

Chapter Two

Literature Review

2.1 Overview:

This chapter gives an introduction to multiband antenna and Broadband wireless networks, and the terminology used in relation to multiband antenna and heterogeneous technology. And introduce the analysis and design of microstrip patch antenna. Finally shown more studies talk about rectangular microstrip patch antenna design and reconfigurable multiband using microstrip patch antenna.

2.2 Broadband Wireless Network:

Broadband wireless sits at the confluence of two of the most remarkable growth stories of the telecommunications industry in recent years. Both wireless and broadband have on their own enjoyed rapid mass-market adoption. Wireless mobile services and Internet grew from being a curious academic tool to having about a billion users. This staggering growth of the Internet is driving demand for higher-speed Internet-access services, leading to a parallel growth in broadband adoption. Broadband users worldwide are finding that it dramatically changes how we share information, conduct business, and seek entertainment. Broadband access not only provides faster Web surfing and quicker file downloads but also enables several multi-media applications, such as real-time audio and video streaming, multimedia conferencing, and interactive gaming. Broadband connections are also being used for voice telephony using voice-over-Internet Protocol (VoIP) technology. More advanced broadband access systems, such as fiber-to-the-home (FTTH) and very high data rate digital subscriber loop (VDSL), enable such applications as entertainment-quality video, including high-definition TV (HDTV) and video on demand (VoD). As the broadband market continues to grow, several new applications are likely to emerge, and it is difficult to predict which ones will succeed in the future [5].

Broadband wireless is about bringing the broadband experience to a wireless context, which offers users certain unique benefits and convenience. There are two fundamen-

tally different types of broadband wireless services. The first type attempts to provide a set of services similar to that of the traditional fixed-line broadband but using wireless as the medium of transmission. This type, called fixed wireless broadband, can be thought of as a competitive alternative to DSL or cable modem. The second type of broadband wireless, called mobile broadband, offers the additional functionality of portability and mobility. Mobile broadband attempts to bring broadband applications to new user experience scenarios and hence can offer the end user a very different value proposition [5].

2.3 Heterogeneous Network:

A heterogeneous network (HetNet) is a network connecting computers and other devices with different operating systems and/or protocols. The word heterogeneous network is also used in wireless networks using different access technologies. And also the reference to a HetNet often indicates the use of multiple types of access nodes in a wireless network. Heterogeneity has been introduced to be one of the most important features in the next generation wireless network (e.g., the fourth generation or 4G). In heterogeneous wireless networks, different wireless access technologies are integrated to complement each other in terms of coverage area, mobility support, bandwidth, and price [6].

2.4 Fixed Mobile Convergence:

Fixed-mobile convergence (FMC) is the trend towards seamless connectivity between fixed and wireless telecommunications networks. The term also describes any physical network that allows cellular telephone sets to function smoothly with the fixed network infrastructure. The goal of FMC is to optimize transmission of all data, voice and video communications to and among end users, no matter what their locations or devices. In the more immediate future, FMC means that a single device can connect through and be switched between wired and wireless networks [7].

Mainly the differences between WiFi and WiMax are at medium access control (MAC) and physical layer (PHY), while at upper layer working at internet protocol (IP) where all packets from all radios are converged at with convergence sub-layer (SC). At MAC layer there are many convergence protocols has been proposed by re-

searchers. Several technologies have been developed for vertical handover purposes, for example, media independent handover 802.21 MIH is an emerging IEEE standard that enables handover and interoperability between the heterogeneous network types including both 802 and non 802 networks which allow handover between the cellular and the 802 based technologies, i.e., 802.11, 802.15 and 802.16 networks. UnlicensedMobile Access (UMA) based on IMS (IP multimedia subsystem) is ETSI 3GPP standard which provides vertical handover and inter-working to extend mobile voice, data and Multimedia applications over the IP networks [7]. However these standards are designed for separate entities, i.e., gateway or server works as inter-working device between the two networks which can be owned and controlled by the operator. The needs for lightweight handover module that can work on the mobile or small access point open the door for many research proposals.

At physical layer there are many efforts and concern has been given to radios convergence. Two approaches can be considered for convergence at baseband and RF levels. At baseband level, one of the most interested topics in recent year was software defined radio (SDR). In SDR all the baseband portion in the transceiver is combined in one chip i.e. digital signal processing. At RF level, convergence can be done for zero IF or at multiband antenna levels. Multiband antenna, an antenna designed to operate on several bands. These antennas often use designs where one part of the antenna is active for one band, and another part is active for a different band. Convergence techniques can be summarized as in Figure 2.1.

2.4.1 Multiband antenna:

Antennas are transducers that transfer electromagnetic energy between a transmission line and free space. Antennas are in general reciprocal devices, which can be used both as transmitting and as receiving elements. Antenna measurement techniques refer to the testing of antennas to ensure that the antenna meets specifications or simply to characterize it. Antenna Parameters are gain, bandwidth, efficiency,directivity andradiation pattern. Gain as a parameter measures the directionality of a given antenna. An antenna with a low gain emits radiation in all directions equally, whereas a high-gain antenna will preferentially radiate in particular directions. The bandwidth is the range of frequencies within which the performance of the antenna, with respect to

some characteristic, conforms to a specified standard. In other words, bandwidth depends on the overall effectiveness of the antenna through a range of frequencies, so all of these parameters must be understood to fully characterize the bandwidth capabilities of an antenna. Efficiency is the ratio of power actually radiated to the power put into the antenna terminals. Antenna directivity is the ratio of maximum radiation intensity (power per unit surface) radiated by the antenna in the maximum direction divided by the intensity radiated by a lossless isotropic antenna with the same input power. Directivity is a dimensionless ratio and may be expressed numerically or in dB. Directivity is determined without respect to antenna efficiency and differs from gain where antenna efficiency is considered. Directivity is a theoretical quantity based on the lossless case and will always be greater than gain. The radiation pattern is a graphical depiction of the relative field strength transmitted from or received by the antenna. As antennas radiate in space often several curves are necessary to describe the antenna [11].

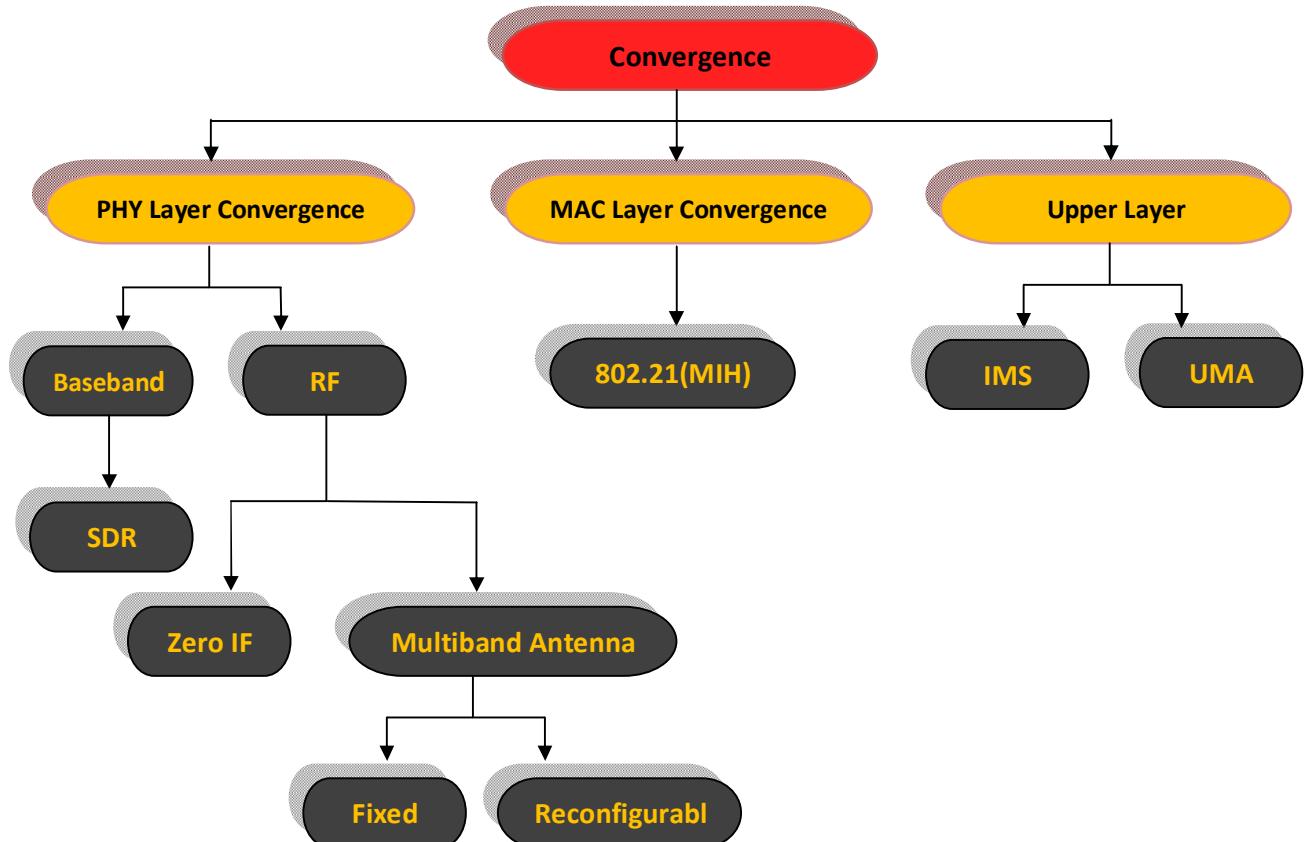


Figure 2.1: Convergence Techniques at Different Levels.

