CHAPTER 1

INTRODUCTON

1.1 BRIEF TECHNCAL OVERVIEW

The rapid advances in the wireless communication have been brought by revolution in antenna, VLSI electronics, computers, and software's technologies. In order to face the technological development, mankind needs to keep up with the evolution. This evolution is in the field of cellular devices and many other portable devices. Our main aim is to provide the standard communication bands like GSM, DCS, PCS, UMTS, and WWANs to the user, so they meet all the requirements of present and future applications. If a device is capable of operating at multiple communication bands, it means device antenna must have multiple frequency characteristics. So to meet these requirement meander antenna is used. It is a multi-resonant antenna operates on different frequencies. Due to the advancement in technology the size of the devices are getting small so it is a difficult to design a external antenna for such devices like mobile phones in which size is matter. But internal antenna also has a large shape which is not able to place in mobile phone. So meander antenna has folded characteristics due to which it is easily place inside the mobile phone. And also able to operate on the entire communication band due to its multiple resonant characteristics.

1.2 OBJECTVE

The goal of this thesis is to study, analyse and design of a Compact Planar Multi-Band internal Antenna for Mobile Phone capable of facing needs of modern wireless communication transceivers. Objective of this project is to minimize the size of the internal antenna such that it operates on the five communication bands and also operate on the wireless wide area networks in order to access the internet. And to dismiss the effect of intensive coupling between the radiator (antenna) and the ground plane. The optimisation will be done by varying certain things like antenna length, values of dielectric constant and dielectric loss of dielectric substrate etc. to obtain desired frequency range. Simulation is done using ADS software.

1.3 METHODOLOGY

- Understanding of basic concept of meander and planar antenna.
- Studying various type of geometry and selecting one among them.
- Selecting the simulation software and learning it.
- Preliminary design of Main Radiator
- Design of Parasitic Structure
- Design of Impedance-adjustment Structure
- Implementing the final design of Main Radiator for better impedance matching meander antenna using simulation software and obtaining result.
- Study the change in antenna properties and comparison among results.

1.4 REPORT ORGANIZATION

This report is organized in 6 chapters.

Chapter 1 tells about the technical overview, objective, and methodology about the thesis.

Chapter 2 is about the definition and concept of antenna theory.

In chapter 3 microstrip antenna and its feeding technique are introduced and its geometries are described. The generation of the mobile antenna like meander line, dipole, monopole, inverted-L and inverted-F antenna are also presented in this chapter.

Chapter 4 describe the configuration of compact planar multi-band internal antenna for mobile phone antenna. And also presents the concepts and procedure of compact planar multi-band mobile antenna simulation by step wise.

Chapter 5 presents the simulation work of mobile antenna with the help of ADS simulation tool.

Chapter 6 gives the final conclusion of this project which also includes future work which can be expected.

CHAPTER 2

THEORY OF ANTENNA

2.1 INTRODUCTION

The antenna is the transition between a guiding device (transmission line, waveguide) and free space (or another usually unbounded medium). Its main purpose is to convert the energy of a guided wave into the energy of a free-space wave (or vice versa) as efficiently as possible, while at the same time the radiated power has a certain desired pattern of distribution in space.

2.2 DEFINITIONS AND CONCEPTS

2.2.1 RADIATION

Electromagnetic radiation is produced by accelerating charge particles. In an antenna, the radiation is produced by an alternating current, which is composed of accelerating electrons. A non-accelerating electron has a static electric field around it. The static field is retarded and derived directly from Maxwell's equations [1]. This retardation means that a change of the electron position won't be noticed at a distance r from the electron until r / c seconds later. That is, if the electron is moved (accelerated), it will start to produce a static field from a new position and therefore create a crease in the electric field. This crease is a phi directed electric field that propagates in r direction and is what we call an electromagnetic wave.

2.2.2 dB, dBi, dBm

The unit decibel is commonly used when working with electromagnetic fields. Decibel is abbreviated as dB and is defined by ten times the logarithm of a dimensionless fraction. See the definition in equation 2.1. Hence, a negative decibel is a number between 1 and 0, not negative. For example, 1 is equal to 0 dB, 100 is equal 20dB and 25% is approximately equal to -6.02 dB.

$$\mathrm{AdB} = 10\log10\left(\frac{A1}{A0}\right) \tag{2.1}$$

dBm is a logarithmic unit used to express power [W]. The definition is given in 2.2. Therefore, dBm is simply adding the unit [mW] to decibel, that is, 0 dBm is 1mW, 20dBm is 100mW and -6dBm is approximately 0.25mW.

$$\mathrm{PdB} = 10\log10\left(\frac{\mathrm{P}}{1\mathrm{mW}}\right) \tag{2.2}$$

dBi works in the same way as dBm, but instead of comparing size with 1mW the reference is the Gain of an isotropically radiating antenna. That is 30dBi means a gain 1000 times stronger than if the same amount of radiated power was uniformly radiated in space.

2.2.3 ANTENNA IMPEDANCE

Basically, small antenna design is all about matching the antenna so that it can resonate. Antenna impedance is therefore a very important parameter, which generally is a complex number. However, it is when the imaginary part is zero or close to zero, that the antenna is resonating and radiating at an exited mode. Doing modifications and changes to the antenna design is usually done by modifying the complex part of the impedance. For example, by matching the antennas ends with capacitors or inductors. The real part and imaginary part of the impedance plotted as a function of frequency give much information of the antennas behavior. What usually is needed to get good performance is moving or attending the curve of the imaginary part of the impedance, where attending means increased bandwidth.

2.2.4 RETURN LOSS

Return loss is traditionally expressed as the ratio between incident and reflected power expressed in dB, see equation 2.3. However, this report will in accordance with common practice within antenna engineering report return loss with a negative sign, which is the fraction of reflected power divided by incident power in dB.

$$\mathrm{RL} = 10\log10\left(\frac{\mathrm{Pr}}{\mathrm{Pi}}\right) \tag{2.3}$$

Return loss evaluated at different frequencies of an antenna usually give a good representation of its radiating properties. For example, if the return loss is close to 0 dB, it means that the antenna isn't radiating at that frequency and if the return loss is around -20dB or lower, it means that at least 99% of power either is radiated or absorbed and converted into heat inside the antenna. Microstrip antennas usually have rather poor efficiency; of those 99% typically 70-80% would be radiated power. The reason small antennas have low efficiency is due to the fact that they are working in resonance, allowing the wave to travel through the antenna many times and thereby lose more power [2]. For systems with more than one antenna low return loss and low losses inside the antenna won't necessarily mean the energy is radiated to the far field, it might also get absorbed by other antennas. Hence, it is important to also consider the energy absorbed

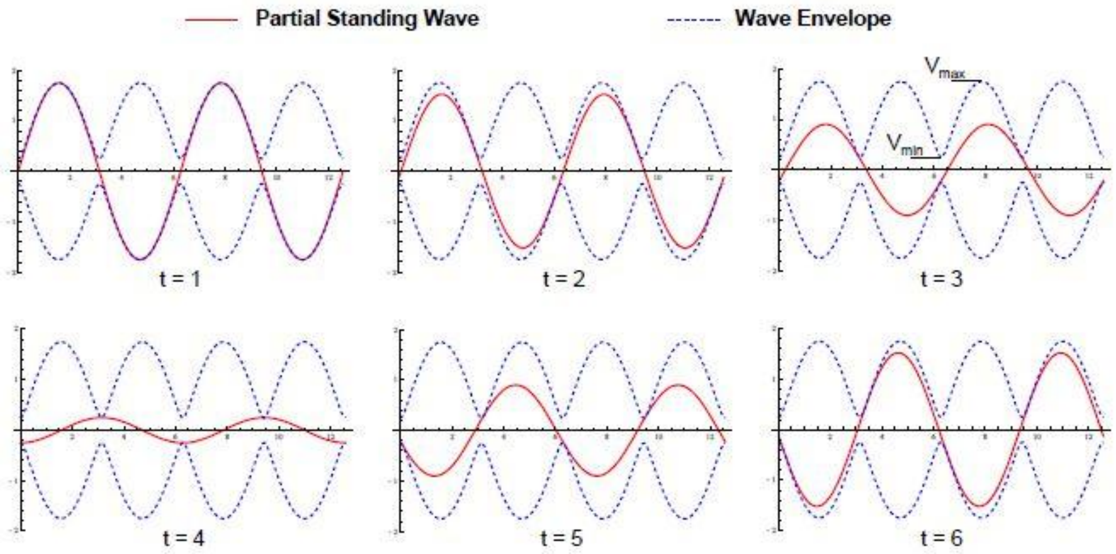


Figure 2.1: A partial standing wave with its envelope. The VSWR is decided from the minima and maxima of the envelope. The six graphs are representing different times**.**

by the diversity antenna when simulating and measuring MIMO configurations. Simulation software can give direct information about radiation efficiency, but since return loss is much faster to calculate, it is the most common parameter to use as guidance during the design. This is true since calculating radiation efficiency requires knowledge about the radiated far-field, while calculating return loss only requires knowledge of the lumped element circuits and the antenna**.**

