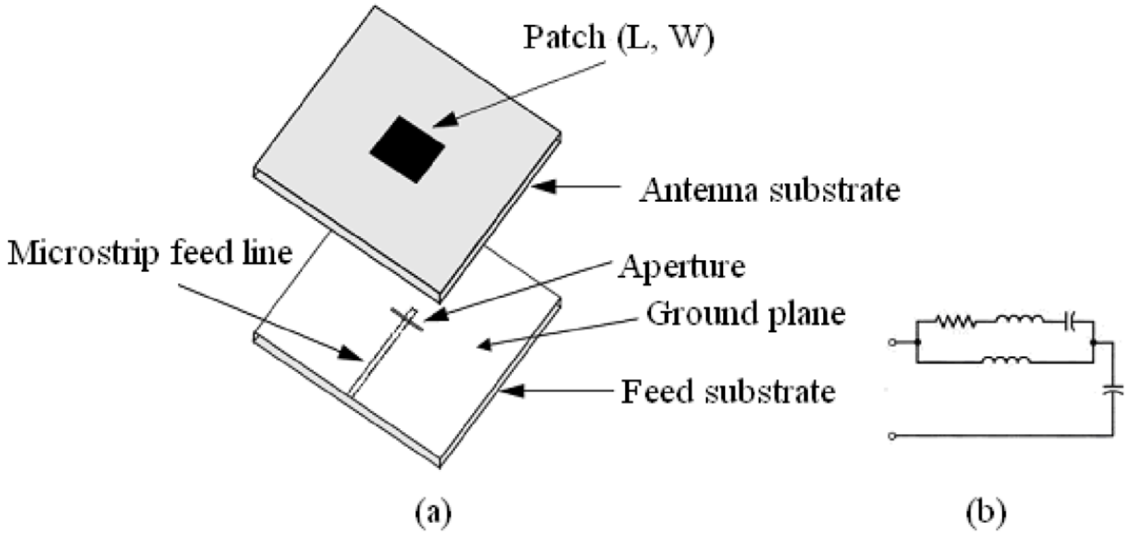

Fig. 6 (a) Aperture coupled feed patch antenna, (b) its equivalent circuit diagram

Equivalent circuit of the aperture coupled feed patch antenna showing, patch as a series RLC resonator is presented in Fig. 6 (b) [Pozar and Schaubert 1996]. In this case, the patch is a load for the slot and then this combination is terminated with the open circuit stub or capacitance.

Coplanar Waveguide Feed [CPW Feed]

A CPW (coplanar waveguide) comprises of conductors on the top of dielectric substrate by [C. P. Wen 1969]. A centre strip is formed by conductors. This strip is separated by a narrow gap either side form two ground planes [R. N. Simons 2001]. For MMICs (Microwave Monolithic Integrated Circuits) CPW is found desired transmission line. Microstrip antennas and CPW both related to planar geometry. Therefore, for integration of MMICs with microstrip antennas, it is desired to feed the microstrip antennas with CPW [Smith and Williams 1992, Garg et al. 2001]. In CPW feed the radiation from the feed structure is negligible and cross polarized radiation from the feed is lower. Due to odd mode excitation, both CPW slots radiate nearly out of phase magnetic currents, near negligible amount is contributed to the feed radiation. Above feature of CPW feed is used in the microstrip antennas design, because in adjacent lines mutual coupling is minimized [Garg et al. 2001].

METHODS OF ANALYSIS FOR MICROSTRIP ANTENNAS

On a thin dielectric substrate a two-dimensional radiating patch is created. Therefore, for analysis purposes it can be consider a two-dimensional planar element.

Prediction of radiation characteristics is the main task in antenna analysis. Sum of radiation characteristics are gain, radiation patterns, polarization and near-field characteristics such as impedance bandwidth, input impedance, antenna efficiency and mutual coupling. Following are the cause which makes analysis part complicated in microstripe antennas: inhomogeneous boundary conditions, presence of dielectric inhomogeneity narrow frequency band characteristics and a wide variety of patch shape, substrate configurations, and feed. Thus, by compromising sum features of microstrip antennas a balance is reached between accuracy of solution and complexity of technique [Garg et al. 2001].