Modern wireless devices or systems are getting smaller and thinner in addition to the increase in the number of services required to be integrated in one device. Therefore, antennas are required to fulfill these needs with multiple bands capabilities and with small and slim overall size. Some of wireless applications requires fixed antenna where the antenna is designed and optimized to operate at particular frequencies and some requires adaptive antenna (reconfigurable) where the antenna's operating frequencies can change to other bands by using reconfigurable elements (multifunctional antenna). In the fixed designs, independent control of the operating frequencies is investigated to enhance the antennas capabilities and to give the designer an additional level of freedom to design the antenna for other bands easily without altering the shape or the size of the antenna. Although fixed multiband antennas can widely be used in many different systems or devices, they lack flexibility to accommodate new services compared with reconfigurable antennas. A reconfigurable antenna can be considered as one of the key advances for future wireless communication transceivers. The advantage of using a reconfigurable antenna is to operate in multiband where the total antenna volume can be reused and therefore the overall size can be reduced [17].

2.4.2 Software Define Radio:

As the numbers of different wireless systems grow, the need for interoperability is being addressed through multimode radios that support multiple standards. Today, such radios use one receiver chain for each standard, and channels are selected using fixed analog-defined channel filters. However, given the absence of a single standard, the ability to reconfigure the radio to each standard on demand is more appealing because of the flexibility and apparent cost advantages it could provide.

The goal of software-defined radios (SDRs) is to enable coverage of multiple radio systems with a single handset using common hardware whose configuration is under software control. In principle, SDR systems could use a single wideband analog stage and convert all channels to and from digital form by a single high-speed analog-to-digital converter (ADC) in the receiver, or a digital-to-analog converter (DAC) in the transmitter. At the receiver, the desired channel could be selected from the digitized carrier waveform by software-defined channel selection filters within the digital signal processor. Analog filters would still be essential to limit the noise bandwidth, to

prevent aliasing, and to limit the bandwidth to prevent spurious signals entering the ADC. Some compromise would be required, since the need for multimode coverage would imply that these filters would need to be kept broadband to cover the entire range of possible input bandwidths. Digital filtering would in principle be used after the ADC to pick out the desired channel component from an array of possible channels that exist within this bandwidth [8].

2.5 Wireless Transceiver Design:

The insatiable requirement for high-speed real-time computer connectivity anywhere, at any time, fuelled by the wide-spreading acceptance of the Internet Protocol, has accelerated the birth of a large number of wireless data networks. Buzzwords, such as WiFi, Bluetooth and WiMax, have already become everyday language even for people unfamiliar with their technological meaning. They all, however, refer to the same basic functionality: the transfer of high-speed data through wireless networks. As we proceed in the twenty-first century, the variety of wireless standards is far from converging, since each one has its own peculiar advantages. Trying to figure out their evolution is very difficult. The only certain fact is that all of them will seek to enable digital communications through broadband wireless equipment, and one of the main tasks being the capability of allowing a large number of different users to coexist and operate in a crowded and often unregulated electromagnetic environment [9].

The design of modern digital wireless modems and transceivers, capable of supporting high-speed data protocols in such wild scenarios, is very different from the traditional one. Many of the components in the wireless chain require an integration scale whose cost can be justified only for extremely large production quantities, thus, their design and production is way beyond the capability of most hi-tech industries.

Modern transceiver architectures are very different from traditional ones. Many of the functions traditionally belonging to radio-frequency (RF) circuitry have been taken over by digital signal processors, and the boundaries between baseband (low-frequency) functionality and radio-frequency performance have become fuzzy [9].

The small physical size and low cost, required by competitive commercial equipment, together with mandatory multisystem operability and very low current consumption,

dictate large integration scales for both baseband and RF subsystems. Such a high integration level on a chip cannot be achieved with conventional transceiver configurations [9].

5.2.1 Basic Wireless Transceiver Design:

The receiver can divide into three main functional blocks as shown in Figure 2.2:

- Front end: all the circuits that carry out operations at final RF frequency, such as RF front filters, low-noise amplifiers (LNA), high frequency mixers etc.
- Intermediate frequency (IF) chain: all the circuits operating at non-zero IF frequency (if any).
- Backend: all the circuits operating at a frequency below first IF (if any) or other than final RF frequency, such as baseband processing, detector etc.

And also, the transmitter can divide into three main functional blocks:

- Power amplifier (PA): all the amplifiers at final RF frequency with input $>+10$ dBm.
- Exciter: the amplifier chain whose output drives the PA.
- Backend: all the other circuits.

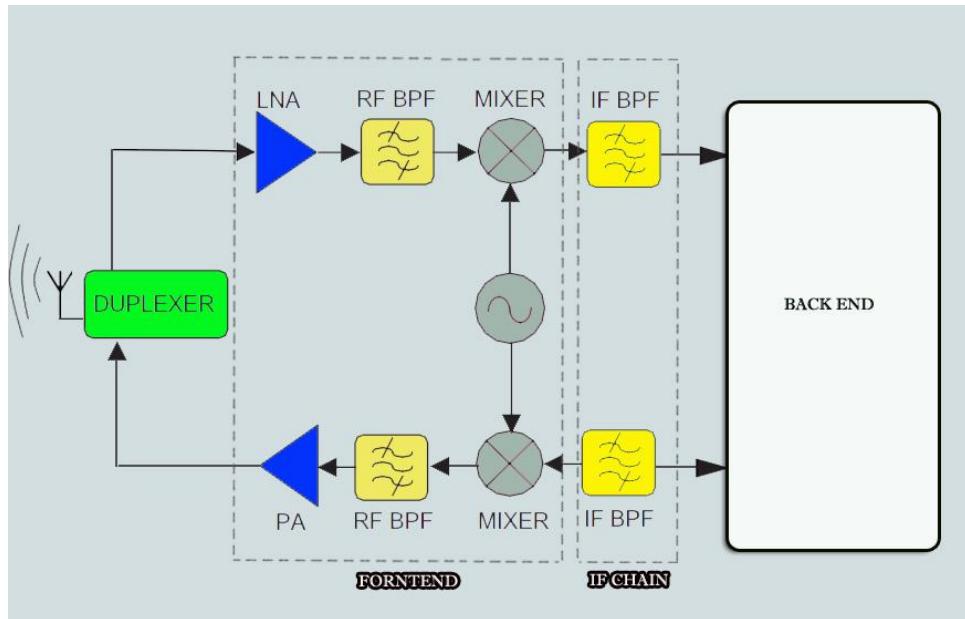


Figure 2.2: Basic Transceiver Design [9]

2.5.2 Heterogeneous Transceiver :

Heterogeneous transceiver that can support many frequency band and radio transmission system on a single mobile terminal and more efficient use of the radio spectrum through the future technology of cognitive radio. Figure 2.3 is shown heterogeneous transceiver design.

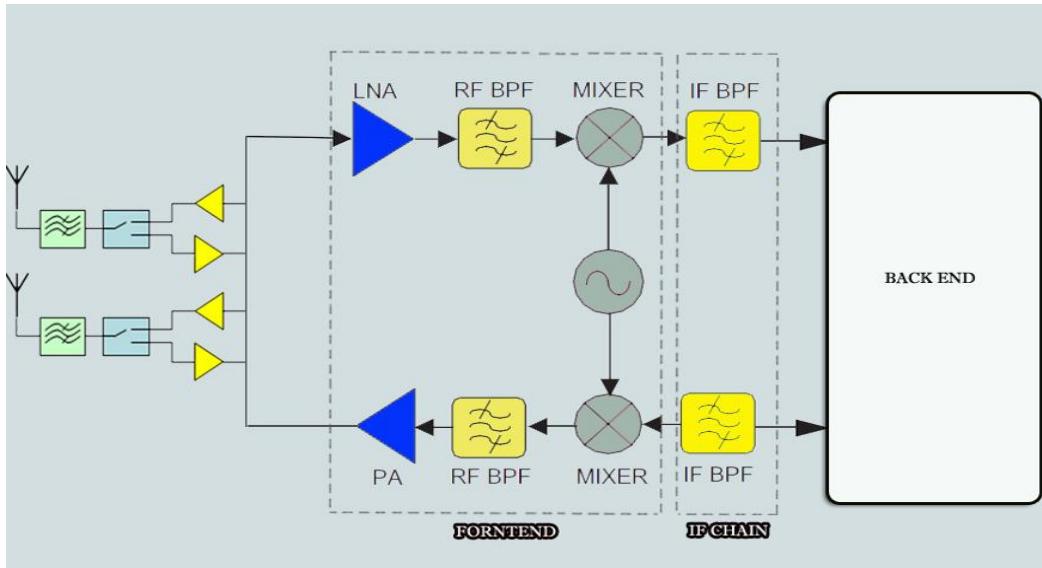


Figure 2.3: Heterogeneous Transceiver Design.