2.2.5 VOLTAGE STANDING WAVE RATIO

Voltage standing wave ratio is usually noted VSWR. It gives information about how much of a wave that is reflected. The properties of an electromagnetic wave needed to calculate the VSWR can't be read directly from a time independent plot of the wave. Both time and space need to be considered to get the properties of the wave needed to do the calculation, see figure 2.1. The definition of VSWR is seen in equation 2.4.

$$\text{VSWR} = \frac{\text{Vmax}}{\text{Vmin}} = \frac{1+\Gamma}{1-\Gamma} \qquad (2.4)$$

As it can be seen from the definition, the VSWR will be equal to infinity for total reflection and to 1 for zero reflection. A partial standing wave is partially travelling and thereby making a net transport of power. A VSWR of 3:1 will be used as a design guide line and is approximately equal to a return loss of -6dB.

2.2.6 SCATTERING PARAMETERS

Scattering parameters, usually referred to as S-parameters, of a electrical system is describing the behavior of the system. The S-parameters is a very useful quantity since it is very easily measured and can be used to calculate for example return loss, VSWR and isolation between MIMO antennas. See equations 2.5, 2.6 and 2.7 for calculation of antenna design parameters from S-parameters.

$$\text{Return Loss} = 10\log_{10}(|S11|) \tag{2.5}$$

$$\text{Isolation} = 10\log_{10}(|S12|) \tag{2.6}$$

$$\text{VSWR} = \frac{1+|S12|}{1-|S11|} \tag{2.7}$$

2.2.7 GAIN

The Absolute Gain of an antenna is defined as the ratio between the antennas radiation intensity in a certain direction to the radiation intensity of an isotropic antenna fed by the same input power, therefore it can be given by:

$$G\ (\theta, \Phi) = \frac{U(\boldsymbol{\theta},\boldsymbol{\Phi})}{Uo} \tag{2.8}$$

Where

$$Uo = \frac{Pin}{4\boldsymbol{\pi}} \tag{2.9}$$

Where G (θ, Φ) is the gain of the antenna in a direction characterised by θ and Φ, U (θ, Φ) is the radiation intensity in a certain direction and U_0 is the radiation intensity of an isotropic antenna. P_{in} is the input power.

The Absolute Gain is expressed in dB_i as its reference is an isotropic antenna. The Relative Gain of an antenna is defined as the ratio between the antenna radiation intensity in a certain direction and the intensity that would be generated by a reference antenna considered. The Relative Gain is expressed according to reference antenna. Generally short dipole and short monopole are used as reference antenna.

2.2.8 DIRECTIVITY

Directivity allows us to measure the concentration of radiated power in a certain direction. Hence it is one of the important parameter. It is given by:

$$D(\theta, \Phi) = \frac{U(\theta,\Phi)}{Uo} \tag{2.10}$$

Where D (θ, Φ) is the directivity of the antenna in a certain direction, U (θ, Φ) is the radiation intensity in a certain direction. Another way of measuring the directivity of an antenna is to calculate the HPBW (half power beam width)

2.2.9 POLARIZATION

The polarization of an electromagnetic wave is defined as the orientation of the electric field vector. Recall that the electric field vector is perpendicular to both the direction of travel and the magnetic field vector. The polarization is described by the geometric figure traced by the electric field vector upon a stationary plane perpendicular to the direction of propagation, as the wave travels through that plane. An electromagnetic wave is frequently composed of (or can be broken down into) two orthogonal components as shown in Figure 2.2. This may be due to the arrangement of power input leads to various points on a flat antenna, or due to an interaction of active elements in an array, or many other reasons

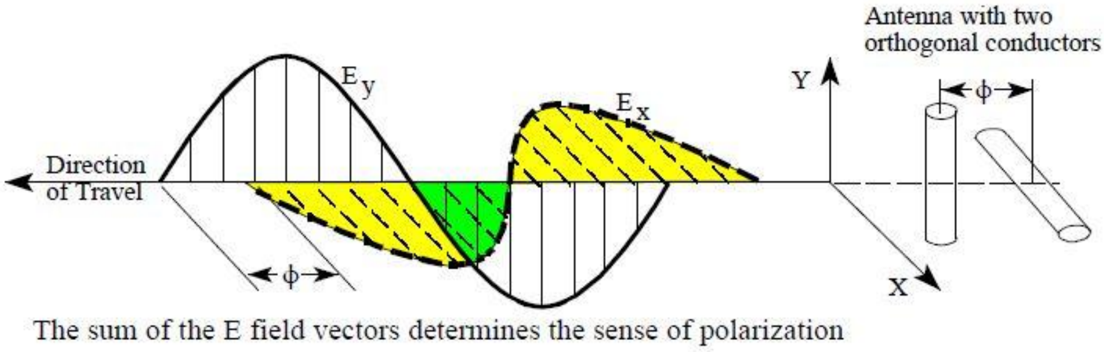


Figure 2.2: The polarization of an electromagnetic wave

2.2.10 RADIATION EFFICIENCY

Radiation efficiency is by IEEE defined as "The ratio of the total power radiated by an antenna to the net power accepted by the antenna from the connected transmitter [3]. Radiation efficiency does not consider losses in the mismatch between the antenna and the transmitter and is therefore rarely used in this report.

2.2.11 TOTAL EMBEDDED EFFICIENCY

Total embedded efficiency is the ratio of total power radiated to the far-field by the antenna to the net power supplied to the port of the antenna. That is, it includes both mismatch in the port and radiation absorbed by other antennas in MIMO configuration. While return loss is most frequently used during the design, what really matters in the end is the antenna's efficiency. Total embedded efficiency is what will be used throughout this report and will be used interchangeably with antenna efficiency.

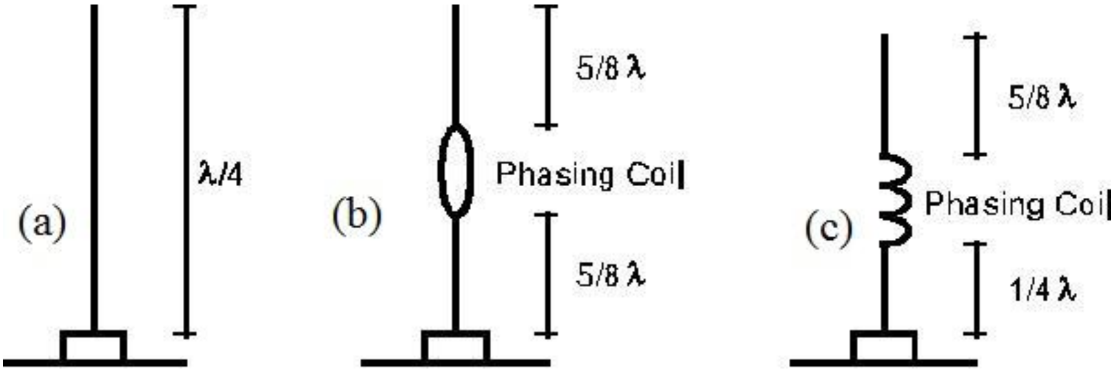
SUMMARY

In this chapter the theory of antennas was presented. The parameters that define an antenna and its efficiency were detailed namely, VSWR, input impedance, gain, radiation pattern, HPBW, directivity, polarization and bandwidth.

CHAPTER 3
TYPES OF MOBILE ANTENNA

3.1 INTRODUCTION

Nearly all vehicular antennas are monopoles mounted over a (relatively) flat body surface (as described above). In this application, the monopole is often called a “whip” antenna. At VHF low-band, a quarter-wave monopole can be 2.5 m (approximately 8 ft) long. However, an inductor (coil) at the base of a monopole adds electrical length, so the physical length of the antenna can be shorter. Although this kind of “loaded” antenna will appear to be a quarter-wave antenna, it will have a gain value somewhat less than a true quarter-wave monopole. This disadvantage can be somewhat offset, however, by the ability to mount the (shorter) antenna in the centre of a surface that will act as an acceptable ground plane (*e.g.*, the roof or trunk of the vehicle). Figure 3.1(a) shows an illustration of this kind of antenna.