A method for analysis can be generally divided into two groups. One group consists of analytical models for analysis of microstrip antennas. These are based on equivalent magnetic current distribution around the edges of patch. Some of the analytical techniques for analysing microstrip antennas are:

- Multiport Network Model
- Transmission Line Model
- Cavity Model

Second group has full wave analysis models for analysis of microstrip antennas. Full wave analysis utilizes electric current distribution on the ground plane and patch conductor. Full wave techniques for analysing microstrip antennas are:

- Finite-Difference Time-Domain Analysis (FDTD)
- Spectral-Domain Full-Wave Analysis
- Mixed-Potential Integral Equation Analysis

Full wave techniques maintain rigor and accuracy at the expense of numerical simplicity. These techniques generally provide the most accurate solution for the impedance and radiation characteristics. The solution includes the effects of dielectric loss, conductor loss, space wave radiation, surface waves, and external coupling. Full wave technique can be used for arbitrarily shaped microstrip elements and arrays, various types of feeding techniques, multilayer geometries and active antennas. A brief introduction of the above mentioned analysis techniques and their salient feature is included here. Mathematical modelling may be found in [James and Hall 1989, Garg et al. 2001].

Several other techniques are also available which can provide Maxwell's equations solution and can be implemented on computing platforms. These techniques are divided into two categories: the first is based on IE (integral equation) model and second is based on DE (differential equation) model [J. W. Hand 2008]. Some of the techniques available in the literature for analysing the various shapes of antennas are:

- Finite Integration Technique (FIT)
- Method of Moments (MoM)
- Finite Element Method (FEM)

Transmission Line Model

Most intuitively appealing models for microstrip antennas are transmission line model. Rectangular and square patches have a shape derived from microstrip transmission lines. Therefore, these antennas can be modeled as sections of transmission lines. Similarly, circular patches, annular rings, and sectors of circular patches and annular rings can be modeled as section of radial transmission lines. In transmission line model, inner region of patch antenna is modeled as section of transmission line. The antenna has a physical structure derived from a microstrip transmission line [Garg et al. 2001].

Transmission line model was the first technique and employed by [Munson 1974] for analyzing a rectangular microstrip antenna. This model was further improved by [Derneryd 1978]. A length of transmission line of propagation constant $\gamma=\alpha+\beta$ and characteristic impedance Z_0 is represented as microstrip antenna by this model. The fields vary along the length of the patch, which is usually a halfwavelength, and remain constant across the width. The fringing fields at the open ends cause radiation. Radiation pattern of antenna are assumed to be the same as that obtained from array that consists of two narrow slots and these are apart by a distance equal to the length of the patch. The input admittance of the feed port is obtained by transforming the edge admittances to the feed point. Input impedance or driving point impedance is the impedance measured at a point where the antenna is connected to the transmission line. Resulting expression for input admittance of probe-fed patch radiator along with the transmission line equivalent circuit as shown in Fig. 7 [Bancroft 2004] is mathematically given by:

$$Y_{in} = \frac{jY_0 \tan(\beta L) + Y_L}{jY_L \tan(\beta L) + Y_0}\ Y_0 \qquad (1.7)$$

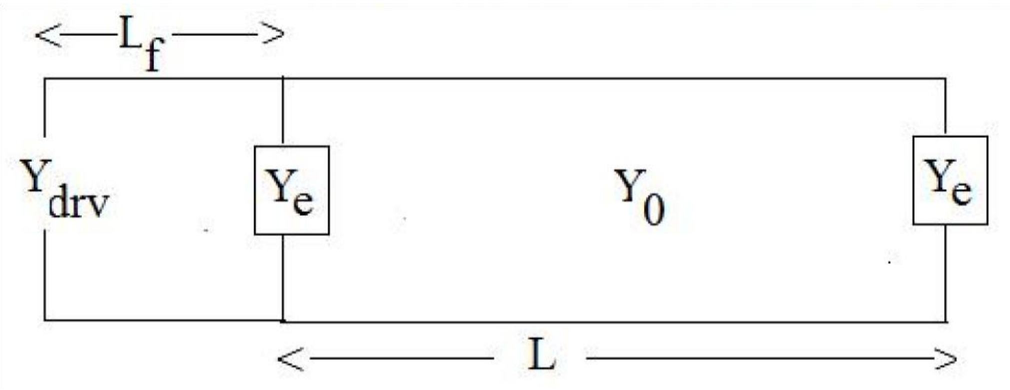

Fig. 7 Transmission line feed at radiating edge

The driving point Z_{drv} at any point along the center line of a rectangular microstrip antenna can be computed using transmission line model. Popularity of the transmission line model may be gauged by number of extensions to this model developed by [Pues and Van de Capalle 1984, Bhattacharyya and Garg 1985, 1991]. "GTLM" Generalized transmission line model was given by [Bhattacharyya and Garg 1985, 1991]. In this method, sections of transmission line are converted into π network equivalents. GTLM approach is applicable to microstrip antenna; geometry utilized for this approach is rectangular patch or any separable geometry.