2.6 Microstrip Antenna:

The concept of microstrip antenna dates back to the 1950's, but it was not until the 1970's that greater emphasis was given to develop this technology. This is mainly due to the availability of good substrates. Since then, extensive research and development of microstrip antenna and arrays, exploiting the numerous advantages such as light weight, low volume, low cost, planar configuration, compatibility with integrated circuits, have led to diversified applications and to the establishment of the topic as a separate entity within the broad field of microwave antennas. [10] The rapidly developing markets, especially in personal communication systems (PCS), mobile satellite communications, direct broadcast (DBS), wireless local area networks (WLAN) and intelligent vehicle highway systems (IVHS), suggest that the demand for microstrip antennas and arrays will increase even further. In the meantime, the increasing demand calls for the further development of them[11]. Microstrip antennas are

characterized by a larger number of physical parameters than a conventional microwave antenna. All microstrip antennas can be divided into four categories: microstrip patch antennas, microstrip dipoles, printed slot antennas and microstrip traveling-wave antennas [12][13].

2.6.1 Microstrip Patch Antenna Structure:

A microstrip antenna generally consists of a dielectric substrate sandwiched between a radiating patch on the top and a ground plane on the other side as shown in Figure 2.4. 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.

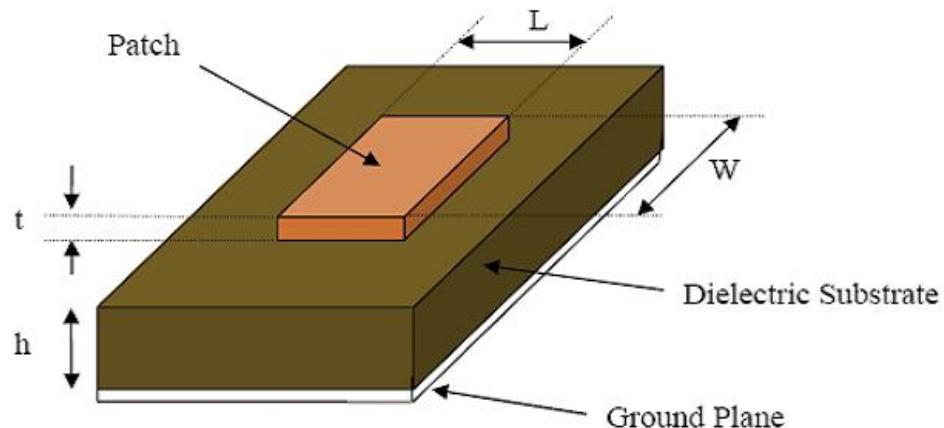


Figure2.4: Basic Structure of Microstrip Antenna.

2.6.2 Advantages and Disadvantages:

Microstrip antennas are used as embedded antennas in handheld wireless devices or mobile node such as cellular phones and wireless access point, and also employed in Satellite communications. Some of their principal advantages are given below:

- Light weight and low fabrication cost.
- Supports both, linear as well as circular polarization.
- Can be easily integrated with microwave integrated circuits.
- Capable of dual and triple frequency operations.
- Mechanically robust when mounted on rigid 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 and Gain.
- Extraneous radiation from feeds and junctions.
- Low power handling capacity.
- Surface wave excitation.

2.6.3 Types of Microstrip Patch Antenna:

The radiating patch may be square, rectangular, thin strip (dipole), circular, elliptical, triangular, or any other configuration. These and others are illustrated in Figure 2.5. Square, rectangular, dipole (strip), and circular are the most common because of ease of analysis and fabrication, and their attractive radiation characteristics, especially low cross-polarization radiation.[13]

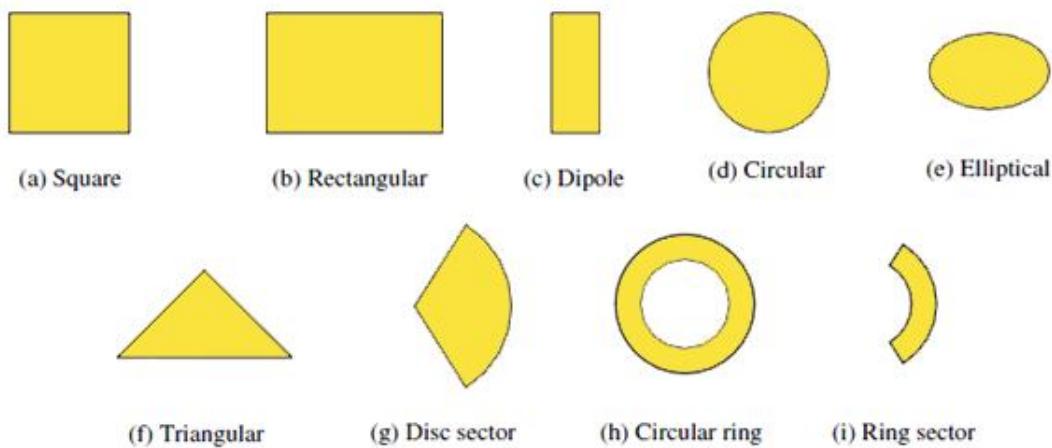


Figure 2.5: Shapes of Microstrip Patch [11]

2.6.4 Rectangular Microstrip Patch antenna:

As shown in Figure 2.6, the basic structure of rectangular microstrip patch antenna consists of a very thin ($t \ll \lambda_0$, where λ_0 is the free-space wavelength) metallic strip (patch) placed a small fraction of a wavelength ($h \ll \lambda_0$) above a ground plane. The strip (patch) and the

ground plane are separated by a dielectric substrate. The length L of the element is usually $\lambda_0/3 < L < \lambda_0/2$.

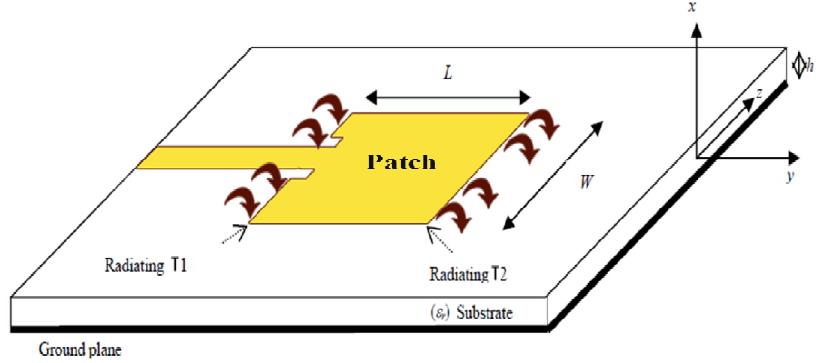


Figure2.6: Basic Structure of Rectangular Microstrip PatchAntenna

2.6.4.1 Substrates Characteristics:

There are many substrates that can be used for the design of microstrip antennas, and their dielectric constants (ϵ_r) are usually in the range of $2.2 \leq \epsilon_r \leq 12$. Thick substrates are most desirable for antenna performance as their dielectric constants are in the lower end, which provide better efficiency, larger bandwidth, loosely bound fields for radiation into space (better radiation power). However, these are achieved at the expense of larger element size, increase in weight, dielectric loss, surface wave loss and extraneous radiations. Thin substrates with higher dielectric constants, on the other hand, are desirable for microwave circuitry because they require tightly bound fields to minimize undesired radiation and coupling, thus leading to smaller sizes. However, because of their greater losses, they are less efficient and have relatively smaller bandwidth [13]. Since microstrip antennas are often integrated with other microwave circuitry, a compromise has to be reached between good antenna performance and circuit design.

2.6.4.2 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).

a) **Microstrip feed line:** The microstrip feed line as shown in Figure2.7 is a conducting strip of much smaller width compared to the patch. It is easy to fabricate, simple to match by controlling the inset position and rather simple to model. However, as the substrate thickness increases surface waves and spurious feed radiation, the usage limits the practical bandwidth (typically 2-5%).

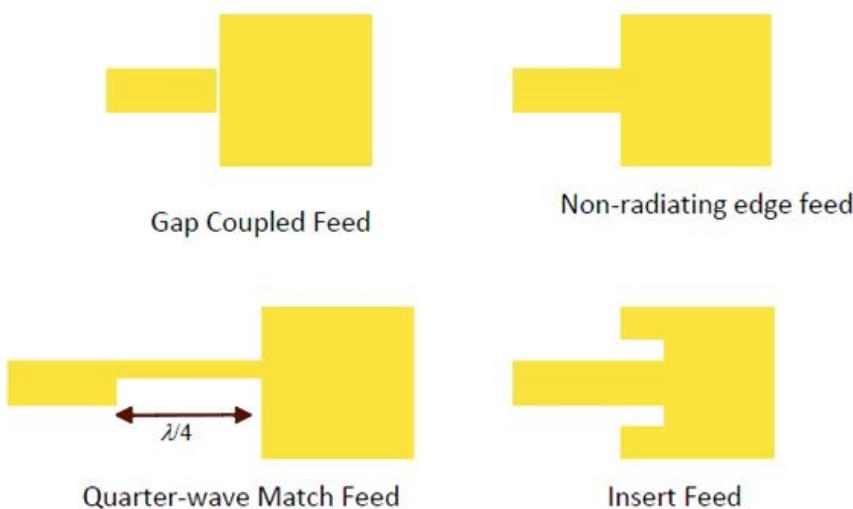


Figure2.7: Microstrip Line Feed

b) **Coaxial feed:** The coaxial feed as shown in Figure2.8 is an inner conductor of the coax and is attached to the radiation patch where the outer conductor is connected to the ground plane. It is easy to fabricate, match and it has low spurious radiation. The disadvantages are that it has a narrow bandwidth and more difficult to model especially for thick substrate($h > 0.02\lambda_0$).