(a) VHF low band base loaded monopole (b) UHF mobile antenna (c) 800MHz mobile antenna
Figure 3.1 Typical mobile antennas

At 800 MHz, a quarter-wave monopole does not perform well, so the approach of stacking two monopoles, with a phasing coil between, is used. Such an antenna, illustrated in figure 3(c), looks much like a mobile cellular phone antenna and has a gain of approximately 3 dBi.

The azimuthal pattern of all monopoles is ideally a circle. In other words, the gain versus azimuth angle in the horizontal plane is constant. In practice, the pattern in the horizontal plane generally is not omnidirectional, since the portion of the vehicle used as a ground plane is not symmetric, and usually there are other obstructions. Figure 3.1 shows the horizontal plane pattern for an 840 MHz whip located in the centre of the roof of a vehicle [4]. The dotted line in the figure shows the effects, on the pattern, of a law-enforcement light bar mounted on the roof ahead of the antenna

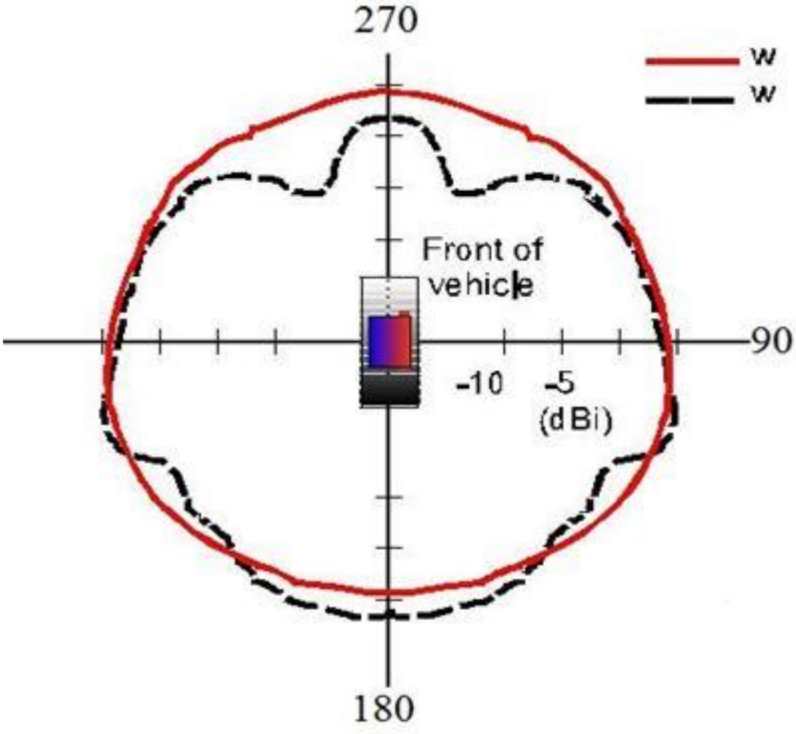


Figure 3.2. A mobile antenna horizontal-plane pattern

3.2 MEANDER LINE ANTENNA

Meander line antenna is one type of the microstrip antennas. Meander line technology allows designing antennas with small sizes and provides wideband performance [5]. Meander line antenna is an interesting class of resonant antennas and they have been widely studied in order to reduce the size of radiating elements in wire antenna, monopole, dipole, and folded dipole type antenna [6]. In meander line antenna the wire is continuously folded intended to reduce the resonant length. Increasing the total wire length in antenna of fixed axial length lowers its resonant frequency. According to [6] when made to be resonant at the same frequency, the performance characteristics of these antennas are independently of the differences in their geometry or total wire length. Uniform U-MLA structures the geometry are described to 3 parameter: the number of turn, length of the horizontal and vertical section. For NU-MLA these are no tied values for the variables. The operating frequency is the frequency where the reflection coefficients are less than -20dB. The good return loss for antenna is less than -10dB

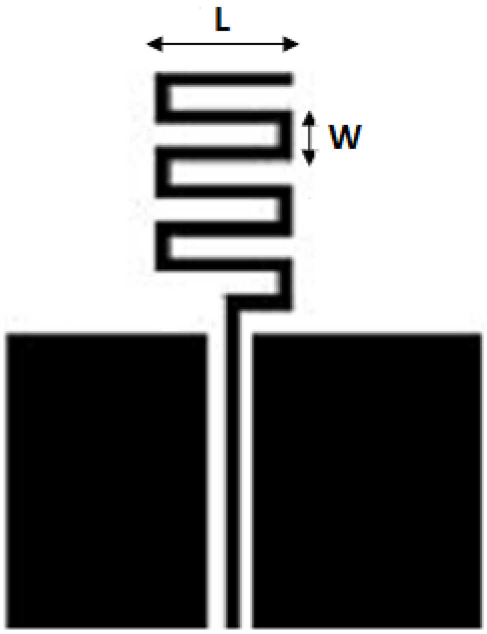


Figure 3.3: The length (L) and horizontal (W) of meander line

$$\frac{\Delta L}{h} = 0.412\frac{(\mathcal{E}\mathrm{eff}+0.3)(\frac{W}{h}+0.264)}{(\mathcal{E}\mathrm{eff}-0.258)(\frac{W}{h}+0.8)} \tag{3.1}$$

$$L = \frac{\lambda}{2} - 2\Delta L \tag{3.2}$$

$$W = \frac{1}{2f\sqrt{\mu o\,\mathcal{E}o}}\sqrt{\frac{2}{\mathcal{E}r+1}} \tag{3.3}$$

3.3 DIPOLE ANTENNA

A dipole antenna [7] is a symmetrical antenna, consisting of two quarter wave elements, connected to each of the two conductors (inner and outer) of a coaxial cable. You will need a centre insulator for connection of the two quarter wave elements and the coaxial cable. The dipole antenna can be erected in different ways, in order to obtain different benefits for the radio propagation, or for the given physical and practical conditions. Radio signals can be propagated with two major polarizations: horizontal and vertical.

For ground wave propagation the polarization should ideally be the same for all stations. For ionospheric propagation the horizontal polarization gives higher radiation angles (short-haul) than vertical polarization (long-haul)

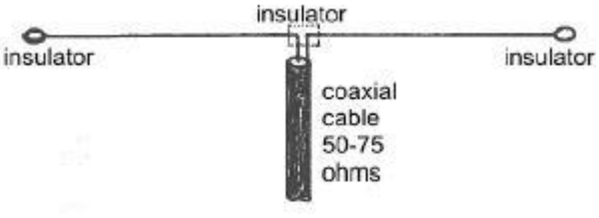


Figure 3.4 (a)

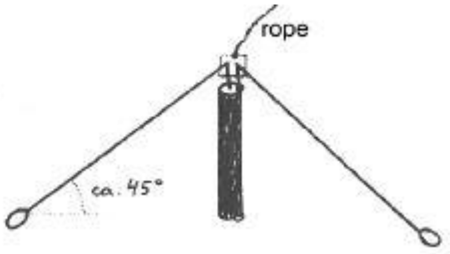


Figure 3.4 (b)

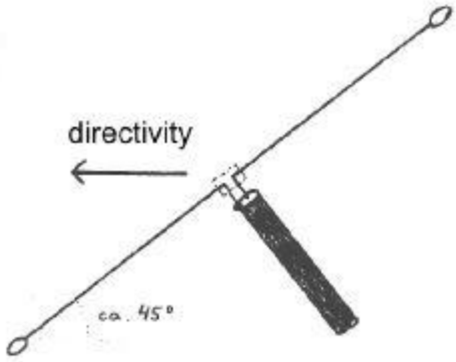


Figure 3.4(c)

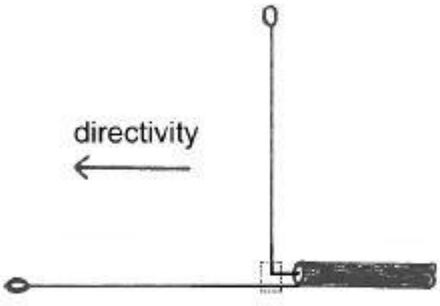


Figure 3.4 (d)

Figure 3.4 (e)

The horizontal dipole antenna 3.4(a) is horizontally polarized, and has a bidirectional directivity perpendicular to the antenna. The antenna needs two points of suspension for ropes from the dipole end insulators. This antenna is ideal for ionospheric radio wave propagation.

The inverted V dipole antenna 3.4(b) needs only one point of suspension. It combines both horizontal and vertical polarization, is omnidirectional, and is ideal for both ionospheric and ground wave propagation.