Cavity Model

Microstrip patch antennas are narrow-band resonant antennas and termed as lossy cavities, and these are exhibited high order resonances. Therefore, this cavity model becomes a natural choice to analyse the patch antennas. The cavity model was advanced by [Lo et al. 1979, Richards et al. 1981]. In this model, the inner region modelled as a cavity restricted by electric walls on both bottom and top, and a magnetic wall all alongside the periphery. The bases for above assumption are the following observations for thin substrates ($h <<$ □$_0$):

- The fields in the interior region do not vary with z (that is, □/□z = 0) because the substrate is very thin $h <<$ □$_o$.
- In the region which is restricted by the patch metallization and the ground plane has an electric field z directed only and a magnetic field has transverse components H_x and H_y.

• Electric current in the patch normal to the edge of patch metallization is zero, which implies that the tangential component of H along the patch periphery is negligible, and a magnetic wall can be placed there, The field distribution in the patch can be divided into two regions: the interior fields and the exterior fields. The exterior fields are the fields outside the cavity region that determine the radiation characteristics of the patch antenna. The interior fields are useful in determining input impedance and the currents responsible for radiation [Garg et al. 2001]. The cavity model has been applied to a number of patch shapes of microstrip antennas, including rectangular and circular patches analysed by [Richards et al. 1981, Lo et al. 1979], equilateral triangles analysed by [Lee et al. 1988], circular and annular rings analysed by [Richards et al. 1984, Lee and Dahele 1985].

To analyse non separable geometries [Palanisamy and Garg 1985, 1986] proposed a generalised cavity model and in this model, the electric field in the patch is determined by segmenting the given patch into a number of regular shapes.

Multiport Network Model (MNM)

Extension of cavity model was the multiport network model and it was proposed by [James and Hall 1989]. This model has been used to determine mutual coupling between various edges of the rectangular patches. The MNM has been applied to analyse a variety of microstrip antennas [Gupta K.C. and Benella A. 1986, 1988]. The major advantage of MNM is that any discontinuity in the patch is also included in the analysis of various shapes of the patches.

Spectral-Domain Full-Wave Analysis

The spectral-domain full-wave approach uses the Green's function for the mixed dielectric nature of the microstrip antenna [Pozar 1987, Deshpande and Bailey 1982]. The Green's function is employed in the electrical field integral equation formulation to satisfy the boundary condition at the patch metallization. Further, the resulting equation is discredited into a set of linear equations by means of the method of moment to yield a matrix equation. The solution of the matrix equation provides the current distribution on the patch metallization. The antenna far field and near field characteristics are obtained from the current distribution and Green's function [Garg et al. 2001].

The integral equation solution in the spectral domain has been used to analyse various microstrip antenna configurations. [Deshpande and Bailey 1982, Pozar 1987] applied this method for analysis of rectangular patch. [Bailey and Deshpande 1985] applied this technique for elliptic patch, and [Shively et al. 1994] used this for arbitrary shaped geometry.

Mixed-Potential Integral Equation Analysis

The mixed-potential integral equation approach is computationally more efficient than the integral equation analysis described in the spectral domain. Most commercial integral equation solver uses this technique for the analysis of microstrip antenna configurations. Different types of potential Green's functions are used in MPIE to set up the integral equation [Garg et al. 2001]. Using the method of moment's integral equation can be solve [Harrington R. F. 1968, 1993].

Solution of integral equation based on MPIE has been used to analyse various types of microstrip antenna configurations such as patch shapes, feed types, stacked geometries, an isotropic substrates, and array geometries. [Mosig and Gardiol 1985, Demuynck et al. 1998] applied this method for basic technique and analysis of rectangular patch. [Wu et al. 1991] applied this technique for triangular patch, and [Wu et al. 1991, Uckun et al. 1997, Hall and Mosig 1996] used this technique for arbitrary shaped geometry.

Finite-Difference Time-Domain Analysis

The FDTD technique is used extensively in the analysis and design of microstrip antennas [Yee 1966]. The major difference between FDTD and other numerical techniques is that analytical pre-processing and modelling are almost absent in FDTD. Therefore, complex antennas can also be analysed using FDTD. This approach can be used to include the effect of finite size of substrate and ground plane, which is important in the design of many microstrip antennas like microstrip patch antennas for handheld receivers, ultra-wideband antennas and many more microwave planar antennas. Interaction between the device and circuits at the field level can be incorporate using FDTD. This is necessary for accurate analysis of microwave active circuits and antennas. Active microstrip antennas can be analysed using FDTD.