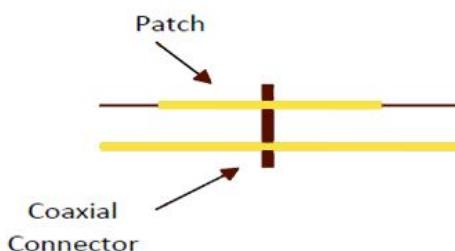


Figure 2.8: Coaxial Feed

c) **Aperture coupling:** The aperture coupling as shown in Figure 2.9 is the most difficult of all four to fabricate and it also has narrow bandwidth. However, it is easier to model and has moderate spurious radiation. The aperture coupling consists of two substrates separated by a ground plane. On the bottom side of the lower substrate, there is a microstrip feed line whose energy is coupled to the patch through a slot on the ground plane separating the two substrates. The ground plane between the substrates also isolates the feed from the radiating element and minimizes interference of spurious radiation for pattern formation and polarization purity [13].

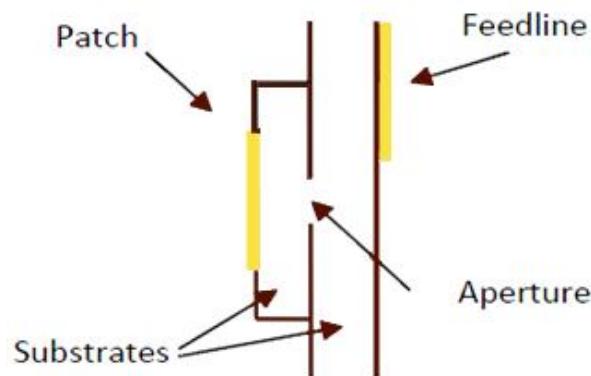


Figure 2.9: Aperture Coupling

d) **Proximity coupling:** The proximity coupling as shown in Figure 2.10 has the largest bandwidth, is easy to model and has low radiation but the fabrication is more difficult.

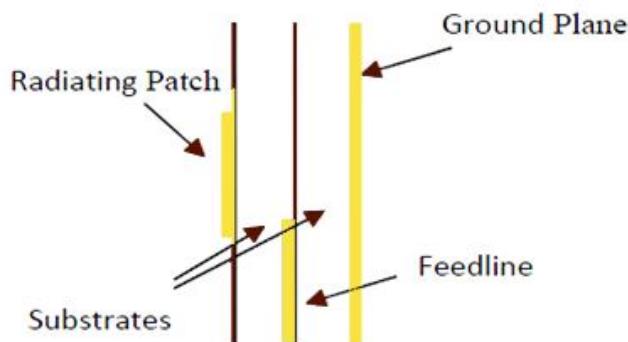


Figure 2.10: Proximity Coupling

2.6.4.3 Analysis Methods:

The preferred models for the analysis of Microstrip patch antennas are the transmission line model, cavity model, and full wave model. The transmission line model is the simplest of all and it gives good physical insight but it is less accurate. The cavity model is more accurate and gives good physical insight but is complex in nature. The full wave models are extremely accurate, versatile and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements and coupling. These give less insight as compared to the two models mentioned above and are far more complex in nature.

2.6.4.4 Transmission line Models:

This model represents the microstrip antenna by two slots of width **W** and height **L**, separated by a transmission line of length **L**. The microstrip is essentially a non homogeneous line of two dielectrics, typically the substrate and air. Hence, most of the electric field lines reside in the substrate and parts of some lines in air. As a result, this transmission line cannot support pure transverse-electric-magnetic (TEM) mode of transmission, since the phase velocities would be different in the air and the substrate. Instead, the dominant mode of propagation would be the quasi-TEM mode. Hence, an effective dielectric constant (ϵ_{eff}) must be obtained in order to account for the fringing and the wave propagation in the line. The value of ϵ_{eff} is slightly less than ϵ_r because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in air.

The expression for ϵ_{eff} is given by [14] as:

$$\epsilon_{\text{eff}} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12h/w}} \quad (2.1)$$

Where:

ϵ_{eff} : Effective dielectric constant

ϵ_r : Dielectric constant of substrate

h : Height of dielectric substrate

W : Width of the patch

The lowest order mode TM01 resonates when the effective length of the rectangular patch is half wavelength. Radiation occurs from the fringing fields. For the principal E-plane,

the dimensions of the patch along its length have been extended on each end by a distance ΔL , as shown in Figure 2.11, which is a function of the effective dielectric constant and the width-to-height ratio (W/h). The extension of length is given by [14]

$$\Delta L = 0.412h \frac{(\epsilon_{\text{eff}} + 0.300)(\frac{W}{h} + 0.264)}{(\epsilon_{\text{eff}} + 0.258)(\frac{W}{h} + 0.800)} \quad (2.2)$$

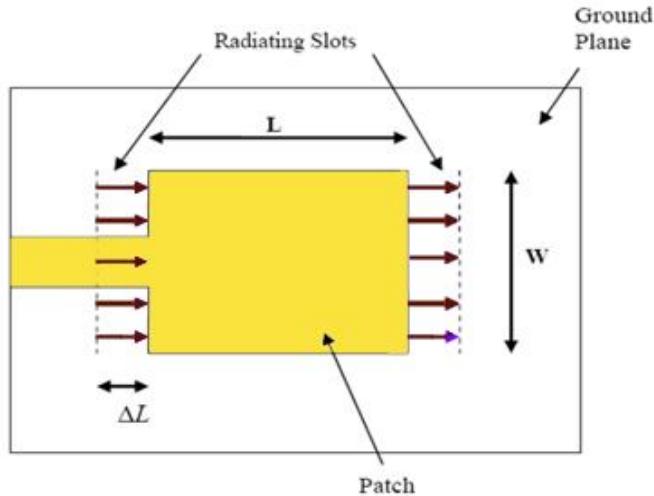


Figure 2.11: Effective Length(ΔL) Distance.

The actual length L of the patch is given as

$$L = \frac{c}{2f_0\sqrt{\epsilon_{\text{eff}}}} - 2\Delta L \quad (2.3)$$

Hence the effective length of the patch is now

$$L_{\text{eff}} = L + 2\Delta L \quad (2.4)$$

OR

$$L_{\text{eff}} = \frac{c}{2f_0\sqrt{\epsilon_{\text{eff}}}} \quad (2.5)$$

The width of the patch is given as

$$W = \frac{c}{2f_0 * \sqrt{(\epsilon_r + 1)/2}} \quad (2.6)$$

2.6.5 Performance Parameter:

2.6.5.1 Far Field and Radiation Pattern:

As shown in Figure 2.12 (a) [13], a rectangular microstrip patch is placed a small fraction of a wavelength above a ground plane. Assuming no variations of the electric field along the width and the thickness of the microstrip structure, the electric field configuration of the radiator can be represented as shown in Figure 2.12 (b).

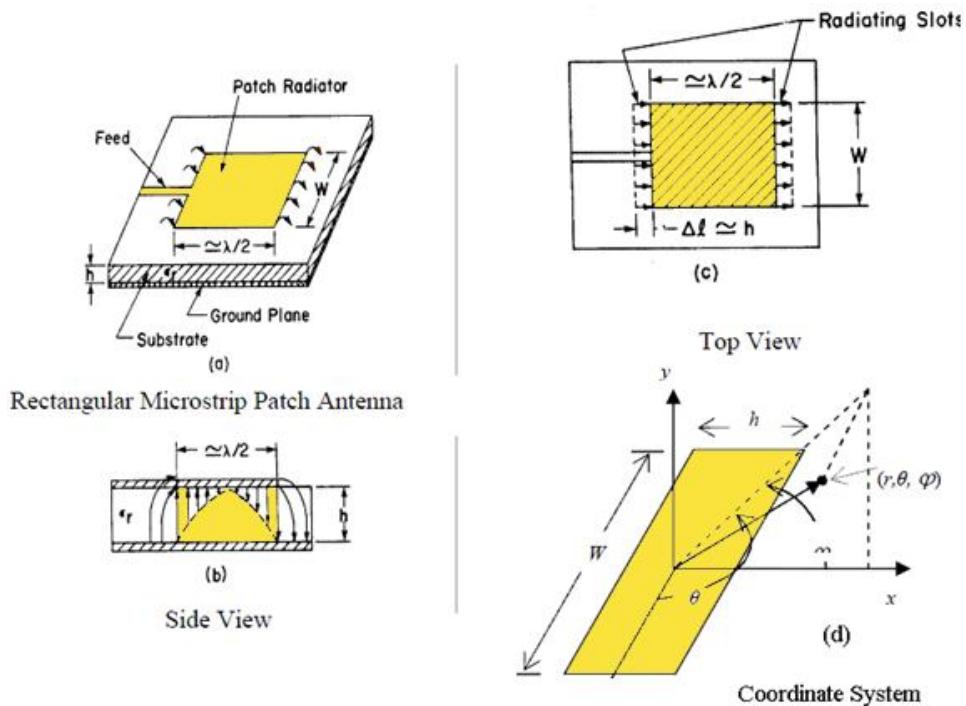


Figure 2.12: Field Analysis of Rectangular Microstrip Patch Antenna[13]