The sloping dipole antenna 3.4(c) offers directivity in the direction of the sloping antenna. Note that the dipole element pointing up should be connected to the centre conductor of the coaxial cable. This antenna is for vertical polarization via ground wave and long-haul ionospheric propagation, and requires just one point of suspension

The vertical dipole 3.4(d) is offering vertical polarization and is omnidirectional, and perfect for ground wave propagation. It requires just one point of suspension. For longer wavelengths (lower frequencies) the height of suspension may be too long.

In this case the broken vertical dipole 3.4(e) may be easier to erect. This variety will show directivity in the direction of the lower; horizontal part [if adding more wires here, and spreading them horizontally, gives an omnidirectional antenna called a ground-plane antenna]. Note that the top dipole element is connected to the centre coaxial cable conductor [unless we had a balun].

3.4 MONOPOLE ANTENNA

A monopole antenna is one half of a dipole antenna [8], almost always mounted above some sort of ground plane. The case of a monopole antenna of length L mounted above an infinite ground plane is shown in figure 3.5 (a)

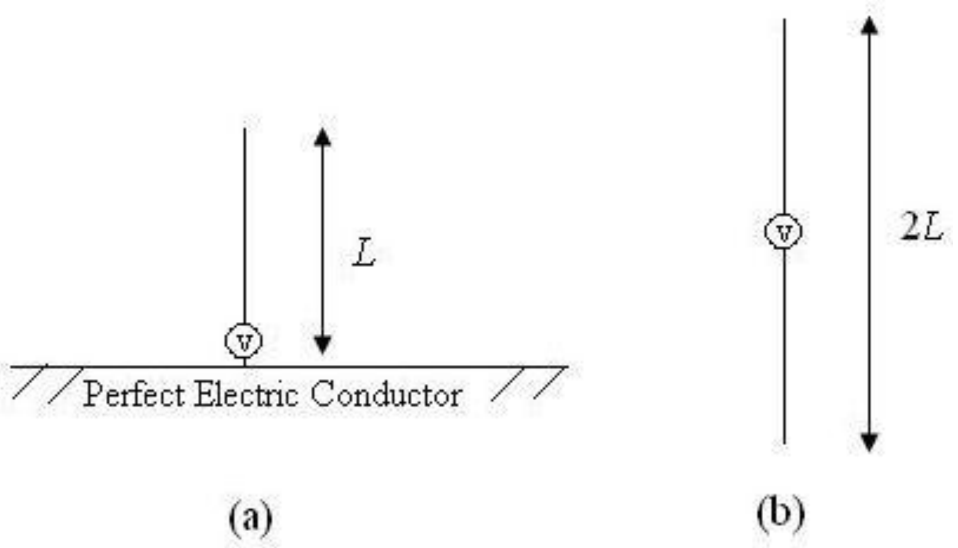


Figure 3.5: (a) Monopole above a PEC, (b) equivalent source in free space

Using image theory, the fields above the ground plane can be found by using the equivalent source (antenna) in free space as shown in figure 3.5 (b). This is simply a dipole antenna of twice the length. The fields above the ground plane in figure 3.5 (a), which are known and presented in the dipole antenna section. The monopole antenna fields below the ground plane in figure 3.5 (a) are zero.

The impedance of a monopole antenna is one half of that of a full dipole antenna. For a quarter wave monopole ($L=0.25\lambda$), the impedance is half of that of a half wave dipole, so Zin=36.5+j21.25 ohms. This can be understood since only half the voltage is required to drive a monopole antenna to the same current as a dipole (think of a dipole as having +V/2 and –V/2 applied to its ends, where as a monopole antenna only needs to apply +V/2 between the monopole antenna and the ground to drive the same current). Since Zin=V/I, the impedance of the monopole antenna is halved.

The directivity of a monopole antenna is directly related to that of a dipole antenna. If the directivity of a dipole of length of length 2L has a directivity of D1 (dB), then the directivity of a monopole antenna of length L will have a directivity of D1+3 (dB). That is, the directivity of a monopole antenna is twice the directivity of a dipole antenna of twice the length. The reason for this is simply because no radiation occurs below the ground plane; hence antenna is effectively twice as directivity.

3.5 QUARTER WAVELENGTH MONOPOLE ANTENNA

The quarter wave antenna is a single element antenna fed at one end that behaves as a dipole antenna. It is formed by a conductor in length $\lambda/4$. It is fed in the lower end, which is near a conductive surface which works as a reflector. The current in the reflected image has the same direction and phase that the current in the real antenna. The set quarter-wave plus image forms a half-wave dipole that radiates only in the upper half of space.

In this upper side of space the emitted field has the same amplitude of the field radiated by a half-wave dipole fed with the same current. Therefore, the total emitted power is one-half the emitted power of a half-wave dipole fed with the same current. As the current is the same, the radiation resistance (real part of series impedance) will be one-half of the series impedance of a half-wave dipole. As the reactive part is also divided by 2, the impedance of a quarter wave antenna is 36 + j21. The gain is the same as that for a half-wave dipole ($\lambda/2$) that is 2.14 dB part of series impedance) will be one-half of the series impedance of a half-wave dipole. As the reactive part is also divided by 2, the impedance of a quarter wave antenna is 36 + j21. The gain is the same as that for a half-wave dipole ($\lambda/2$) that is 2.14 dB.

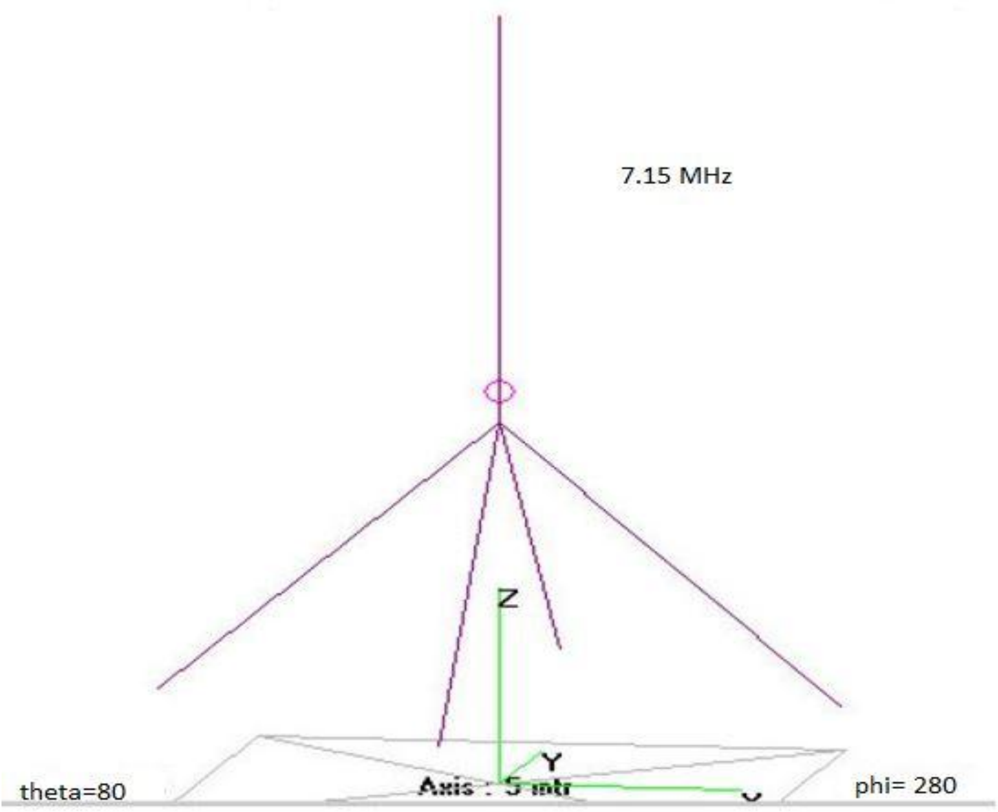


Figure 3.6: Wire model for ground plane antenna

Far from the antenna and near the ground, electromagnetic fields and radiation patterns are the same as for a half-wave dipole. The impedance is not the same as with a good conductor ground plane. Conductivity of earth surface can be improved with an expensive copper wire mesh. When ground is not available, as in a vehicle, other metallic surfaces can serve a ground plane, for example the roof of the vehicle. In other situations, radial wires placed at the foot of the quarter-wave wire can simulate a ground plane

3.6 INVERTED-L AND INVERTED-F ANTENNAS

An Inverted-L antenna is an improved version of the monopole antenna. The straight wire monopole is the antenna with the most basic form, but Inverted-L brings some advantages as: reduced height, reduced backward radiation, and moderate to high gain in both vertical and horizontal polarizations. A disadvantage is that is a narrow band antenna. Its dominant resonance appears at around one-quarter of the operating wavelength

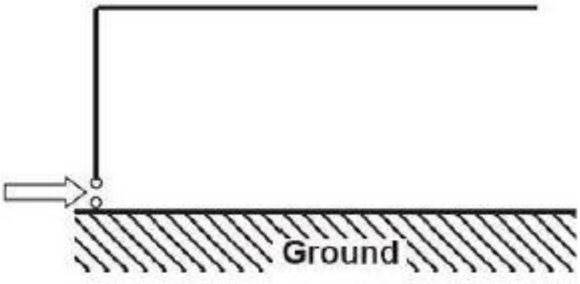


Figure 3.7: Inverted L type antenna

The Inverted-F antenna (IFA) is a printed trace on a PCB that is essentially a quarter-wave vertical antenna [9], but that has been bent horizontally in order to be parallel with the substrate’s copper ground pour, and then fed at an appropriate point that will supply a good input match.