FDTD has the following advantages over other techniques:

- Mathematically, it is a direct implementation of Maxwell's curl equations.

  Therefore, analytical processing of Maxwell's equations is almost negligible.

- It is capable of predicting broadband frequency response because the analysis is carried out in the time domain.

- It is capable of analyzing complex systems, including wave interaction with human body, or satellite, nonlinear device simulations, complex antennas and so on.

- It analyzes structures using various types of materials for example, magnetized ferrites, anisotropic plasmas and lossy dielectric.
- Because it is a time-domain technique, it can predict the transient response of an electromagnetic system. When these transient data are transformed to the frequency domain, they translate into a wideband system response.

For analysis of any problem using FDTD, the structure is divided into different/multiple/various regions based on the material properties [Garg et al. 2001]. The technique is used to analysing various types of slot and microstrip antennas, including rectangular patch antennas with probe feed [Reineix and Jecko 1989, Wu et al. 1992 and Cheng et al. 1995]. [Dey and Mittra 1997] applied this technique for circular patch antennas. The technique is very useful in the analysis of handheld microstrip antennas and antennas with finite ground plane and dielectric. *XFDTD, FIDELITY, EMPIRE Xcel*, and *CONCERTO* are some of the commercially available software based on FDTD.

Finite Element Method

Numerical analysis of the field's interior to the microstrip antenna cavity can also be carried out using finite element approach [Carver and Coffey 1979]. Finite element is a variational method in which a minimization process automatically seeks out the solution closest to the analytical solution. The FEM technique can be used efficiently for analysis of electromagnetic structures that include inhomogeneous and anisotropic materials. Interior region of the microstrip antenna is mathematically decoupled from the exterior region using equivalent aperture admittance as the boundary conditions in the same manner [Carver 1979]. Interior electric field, E_z, satisfies the inhomogeneous wave equation along with an impedance boundary condition on the perimeter walls [Carver and Mink 1981].

Finite element method has advantages in comparison to other methods of computing. Approximation functions for each finite element are derived and these finite elements represented as collection of geometrically simple sub domains. To compute radar cross-section of a two dimensional cavity, finite element technique in concurrence with Fourier transforms was used [Van and Wood 2003]. Steps required for analysis using FEM technique are as follows:

- Discretization of the problem
- Formulation of the system of equations,

- Selection of interpolation functions and
- Solutions of the system of equations

Authors have discussed programmed mesh generation on the acquire statistics [Lee et al. 2005, 2007]. In the recent years, various research articles on microwave planar antennas have been published and these articles were based on FEM. *HFSS (High Frequency Simulation Structure)* and *FEKO* are some commercially available software based on finite element method.

Finite Integration Technique (FIT)

This technique was proposed by [Thomas Weiland 1977]. To a set of staggered grids, Maxwell's equations are applying in integral form. This approach provides high flexibility in boundary handling and geometric modelling in addition to incorporation of arbitrary material distributions and material properties such as dispersion, nonlinearity and anisotropy. This technique covers the full range of electromagnetic and optic applications.

In the past years, various research articles on microwave planar antennas have been published and these articles based on finite integration technique. *CST (Computer Simulation Technology) Microwave Studio* is commercially available software works on finite integration method. In our present work, we are using this software and published several articles in international journals and conferences.

Method of Moments

The MOM is the most powerful tool available nowadays for analysis of fairly general electromagnetic field problems that involve linear media. This technique proposed by [Harrington 1968, 1993], transforms the integral equation into a matrix algebraic equation, which may be easily solved on a computer. Evaluation of the integrals for the impedance matrix and source voltage vector elements requires attention to the geometry and polarization of any given microstrip patch. The method of moments technique of a quarter-wavelength shorted microstrip antenna and can be adapted to other microstrip antennas of nonstandard patch shape [Carver and Mink 1981].

The method of moments is most widespread numerical technique in electromagnetics. The technique uses two important concepts of electromagnetics, namely Green's functions and superposition. The procedure for analysis of microstrip patch antennas using method of moments is provided by [Abd-Alhameed et al. 1998]. In the past years, various research articles on microwave planar antennas have been published and these articles based on method of moment

(MoM) technique. *ENSEMBLE* software is based on full wave moment method is popular simulation software among antenna designers. Other commercially available simulation softwares based on MoM are *FEKO, SONNET EM SUITE3D* and *MULTISTRIP*.