The fields vary along the patch length which is about half a wavelength ($\lambda_g/2$). Radiation may be ascribed mostly to the fringing fields at the open-circuited edges of the microstrip antenna. The fields at the end can be resolved into normal and tangential components with respect to the ground plane. The normal components are out of phase because the patch line is $\lambda_g/2$ long; therefore the far fields produced by them cancel in the broadside direction. The tangential components (those parallel to the ground plane) are in phase, and the resulting fields combine to give maximum radiated field normal to the surface of the structure, i.e.,

the broadside direction. Therefore, the patch may be represented by two slots $\lambda_g/2$ apart (Figure 2.12 (c)) excited in phase and radiating in the half space above the ground plane.

The 2 slots are assumed to be lying flush and have component of slot aperture fields directed in both same direction. It is assumed that the slot width to be same as substrate thickness, h since $h \ll \lambda_0$. Hence, using the coordinate system in Figure 2.12 (d) the total radiated field is the sum of the two-element array radiating in phase separated by $\lambda_g/2$ spacing. The far field of one slot is given as [13]

$$E_{FF\theta}(r) = j \frac{k_e e^{-jk_e r}}{2\pi r} P_Y \sin \Phi \quad (2.7)$$

$$E_{FF\Phi}(r) = j \frac{k_e e^{-jk_e r}}{2\pi r} P_Y \cos \theta \sin \Phi \quad (2.8)$$

$$\text{Where } P_Y = E_e h \operatorname{sinc}(k_e 2h \sin \theta \cos \Phi) W \operatorname{sinc}\left(k_e \frac{W}{2} \sin \theta \sin \Phi\right)$$

The array factor for the two elements of same magnitude and phase, separated by a distance of $\lambda_g/2$ along the y direction is

$$AF = 2 \cos\left(\frac{\pi}{2} \sin \theta \sin \Phi\right) \quad (2.9)$$

Hence, the overall radiation fields for the microstrip antenna consisting of 2 effective radiating slots can be found by multiplying 1 element's radiation fields by the array factor. The principal E-plane is the XOY plane at $\Phi = 90^\circ$ is given as

$$E_{FF\theta}(r) = j \frac{k_e E_e h W e^{-jk_e r}}{2\pi r} \operatorname{sinc}\left(\frac{k_e h}{2} \sin \theta\right) \cos\left(\frac{\pi}{2} \sin \theta\right) \quad (2.10)$$

And the principal H-plane in the XOZ plane at $\Phi = 0^\circ$ is given as

$$E_{FF\Phi}(r) = j \frac{k_e E_e h W e^{-jk_e r}}{2\pi r} \operatorname{sinc}\left(\frac{k_e h}{2} \sin \theta\right) \cos \theta \quad (2.11)$$

2.6.5.2 Radiation Conductance:

Each radiating slot is represented by a parallel equivalent admittance Y with conductance G and susceptance B as shown in Figure 2.13 [13]. The slots are labeled as #1 and #2. The equivalent admittance of slot #1, based on an infinitely wide, uniform slot is given by [13]

$$Y_1 = G_1 + jB_1 \quad (2.12)$$

Where for a slot of finite width W

$$G_1 = \frac{W}{120\lambda_0} \left[1 - \frac{1}{24} (k_0 h)^2 \right] \frac{h}{\lambda_0} < \frac{1}{10} \quad (2.13)$$

$$B_1 = \frac{W}{120\lambda_0} \left[1 - 0.636 \ln(k_0 h) \right] \frac{h}{\lambda_0} < \frac{1}{10} \quad (2.14)$$

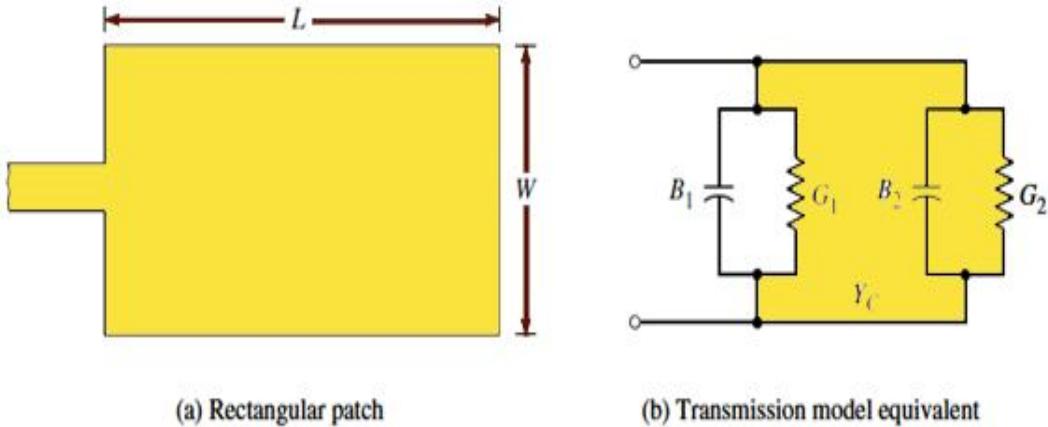


Figure 2.13: Rectangular Microstrip Patch and its Equivalent Circuit Transmission Model

Since slot #2 is identical to slot #1, its equivalent admittance is

$$Y_2 = Y_1, \quad G_2 = G_1, \quad B_2 = B_1 \quad (2.15)$$

The conductance of a single slot given as

$$G_1 = \begin{cases} \frac{1}{90} \left(\frac{W}{\lambda_0} \right)^2 & , W \ll \lambda_0 \\ \frac{1}{120} \left(\frac{W}{\lambda_0} \right) & , W \gg \lambda_0 \end{cases} \quad (2.16)$$

2.6.5.3 Resonant Input Resistance:

The total admittance at slot #1 is obtained by transferring the admittance of slot #2 from the output terminals to input terminals using the admittance transformation equation of transmission line. The separation of the two slots is slightly less than $\lambda/2$, thus the transformed admittance of slot #2 becomes

$$\widetilde{Y}_2 = \widetilde{G}_2 + j\widetilde{B}_2 = G_1 - jB_1 \quad (2.17)$$

Therefore the total resonant input admittance is real and is given by

$$\widetilde{Y}_2 = Y_1 + \widetilde{Y}_2 = 2G_1 \quad (2.18)$$

Hence the total input impedance is also real, or

$$Z_{in} = \frac{1}{Y_{in}} = R_{in} = \frac{1}{2G_1} \quad (2.19)$$

The characteristic impedance of a microstrip line feed to the patch antenna is given by [13]

$$Z_c = \begin{cases} \frac{60}{\sqrt{\epsilon_{\text{eff}}}} \ln \left[\frac{8h}{W_F} + \frac{W_F}{4h} \right] & , \frac{W_F}{h} \leq 1 \\ \frac{120\pi}{\sqrt{\epsilon_{\text{eff}}} \left[\frac{W_F}{h} + 1.393 + 0.667 \ln \left(\frac{W_F}{h} + 1.444 \right) \right]} & , \frac{W_F}{h} > 1 \end{cases} \quad (2.20)$$

Where W_F is the width of the microstrip line.

The resonant input resistance can be changed by using an inset feed, recessed a distance y° from slot #1, as shown in Figure 2.14. The inset feed point can be found using

$$R_{in}(y = y^\circ) = R_{in}(y = 0) \cos^2 \frac{\pi}{L} y^\circ \quad (2.21)$$

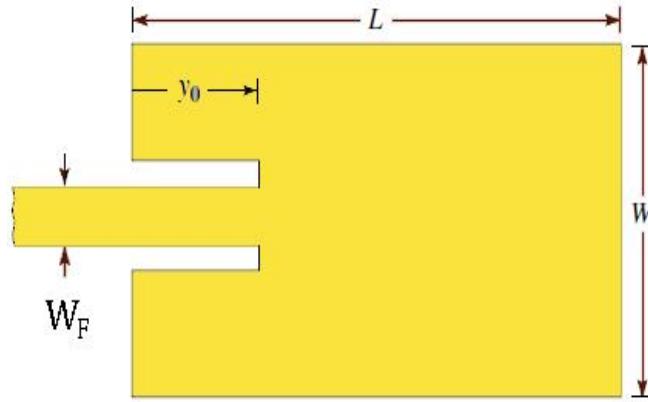


Figure 2.14: Recessed Microstrip-line Feed

2.6.5.4 Q- Factor:

The quality factor is a figure of merit that is representative of the antenna losses. There are four loss mechanisms to be considered, namely, radiation, conduction (ohmic), dielectric and surface wave losses. The total quality factor is given by [13]

$$\frac{1}{Q_t} = \frac{1}{Q_{rad}} + \frac{1}{Q_c} + \frac{1}{Q_d} + \frac{1}{Q_{sw}} \quad (2.22)$$

Where Q_t = Total quality factor.