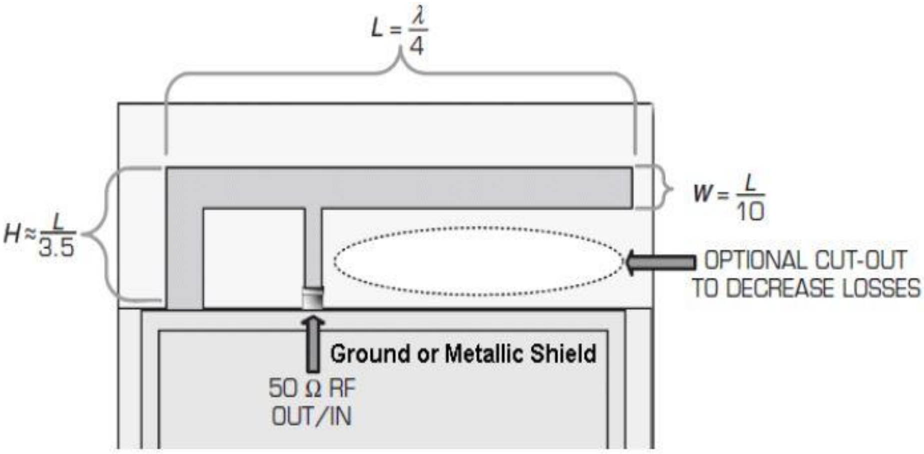


Figure 3.8: Inverted F type antenna

The antenna/ground combination will behave as an asymmetric dipole, the differences in current distribution on the two-dipole arms being responsible for some distortion of the radiation pattern.

- In general, the required PCB ground plane length is roughly one quarter (λ/4) of the operating wavelength.
- If the ground plane is much longer than λ/4, the radiation patterns will become increasingly multi-lobed.
- On the other hand, if the ground plane is significantly smaller than λ/4, then tuning becomes increasingly difficult and the overall performance degrades.
- The optimum location of the IFA in order to achieve an Omni-directional far-field pattern and 50Ω impedance matching was found to be close to the edge of the Printed Circuit Board.
- IFA is an excellent choice for small, low-profile wireless designs, and is not as adversely affected by tiny, poorly shaped ground-planes as that of the monopole above.
- The IFA also supplies decent efficiency, is of a compact geometry, and has a relatively omnidirectional radiation pattern (with some deep nulls).
- IFA antennas do have somewhat of a narrower bandwidth than the average monopole.

3.7 MICROSTRIP ANTENNA

Microstrip is one of most popular of planar transmission because it can fabricate by photolithographic and also can integrated with other passive and active microwave device. Microstrip antennas become very popular in the 1970s primarily for space borne application. Today they are used for government and commercial applications. These antenna consist of a metallic patch can take many different configurations. However, the rectangular and circular patches are most popular because of ease of analysis and fabrication, and their attractive radiation characteristics, especially low polarization radiation [10]. The microstrip antennas are low profile, conformable to planar and non-planar surfaces, simple and extensive to fabricate using modern circuit technology, mechanically robust when mounted on rigid surfaces, com –risible with MMIC design, and very versatile in terms of resonant frequency, polarization, pattern and impedance. These antennas can be mounted on the surface of aircraft, spacecraft, satellites, missiles, cars, and even handheld mobile phones [11].

3.7.1 MICROSTRIP BASIC STRUCTURE

Microstrip is a conductor of width W is printed on a thin grounded dielectric substrate of thickness d and relative permittivity Ɛr. the thickness and type of substrate give different results. The thickness of substrate layer can increase the bandwidth and efficiency, but unfortunately it will generate surface wave with low propagation that cause lost of power. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate.

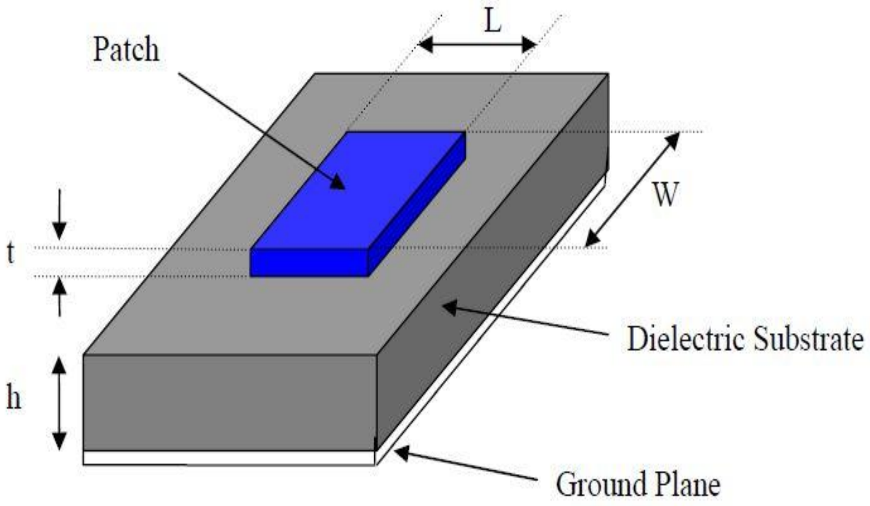


Figure 3.9: microstrip patch

In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, and elliptical or some other common shape as shown in Figure 3.10. For a rectangular patch, the length L of the patch is usually $0.3333\lambda o < L < 0.5\lambda o$, where λo is the free-space wavelength. The patch is selected to be very thin such that $t \ll \lambda$ (where t is the patch thickness). The height h of the dielectric substrate is usually $0.003\lambda o \leq h \leq 0.05\lambda o$. The dielectric constant of the substrate (εr) is typically in the range $2.2 \leq \varepsilon r \leq 12$.

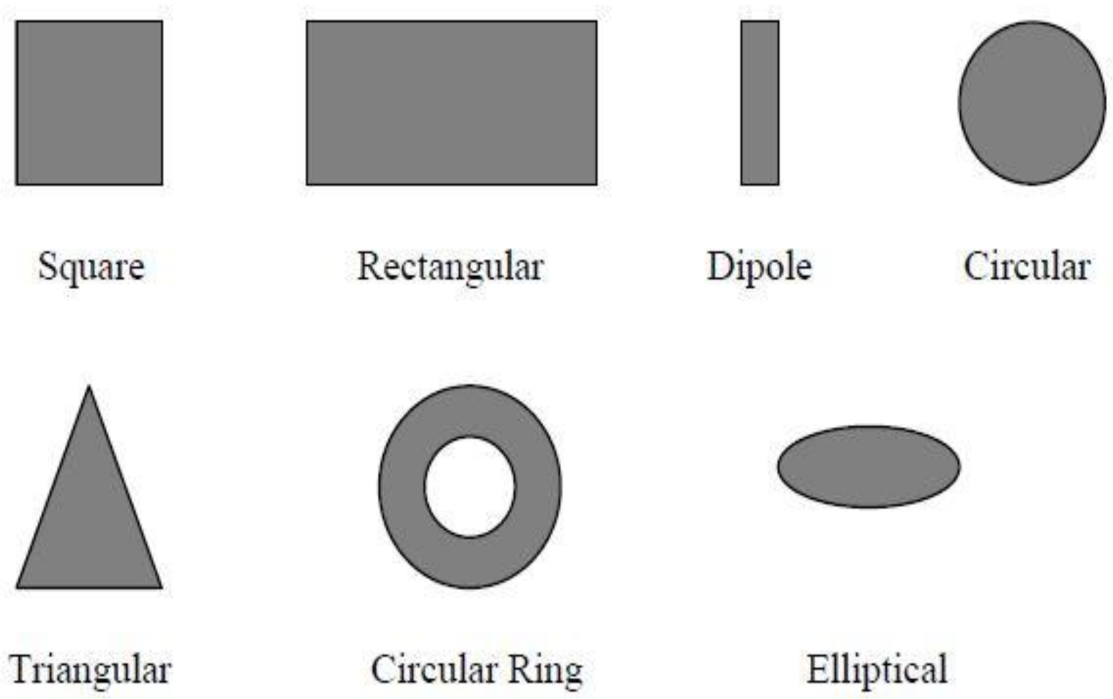


Figure 3.10: different types of microstrip patch

Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. For good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable since this provides better efficiency, larger bandwidth and better radiation [5]. However, such a configuration leads to a larger antenna size. In order to design a compact Microstrip patch antenna, higher dielectric constants must be used which are less efficient and result in narrower bandwidth. Hence a compromise must be reached between antenna dimensions and antenna performance.