AVAILABLE SIMULATION SOFTWARE'S FOR MICROWAVE PLANAR ANTENNAS

Patch antenna generally has a two-dimensional radiating patch formed on a dielectric substrate. Therefore, for analysis purposes these may be characterized as a two-dimensional planar component. Researchers are working on numerical simulations of interactions between customized software and EMFs.

The wide range of commercial available software offers three-dimensional full wave solutions to electromagnetic fields (EMF) coverage. The commercially available simulation software packages in the real world are *CST Microwave Studio*, *FEKO*, *HFSS*, *SONNET EM SUITE3D*, *XFDTD*, *FIDELITY*, *EMPIRE Xcel*, *CONCERTO* and *MULTISTRIP*.

Commercially available software contains the ability of importing the structure such as filters, coils, antennas, etc. in CAD (computer aided design) formats, modelling sources (plane wave, voltage, waveguide and current), providing a selection of boundary conditions, defining lumped elements (inductors, capacitors, resistors), incorporating adaptive meshing, accounting for frequency dependent magnetic and dielectric properties and for thin metallic structures.

In addition to above, commercially available simulation software packages provide visualization current density, power, energy of electric and magnetic fields, voltage standing wave ratio, reflection coefficient parameters (*S*-parameters), and computation of port impedances. A range of useful post-processing features comprise animation of the field parameters, Smith chart representation, overlay of the structures, field and mesh parameters, data processing in both frequency and time domain and export of data in desired formats.

Modular software packages provides many additional features, can be combined with hardware acceleration and support a variety of computing platform in order to achieve desired run times while solving big problems. Some software's suggest additional solvers such thermal solvers and as low frequency solvers based quasistatic estimation. For any package, in view of the amount of data produced and complexity exists in models an intuitive user interface is a key feature [J. W. Hand 2008].

Based on the above analysis, we are using the CST Microwave Studio in our thesis and features of this commercial available software package are presented in the next section.

CST Microwave Studio

For 3-dimensional simulation CST-MWS (CST Microwave studio) is an expert tool. This software is based on the finite integration technique for high frequency data. CST-MWS provides precise and quick analysis for high speed digital circuits, microwave planar antennas, couplers, planar and multi-layer structure filters, electronic components and EMI and EMC effects. This software is a user friendly and gives quick insight into the electromagnetic behaviour for high frequency designs and circuits. CST-MWS provides, other solver modules for specific application, offers broadly applicable frequency domain and time domain solver. The CST-MWS has become the most adaptable, efficient, easy to use, and precise electromagnetic simulation tool because it has following important features:

- General purpose solver provides tetrahedral and hexahedral meshes.
- Transient solver provides efficient calculation for lossy, loss-free structures and *S*-parameters calculation.
- Frequency domain solver with adaptive sampling also contains hexahedral meshes (resonant structures).
- First one (General purpose) does only calculate S-parameters while the second one (Frequency domain) also calculates fields which needs some supplementary calculation time.
- It provides radar cross section calculation and far field (angular beam width, gain, 3D, 2D and more).
- Solver supported by hexahedral grids provides perfect boundary approximation.
- The structure can be observed either as a 3D model or as a schematic. The latter permits for easy coupling of circuit simulation with EM simulation.
- It has expert system based automatic mesh generation with 3D adaptive mesh refinement.

Based on the above features the CST MWS is the complete technology for 3dimensional approach.

Conclusions:

Microstrip antennas are one of the most researched topics in current antenna technology. Due to their compact size they are playing very important role in wireless communication especially, in mobile device. Further, FCC authorized to use 3.1-10.6 GHz (UWB frequency range) as unlicensed band by in the year 2002, UWB communication became an attractive proposition for research community because of its distinguished benefits such as low cost, complexity and power consumption, penetration through any material, etc. The microstrip antenna is an essential part of any communication scheme and hence become a hot topic of research in recent times.

Rectangular, square, triangular, circular and elliptical patch antennas are the most popular geometries among the printed antennas due to their simple structure and easy mathematical modelling in comparison to complex geometries antennas. In the past years, many modifications in these geometries are analysed and improve the characteristics in different aspects. Generally, conventional printed antennas are resonating at a single frequency corresponding to their dominant mode. These antennas have two limitations such as low bandwidth and low gain. In modern wireless communication systems high data rate is desirable along with requirement of coexistence with current communication systems, this needs that these antennas must be capable of resonating on more than one resonant frequency. The broadband and wideband antennas can be made to resonate on more than one frequency by modifications in their geometry and to provide improved characteristics.

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