Q_{rad} = Quality factor due to radiation (space wave) losses.

Q_c = Quality factor due to conduction (ohmic) losses.

Q_d = Quality factor due to dielectric losses.

Q_{sw} = Quality factor due to surface waves.

For very thin substrates, the losses due to surface waves are very small and can be neglected. The approximate formulas to represent the quality factors of the various losses can be expressed as [13]

$$Q_c = h\sqrt{\pi f \mu \sigma} \quad (2.23)$$

$$Q_d = \frac{1}{\tan \delta} \quad (2.24)$$

$$Q_{rad} = \frac{2\omega \epsilon_r}{h G_t / l} K \quad (2.25)$$

Where $\tan \delta$ is the loss tangent of the substrate material, σ is the conductivity of the conductors associated with the patch and ground plane, G_t/l is the total conductance per unit length of the radiating aperture and

$$K = \frac{\iint_{\text{area}} |E|^2 dA}{\oint_{\text{perimeter}} |E|^2 dl} \quad (2.26)$$

For a rectangular aperture operating in the dominant TM_{01} mode

$$K = \frac{L}{4} \quad (2.27)$$

$$G_t/l = \frac{G_{\text{rad}}}{W} \quad (2.28)$$

2.6.5.5 Bandwidth:

The bandwidth of a microstrip antenna is expressed as the percent bandwidth determined from the impedance data as

$$BW\% = [(f_{r2} - f_{r1})/f_r]100 \quad (2.29)$$

Where f_r is the resonant frequency, while f_{r1} and f_{r2} are the frequencies between the magnitude of the reflection coefficient of the antenna is less than or equal to 1/3. In general, bandwidth is proportional to the volume, which for a microstrip antenna at a constant resonant frequency can be express as

$$BW \sim \text{volume} = \text{area} \times \text{height} = \text{length} \times \text{width} \times \text{height} \quad (2.30)$$

An empirical formula by Jackson and Alexopolus for the bandwidth (VSWR<2) is [12]

$$BW = 3.77[(\epsilon_r - 1/\epsilon_r^2)(W/L)(h/\lambda_0)] \quad (2.31)$$

2.6.5.6 Directivity:

The directivity of the antennas is defined as the ratio of the maximum power density in the main beam to the average radiated power density. The directivity of a microstrip antenna comprising two slots at a spacing L is expressed as

$$D = \begin{cases} 6.6 = 8.2 \text{ dB} & , W \ll \lambda_0 \\ 8 \left(\frac{W}{\lambda_0} \right) & , W \gg \lambda_0 \end{cases} \quad (2.32)$$

2.6.5.7 Efficiency:

The radiation efficiency of an antenna is defined as the total power radiated over the net input power of the antenna. It is expressed in terms as

$$\eta = \frac{Q_t}{Q_{rad}} = \frac{P_{rad}}{P_{in}} \quad (2.33)$$

2.6.5.8 Return loss:

Return loss or reflection loss is the reflection of signal power from the insertion of a device in a transmission line or optical fiber. It is expressed as ratio in dB relative to the transmitted signal power. The return loss is given by

$$RL(\text{dB}) = 10 \log \frac{P_r}{P_i} \quad (2.34)$$

Where P_i is the power supplied by the source and P_r is the power reflected. If V_i is the amplitude of the incident wave and V_r that of the reflected wave, then the return loss can be expressed in terms of the reflection coefficient Γ as

$$RL = -20 \log |\Gamma| \quad (2.35)$$

And the reflection coefficient Γ can be expressed as

$$\Gamma = \frac{V_r}{V_i} \quad (2.36)$$

For an antenna to radiate effectively, the return loss should be less than -10 dB .

2.6.5.9 VSWR:

A standing wave in a transmission line is a wave in which the distribution of current, voltage or field strength is formed by the superimposition of two waves of same frequency propagat-

ing in opposite direction. Then the voltage along the line produces a series of nodes and antinodes at fixed positions.

Then the Voltage Standing Wave Ratio (VSWR) can be defined as:

$$\text{VSWR} = \frac{V_{\max}}{V_{\min}} = \frac{1+|\Gamma|}{1-|\Gamma|} \quad (2.37)$$

The value of VSWR should be between 1 and 2 for efficient performance of an antenna.

2.7 Reconfigurable Antenna:

If the traditional antennas are adopted, multiple antennas must be installed within one vehicle, so as to transmit and receive different signals. With regard to the space vehicle, the whole design cost, weight and size will increase greatly, some problems, such as coupling among different antennas and electromagnetic compatibility, will impact on the system performance, the concept of “reconfigurable antenna” is proposed. It can change the electrical structure within one antenna in real time; the radiation characteristic is changed accordingly. [15] Reconfigurable Antenna means the antenna properties can be changed dynamically by external control. A reconfigurable antenna can be considered as one of the key elements in future wireless communication transceivers. The advantage of using a reconfigurable antenna is the ability to operate in multiple bands where the total antenna volume can be reused thus enabling the overall size to be reduced. Modern wireless communication systems relying on multiband reconfigurable antennas are becoming more popular for their ability to serve multiple standards. Devices using a single compact antenna allow reduction in the dimensions of the device and more space to integrate other electronic components.[16]

2.7.1 Types of Reconfigurable antenna:

Reconfigurable antennas can be classified into three different categories:

1. **Frequency reconfigurable:** The first category is based on frequency reconfigurability. The aim is to tune/switch the operating frequency of the antenna and to have a single multifunctional antenna in a small terminal for many applications. The shape of the radiation patterns of these reported antennas remain unchanged when the frequencies are tuned/switched from one band to the other.[16]

Frequency reconfigurable antennas are classified into two categories:

- **Continuous (Tunable Antenna):** This can be achieved by using varactor diodes where the antenna allows for smooth transitions within or between operating bands without hops.
- **Coarse (Switchable Antenna):** This can be achieved by using PIN diode switches. Coarse tuning employs different switching mechanisms to operate at multiple bands.

2. **Radiation pattern reconfigurable:** The second category is based on pattern reconfigurability, where the frequency band remains unchanged while the radiation pattern changes based on system requirements. The antenna can steer its radiation pattern main beam in different directions.
3. **Polarization reconfigurable:** The third category is based on polarization reconfigurability, where the polarization is switched from linear to circular and from left hand (LHCP) to right hand (RHCP) circular.

2.7.2 Switching Technology:

The change of the desired parameter of the reconfigurable antenna is in most cases obtained by the use of a switch. The choice of the switch is critical because overall performance, suitability and cost of the reconfigurable antenna are strongly dependent on its characteristics.[17] The most popular of switches are PIN diode, Varactor diode and RF MEMS (microelectromechanical).

- **PIN Diode:**

PIN diode is a semiconductor device that operates as a variable resistor at RF and Microwave frequencies. It can also be used as a switch and Limiter. PIN diodes are popular in microwave circuit applications due to its fast switching times and relatively high current handling capabilities. The P and N types are separated by an intrinsic region, the P contact is the anode, and the N contact is the cathode as shown in Figure 2.15 where the anode is the side with the arrow, the cathode is the side with the plate. Between the P and N region is the intrinsic where the width of this region has an important role on the performance of the PIN diode. [16]

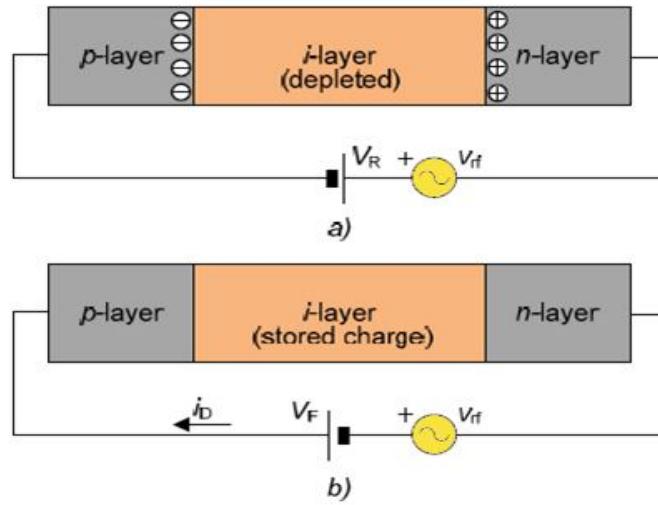


Figure 2.15: PIN diode:a) reverse bias, b) forward bias

This diode operates at DC and low frequencies similar to an ordinary *pn* diode. However, due to the introduction of the intrinsic layer, the PIN diode can operate as a current controlled linear resistor for the RF signal. If one drives the PIN diode using only two bias states, namely the reverse and the forward bias, it will exhibit switch characteristics for the RF signal. Ideally, the intrinsic layer would be depleted of carriers at zero bias. Thus, there would be no support for the current flow, and the diode would act as an open circuit to the RF signal.