3.7.2 ADVANTAGES AND DISADVANTAGES

Microstrip patch antennas are increasing in popularity for use in wireless applications due to their low-profile structure. Therefore they are extremely compatible for embedded antennas in handheld wireless devices such as cellular phones, pagers etc... The telemetry and Square Rectangular Dipole Circular Triangular Circular Ring Elliptical communication antennas on missiles need to be thin and conformal and are often Microstrip patch antennas. Another area where they have been used successfully is in Satellite communication. Some of their principal advantages are given below:

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

Microstrip patch antennas suffer from a number of disadvantages as compared to conventional antennas. Some of their major disadvantages are given below:

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

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

3.7.3 RESONANCE FREQUENCY

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

$$f\mathrm{o} = \frac{\mathrm{C}}{2\mathrm{Le}\sqrt{\mathcal{E}\mathrm{r}}} \tag{3.4}$$

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

$$\mathrm{Le} = \mathrm{L}+2\Delta\mathrm{L} \tag{3.5}$$

The Hammerstad formula for the fringing extension is

$$\frac{\Delta\mathrm{L}}{\mathrm{h}} = 0.412\frac{(\mathcal{E}\mathrm{eff}+0.3)(\frac{\mathrm{W}}{\mathrm{h}}+0.264)}{(\mathcal{E}\mathrm{eff}-0.258)(\frac{\mathrm{W}}{\mathrm{h}}+0.8)} \tag{3.6}$$

Where

$$\mathcal{E}\mathrm{eff} = \frac{\mathcal{E}\mathrm{r}+1}{2} + \frac{\mathcal{E}r-1}{2} / \sqrt{\left(1+\frac{12\mathrm{h}}{\mathrm{W}}\right)} \tag{3.7}$$

3.8 MICROSTRIP LINE FEED

In this type of feed technique, a conducting strip is connected directly to the edge of the microstrip patch as shown in Figure 3.11. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure

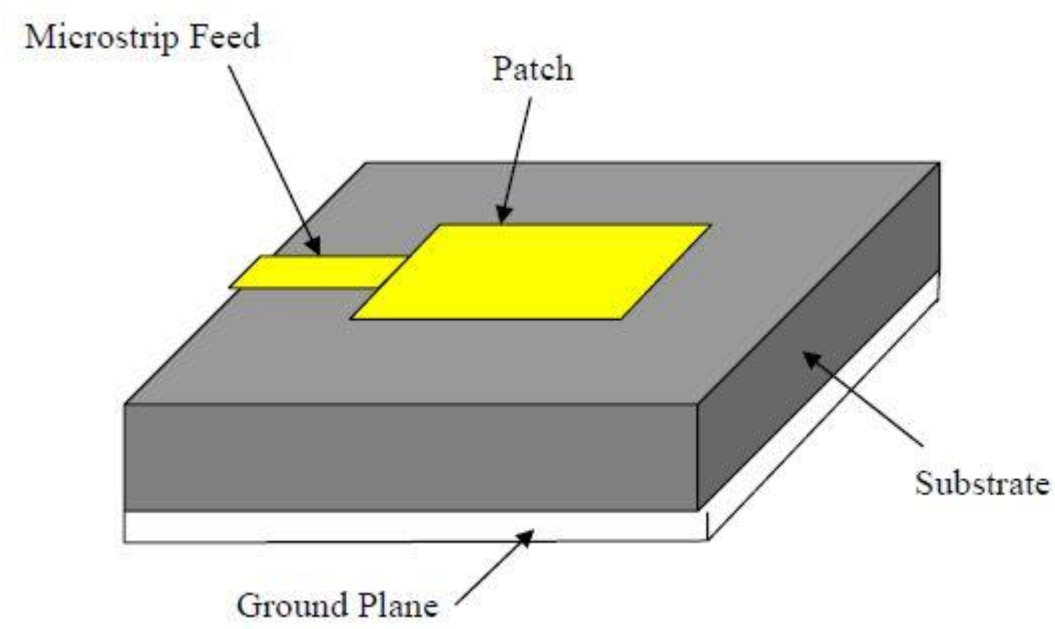


Figure 3.11 Microstrip patch with direct feed

The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. This is achieved by properly controlling the inset position. Hence this is an easy feeding scheme, since it provides ease of fabrication and simplicity in modeling as well as impedance matching. However as the thickness of the dielectric substrate being used, increases, surface waves and spurious feed radiation also increases, which hampers the bandwidth of the antenna [1]. The feed radiation also leads to undesired cross polarized radiation.

3.8.1 COAXIAL FEED

The Coaxial feed or probe feed is a very common technique used for feeding Microstrip patch antennas. As seen from Figure 3.12(a), the inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane.

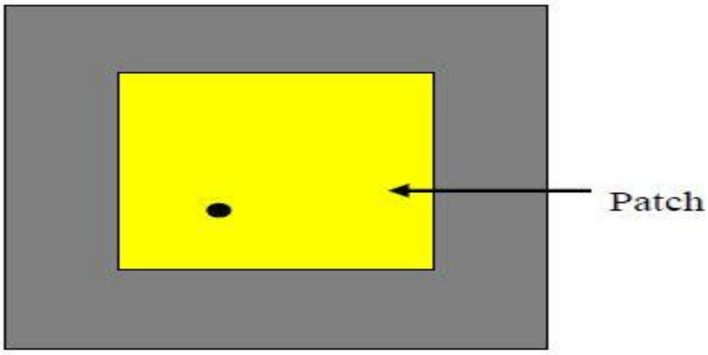


Figure 3.12(a): Top view of microstrip patch with coaxial feed

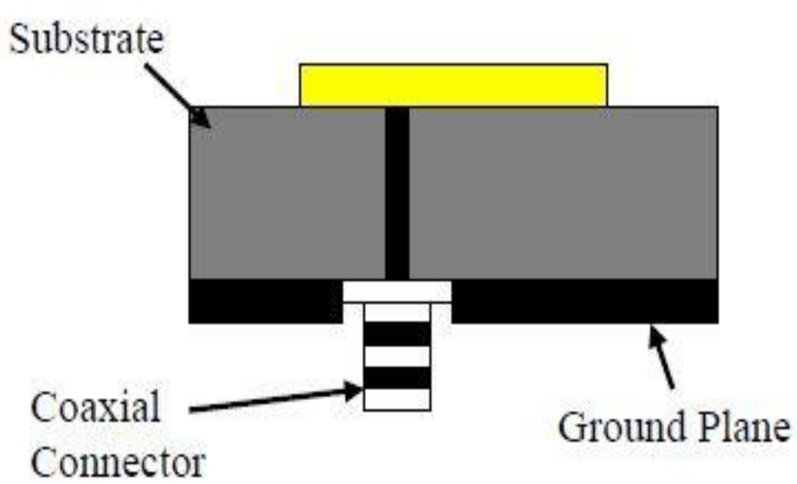


Figure 3.12(b): Side view of microstrip patch with coaxial feed

The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance. This feed method is easy to fabricate and has low spurious radiation. However, its major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates ($h > 0.02\lambda o$). Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems [9]. It is seen above that for a thick dielectric substrate, which provides broad bandwidth, the microstrip line feed and the coaxial feed suffer from numerous disadvantages. The non-contacting feed techniques which have been discussed below to solve these problems**.**

3.8.2 APERTURE COUPLED FEED

In this type of feed technique, the radiating patch and the microstrip feed line are separated by the ground plane as shown in Figure 3.13. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane.