The practical PIN diode has some charge in its *i*-region at zero bias, due to the presence of impurities. To fully deplete the *i*-region of mobile carriers, some reverse voltage is required. This reverse voltage at which the mobile carriers are displaced from the intrinsic layer is referred to as the swept-out or “punch-through” voltage. It is very important to drive the PIN diode with the reverse voltage equal or somewhat higher than the swept-out voltage. Otherwise, the mobile carriers would allow current flow and the PIN diode would not operate well as an open switch.

When the PIN diode is forward biased, electrons and holes are injected into the *i*-region, where they have a finite lifetime before they recombine. The charge density is building up in the *i*-layer, allowing the PIN diode to operate as a linear resistor for the RF signal above some frequency limit, determined by the lifetime of minority carriers’ τ . The charge stored in the intrinsic region is related to the diode current by

$$i_D = \frac{dq_D}{dt} + \frac{q_D}{\tau} \quad (2.38)$$

Where $i_D = I_D + i_d$ is the total current, composed of the DC and the RF components, while $q_D = Q_D + q_d$ is the total charge, also composed of the DC and the RF components. The equation (1) can also be written as

$$I_D + i_d = \frac{d(Q_D + q_d)}{dt} + \frac{Q_D + q_d}{\tau} \quad (2.39)$$

Obviously, $dQ_D/dt = 0$, so the DC component of the current is

$$I_D = \frac{Q_D}{\tau} \quad (2.40)$$

While the RF component is

$$i_d = \frac{dq_d}{dt} + \frac{q_d}{\tau} \quad (2.41)$$

In the frequency domain, the equation (2.41) reads

$$I_d(\omega) = j\omega Q_d(\omega) + \frac{Q_d(\omega)}{\tau} \quad (2.42)$$

Where $I_d(\omega)$ and $Q_d(\omega)$ are the Fourier transforms of the current and the stored charge, and ω is the radial frequency. The equation (2.42) can also be written as

$$\left| \frac{Q_d(\omega)}{I_d(\omega)} \right| = \frac{\tau}{\sqrt{1+\omega^2\tau^2}} \quad (2.43)$$

The PIN diode behaves like an ordinary pn diode at frequencies below $f_0 = 1/2\pi\tau$, since the second term of the equation (2.42) dominates and the low frequency signal just modulates the stored charge. On the contrary, at frequencies above this limit, the stored charge cannot accumulate and de-accumulate at given rate and the PIN diode acts as the resistor which resistance is fairly linear and governed by the amount of the charge stored by the DC (and possibly low frequency) current [16].

- **PIN diode, Varactor diode and RF MEMS:**

The comparison between most popular of switching component (PIN diode, Varactor diode and RF MEMS) as shown in table 1:

Table 2.1: Comparison between PIN diode, Varactor diode and RF MEMS

Switching

component	Advantages	Disadvantages
MEMS	Reduced insertion loss, good isolation, extremely high linearity, low power losses, consumes little or almost no DC power, wide bandwidth	Need high-control voltage (50–100V), poor reliability due to mechanical movement within the switch (0.2–100 μ s), slow switching speed, discrete tuning limited lifecycle
PIN Diode	Needs very low driving voltage, high tuning speed (1–100 ns), high power handling capability, very reliable since there are no moving part, extreme behavior, poor quality factor, discrete low cost	Needs high DC bias current in their on state which consumes a significant amount of DC power, nonlinear
Varactor	The current flow through the varactor is small compared to PIN diode or MEMS, continuous tuning	Varactors are nonlinear and have low dynamic range, and complex bias circuitry are required

2.8 Related Works:

With the rapid growth of the wireless mobile communication technology, the future technologies needs a very small antenna and also the need of wide band and multi band antenna is increased to avoid using two antennas. Reconfigurable antennas are a new generation of antennas that will not be limited to a certain function or resonance

but will change their functionality depending on the implementation requirements. Microstrip patch antenna is promising to be a good candidate for the future technology.

Multi studies for multiband antenna and reconfigurable multiband antenna using microstrip patch antenna. These studies are agreeing in base concept for Patch design and differently in slot shape, dimensions and analysis method.

- **Rectangular Microstrip Patch Antenna:**

Design of dual band and multiband single layer microstrip antenna are presented for wireless communications applications with different method to enhance antenna performance. Also, reduce size and good gain multifrequency microstrip patch antenna by used slot and slit techniques [18]-[21]. The design of rectangular microstrip antenna (RMSA) operating in X-band for 10 GHz is made to several dielectric materials, and the selection is based upon which material gives a better antenna performance with reduced surface wave loss [22]. In order to achieve gain enhancement a rectangular cut structure have been introduced in the rectangular patch antenna as shown in Figure 2.16. The microstrip patch radiated with enhanced gain has been designed of 10 dB with centre frequency of 2GHz. [23]

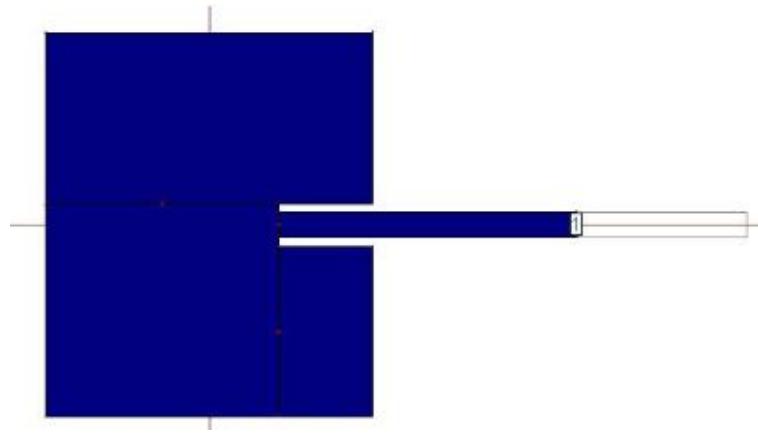


Figure 2.16: Rectangular Cut Design for 2 GHz

In Figure 2.17, Dual frequency operation of rectangular patch antennas with stacked patch has been investigated with resonates at 7.66 GHz and 9.73 GHz fre-

quencies. The antenna design contains two patches one is a U-slot loaded rectangular patch and other is a parasitic H-shaped patch. A combination of these two resulted in a dual frequency of operation with a low return loss. For good antenna performance a thick dielectric substrate having a low dielectric constant is preferred and it's giving the gain of 4.63dB and 6.03dB [24].

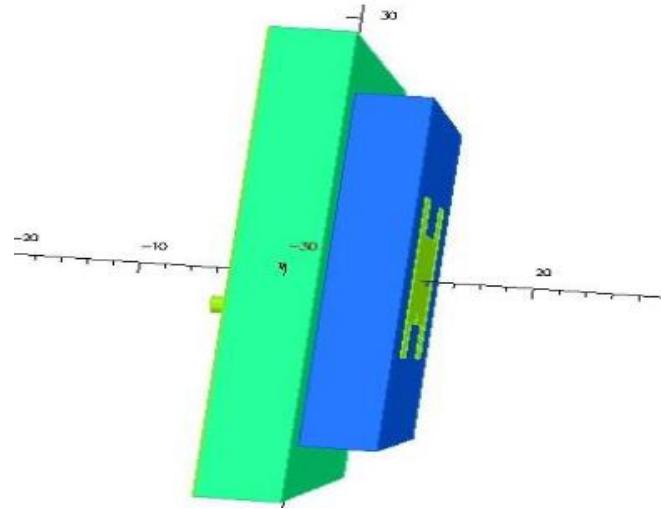


Figure 2.17: Design of Dual Frequency Operation with Stacked Patch

Rectangular microstrip patch antenna is designed to support dual band operation with resonance at 1.8 and 2.4GHz. Dual band operation is possible with proper position of the feed line, proper determination of inset size and proper dimensions of patch slots as shown in figure 2.18.[25]

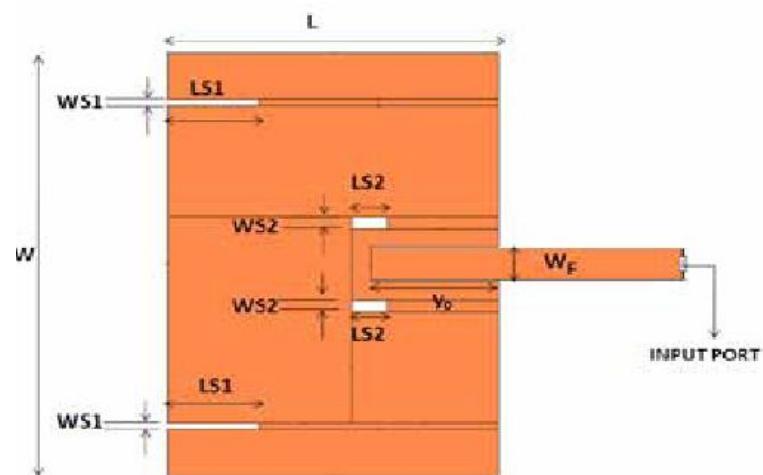


Figure 2.18: Design of Dual bandRectangular Patch Antenna at 1.8 & 2.4GHz.

- **Reconfigurable Microstrip Patch Antenna:**

In last year's, many researches are concentrated effort in development of reconfigurable antennas such as [26] – [30].A novel compact dual-band reconfigurable square-ring microstrip antenna is presented. The tuning is achieved using a single varactor diode connected to a small square patch attached to an inner corner of the square-ring. The square patch perturbs the symmetry and splits the two degenerate modes to create dual-band operation.The frequency ratio in the range of 1.04 to 1.4 can be achieved by the proper selection of the square patch size. The lower resonance frequency can be further decreased by loading the square patch at its corner by a reverse biased varactor diode. The diode has almost no effect on the upper resonance frequency. The resulting lower resonancefrequency is tuned from 1.37 to 1.7 GHz in the voltage range from 0 to 30 V,respectively [31]. Also, dual-band tunable rectangular slot antenna is presented in [32]. The frequency tuning is achieved by utilizing the RF MEMS variable capacitor on a stub. The DC voltage of the MEMS is applied between the RF signal line and the ground plane which eliminated the need for additional bias lines. Simulation and experimental results predicted that the resonance frequencies of the antenna can be shifted from 10.22GHz to 10.57GHz and from 7.7GHz to 8.7GHz.

In [33], a reconfigurable microstrip patch antenna with RF PIN diode switches is implemented for dual band of 2.4 GHz and 5.6 GHz Software Defined Radio (SDR) applications. For the dual band SDR system, the use of a single antenna with a wide bandwidth to cover both of the bands can be limiting for low power level signal applications due to wideband noise. A reconfigurable nested microstrip patch antenna is designed on a Rogers's 5880 RT/DUROID substrate which is fed by a coaxial probe from the back side of the grounded substrate. RF switching circuitry involves four RF pin diodes at each side of the inner patch and frequencyoperation can be simply obtained by switching the PIN diodes on and off. As shown in Figure 2.19, a polarization reconfigurable slot antenna is proposed. The antenna polarization can be switched between vertical and horizontal polarization by changing the feeding structure between CPW feed and slotline feed. The operatingmodes of the CPW-to-slotline transition are

shown in Figure 2.20. When PIN 1 is ON and PIN 2 is OFF, the structure operates in the CPW mode. The slotline mode is activated when PIN 2 is ON and PIN 1 is OFF. The right slotline is used to feed the horizontal polarization.

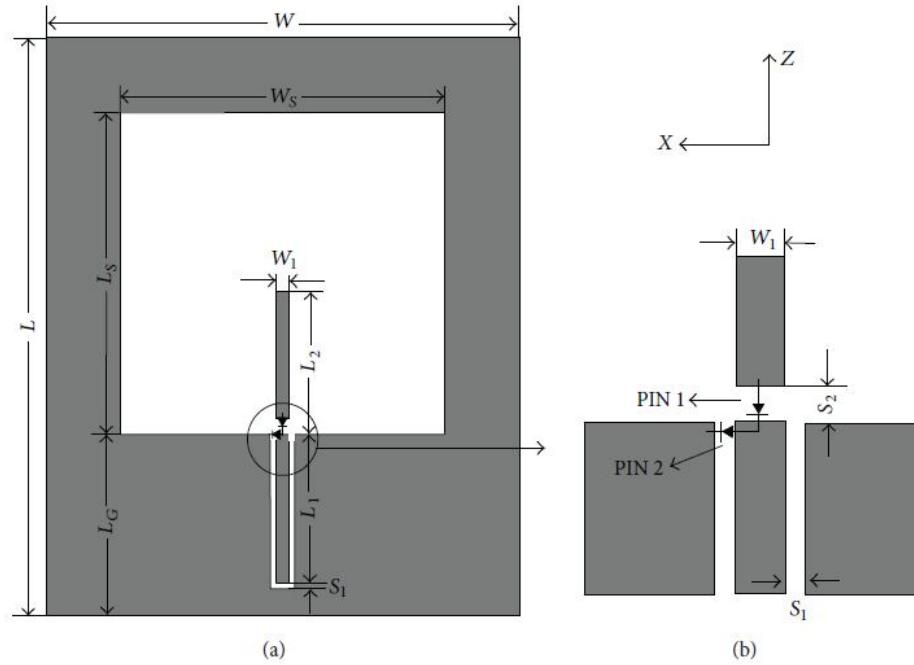


Figure 2.19: Geometry of a Reconfigurable Slot Antenna

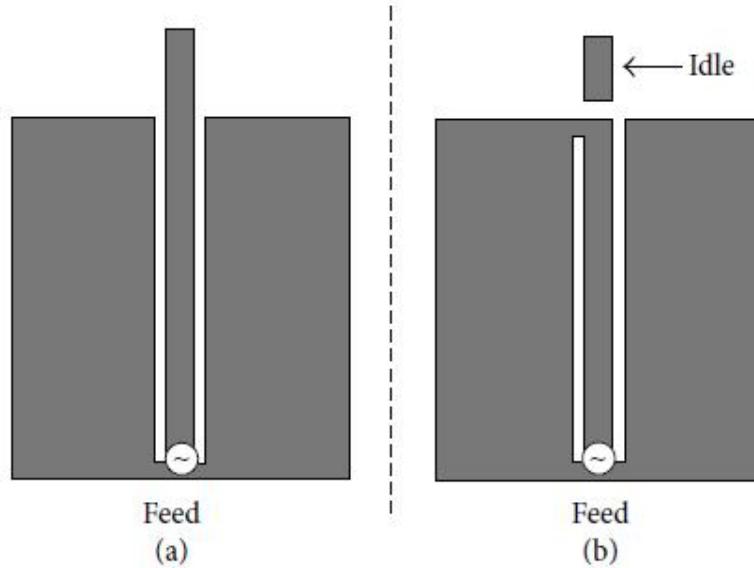


Figure 2.20: Feeding Structure of the Reconfigurable Slot Antenna: (a)

CPW mode; (b) slotline mode

In [34] as shown Figure 2.2 , a compact of a reconfigurable rectangular microstrip slot patch antenna is proposed for Wireless Local Area Network (WLAN) applications. It has one port excited with microstrip line feed mechanism. The antenna consists of a single layer patch antenna with two parallel slots designed that can be controlled via two PIN diode switches. By adjusting the status of the switches state either *on* or *off* mode in simultaneously, the resonance frequencies can be varied, thus achieving frequency reconfigurable. This antenna is capable to achieve return loss less than-10dB in multiband frequencies at 2.4GHz and 5.8GHz when both switches are ON mode while only in 2.4GHz can be achieved when both switches are OFF mode. In this work, the result of 5.8 GHz is not really good in the antenna performance where the gain is very smaller compare to 2.4 GHz.

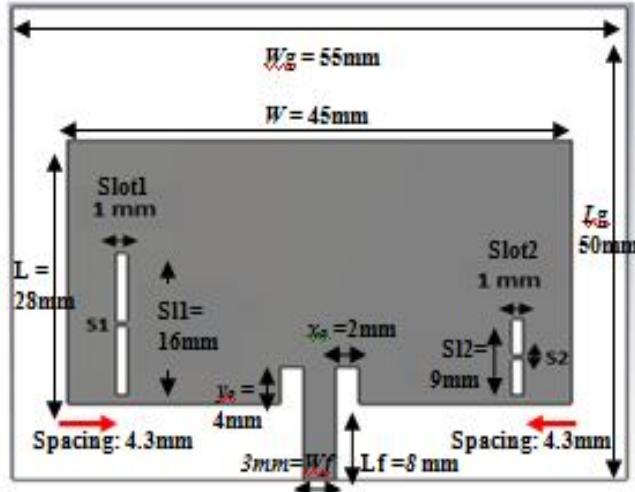


Figure 2.21:Reconfigurable Rectangular Microstrip Patch Antenna for WLAN

However, no of this paper consider reconfigurable dual band antenna for Femtocell Access Point (FAP) applications. In this project we propose design and analysis reconfigurable dual band antenna for WLAN bands at 5.2 GHz and fixed WiMax bands at 3.5 GHZ.

2.9 Chapter Summary:

Heterogeneous network tends to use multiple types of wireless access networks. In heterogeneous wireless networks, different wireless access technologies are integrated to complement each other in terms of coverage area, mobility support, bandwidth, and price. Reconfigurable antennas are a new generation of antennas that will not be limited to a certain function or resonance but will change their functionality depending on the implementation requirements. The microstrip patch antenna is very well suited for heterogeneous network applications, which due to its advantages such as low weight, low profile planar configuration, and low fabrication cost.

This chapter presents the introduction of broadband wireless network, heterogeneous network, fixed-mobile convergence for SDR and multiband antenna and basic wireless transceiver design.

Then introduce the basic concept of microstrip patch antenna structure, characteristics, analysis methods and performance parameters. Also, this chapter presents the reconfigurable antenna technology, as well as switching technology, and RF PIN diode structure.

Finally this chapter discuss some related work for rectangular microstrip patch antenna design and reconfigurable microstrip patch antenna.