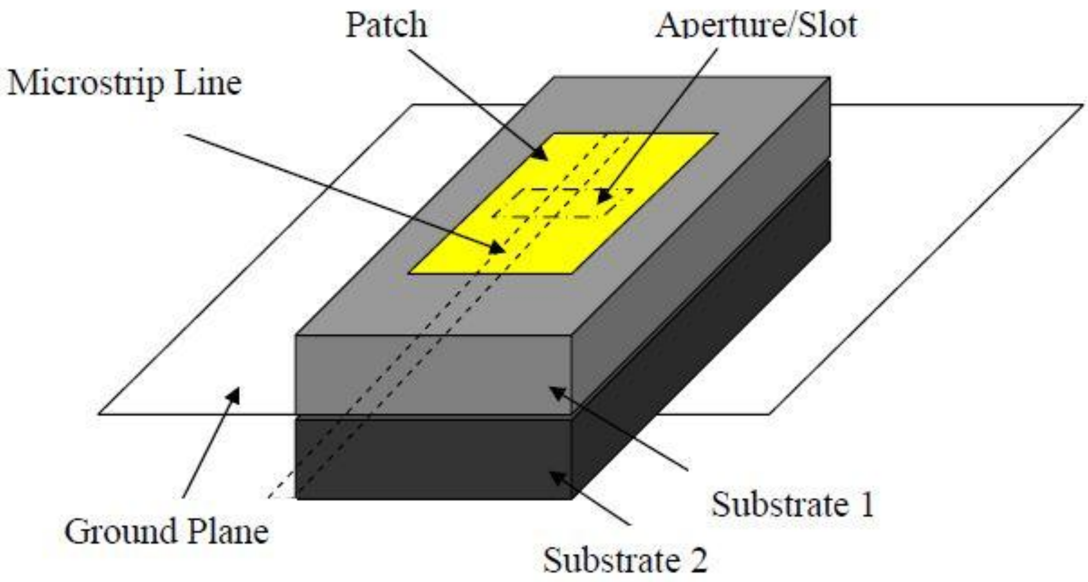


Figure 3.13: Microstrip patch with aperture coupled feed

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

3.8.3 PROXIMITY COUPLED FEED

This type of feed technique is also called as the electromagnetic coupling scheme. As shown in Figure 3.14, two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (as high as 13%) [5], due to overall increase in the thickness of the microstrip patch antenna. This scheme also provides choices between two different dielectric media, one for the patch and one for the feed line to optimize the individual performances.

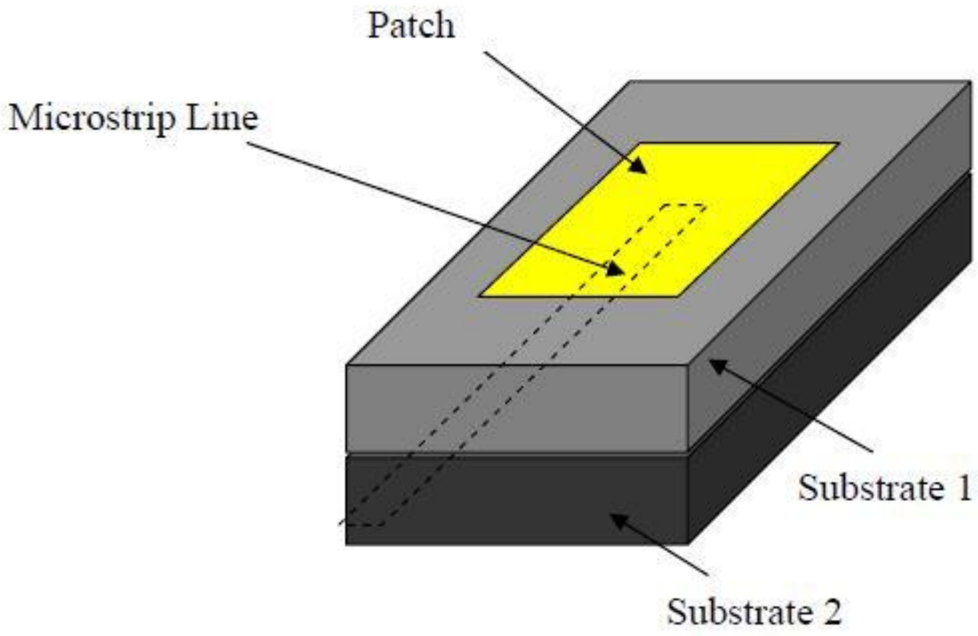


Figure 3.14: Microstrip patch with proximity coupled feed

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

TABLE 3.1 BELOW SUMMARIZES THE CHARACTERSTICS OF THE DIFFERENT FEED TECHNIQUES.

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

3.9 METHOD OF ANALYSIS

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

3.9.1 TRANSMISSION LINE MODEL

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

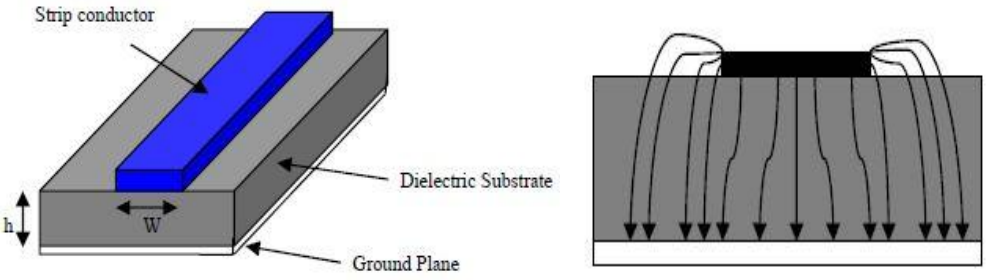


Figure 3.15: Microstrip transmission line model side and front view

Hence, as seen from Figure 3.13, 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 (Ɛref) must be obtained in order to account for the fringing and the wave propagation in the line. The value of Ɛref is slightly less than *Ɛr* because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in the air as shown in Figure 3.15 above. The expression for Ɛref is given by Balanis [1] as:

$$\varepsilon\mathrm{eff} = \frac{\varepsilon\mathrm{r}+1}{2} + \frac{\varepsilon\mathrm{r}-1}{2} / \sqrt{\left(1+\frac{12\mathrm{h}}{\mathrm{W}}\right)} \tag{3.8}$$

Ɛref =effective dielectric constant
Ɛr = dielectric constant of substrate

h = height of dielectric substrate
W = width of the patch

Consider Figure 3.16 below, which shows a rectangular microstrip patch antenna of length L, width W resting on a substrate of height h. The co-ordinate axis is selected such that the length is along the x direction, width is along the y direction and the height is along the z direction.

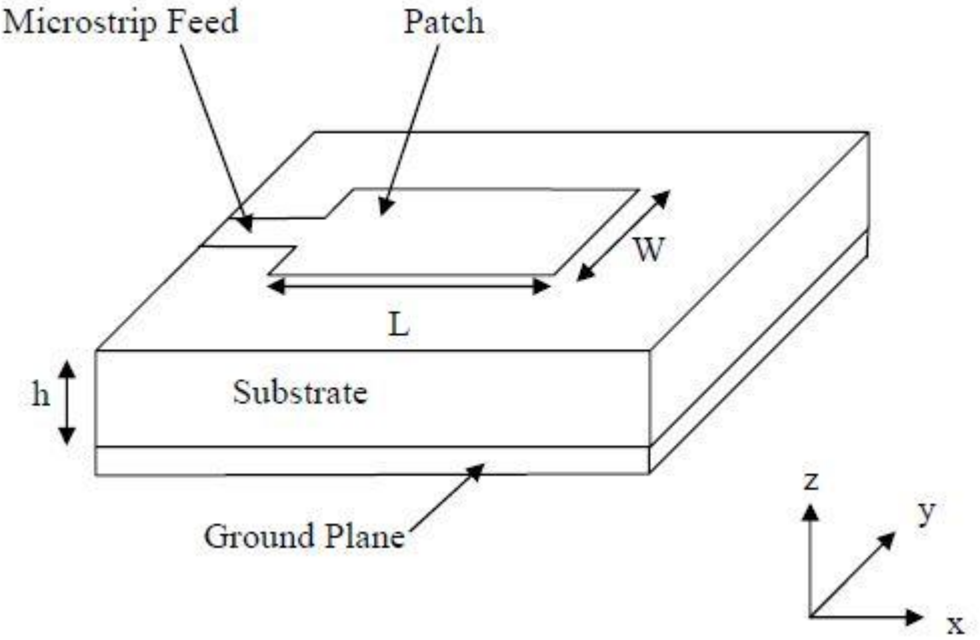


Figure 3.16: Rectangular microstrip patch antenna

In order to operate in the fundamental TM10 mode, the length of the patch must be slightly less than λ / 2 where λ is the wavelength in the dielectric medium and is equal to λo / Ɛreff where λo is the free space wavelength. The TM10 mode implies that the field varies one λ / 2 cycles along the length, and there is no variation along the width of the patch. In the Figure 3.15 shown below, the microstrip patch antenna is represented by two slots, separated by a transmission line of length L and open circuited at both the ends. Along the width of the patch, the voltage is maximum and current is minimum due to the open ends. The fields at the edges can be resolved into normal and tangential components with respect to the ground plane.

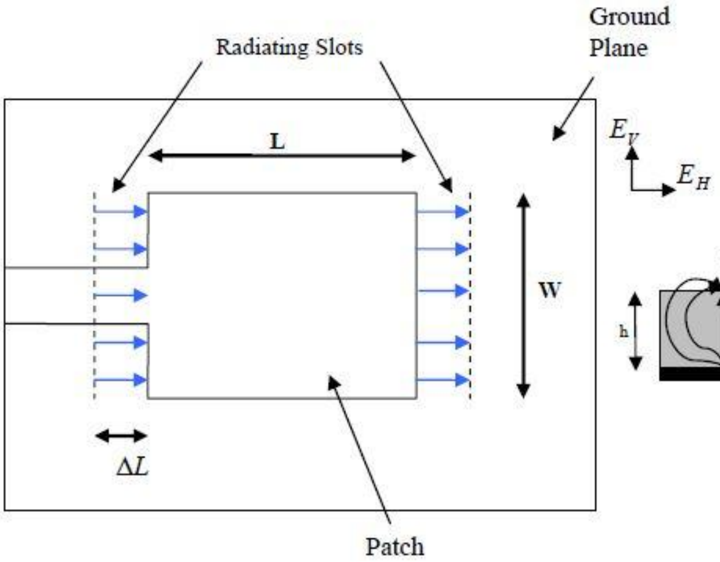


Figure 3.17: Microstrip radiating slot with open end

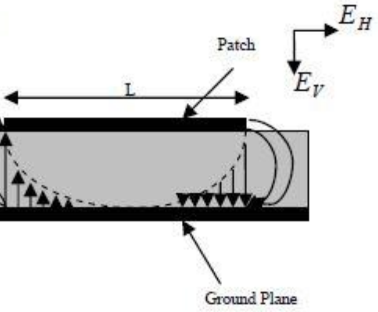


Figure 3.18: Electric field pattern

It is seen from Figure 3.18 that the normal components of the electric field at the two edges along the width are in opposite directions and thus out of phase since the patch is λ / 2 long and hence they cancel each other in the broadside direction. The tangential components (seen in Figure 3.18), which are in phase, means that the resulting fields combine to give maximum radiated field normal to the surface of the structure. Hence the edges along the width can be represented as two radiating slots, which are λ / 2 apart and excited in phase and radiating in the half space above the ground plane. The fringing fields along the width can be modeled as radiating slots and electrically the patch of the microstrip antenna looks greater than its physical dimensions. The dimensions of the patch along its length have now been extended on each end by a distance ΔL, which is given empirically by Hammerstad [13] as:

$$\frac{\Delta \mathrm{L}}{\mathrm{h}} = 0.412\frac{(\mathcal{E}\mathrm{eff}+0.3)(\frac{\mathrm{W}}{\mathrm{h}}+0.264)}{(\mathcal{E}\mathrm{eff}-0.258)(\frac{\mathrm{W}}{\mathrm{h}}+0.8)} \tag{3.9}$$

The effective length of the patch now becomes

$$\mathrm{Leff} = \mathrm{L} + 2\Delta \mathrm{L} \tag{3.10}$$

For a given resonance frequency $f\,o$, the effective length is given by [9] as:

$$\mathrm{Leff} = \frac{\mathrm{C}}{2\mathrm{fo}\sqrt{\mathcal{E}\mathrm{reff}}} \tag{3.11}$$

For a rectangular Microstrip patch antenna, the resonance frequency for any TMmn mode is given by James and Hall [14] as:

$$f_o = \frac{C}{2\sqrt{\mathcal{E}reff}} \sqrt{\left(\frac{m}{L}\right) + \left(\frac{n}{W}\right)} \quad (3.12)$$

Where m and n are modes along L and W respectively. For efficient radiation, the width *W* is given by:

$$W = \frac{C}{2f_o\sqrt{\frac{(\mathcal{E}r+1)}{2}}} \quad (3.13)$$

SUMMARY

This chapter presented the study of different antennas which are suitable for the design purpose of mobile antenna, but suffers from some disadvantage. Loop antennas in the first group are operated as half-wavelength resonant structure. Although being able to achieve penta-band operations for GSM 850, GSM 900, DCS, PCS, and UMTS, antenna in this group suffer from the drawback of having a large radiator area. Next the monopole antennas are operated as a quarter-wavelength resonant structure. When the radiator in this type of antenna is close to the ground plane usually makes it difficult to design a quarter-wavelength monopole antenna. Next the monopole slot antenna can also be operated as a quarter-wavelength resonant structure however the distance between radiator and ground plane is large which is considered as too large for some mobile handsets. Next a simple printed PIFA can be constructed by adding a ground strip to an inverted-L quarter-wavelength monopole. But there is a poorer impedance mismatch for the lower frequencies region hence impedance bandwidth is often still not large enough. That is why PIFAs are frequently adopted in the 2.4 and 5.2-GHz WLAN bands. Design and simulation of meander type antenna is shown in next chapter step wise.

CHAPTER 4

ANTENNA CONFIGURATION AND DESIGN

4.1 ANTENNA CONFIGURATION

Figure 4.1 shows the geometry of the proposed planar internal antenna, which is fabricated using a 0.8-mm-thick, 45-mm-wide, and 112-mm-high FR4 substrate with dielectric constant 4.4. On the lower portion of the FR4 substrate is a 45×100 mm^2 ground plane, above which is an area of 45 ×12 mm^2 (referred to as the antenna area for convenience) reserved to locate the designed antenna. The designed antenna, according to its inherent functions, can be divided into three parts: a main radiation structure (or called a main radiator), a parasitic structure, and an impedance-adjustment structure (see the detailed metal pattern in Fig. 4.1(b), all these structures are printed coplanar with the ground plane. The main radiator is a 1-mm-wide, 80-mm-long metal strip that starts from the upper-right corner and is printed along the E-D-C-B-A meandered path [12]. This strip, which is to be excited at point A and whose bottom edge is 1-mm away from the ground plane, can be designed to resonate at about 960 and 2100 MHz .The parasitic structure lies in the lower-right corner of the antenna area and is a 1-mm-wide grounded inverted-L metal strip. This strip originates from

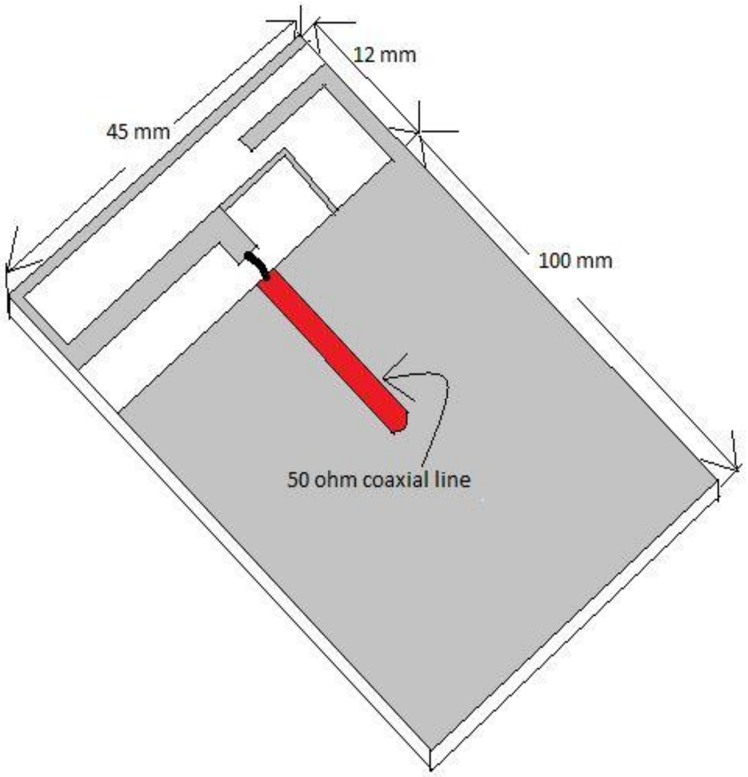


Figure 4.1: (a) Perspective view of the entire structure

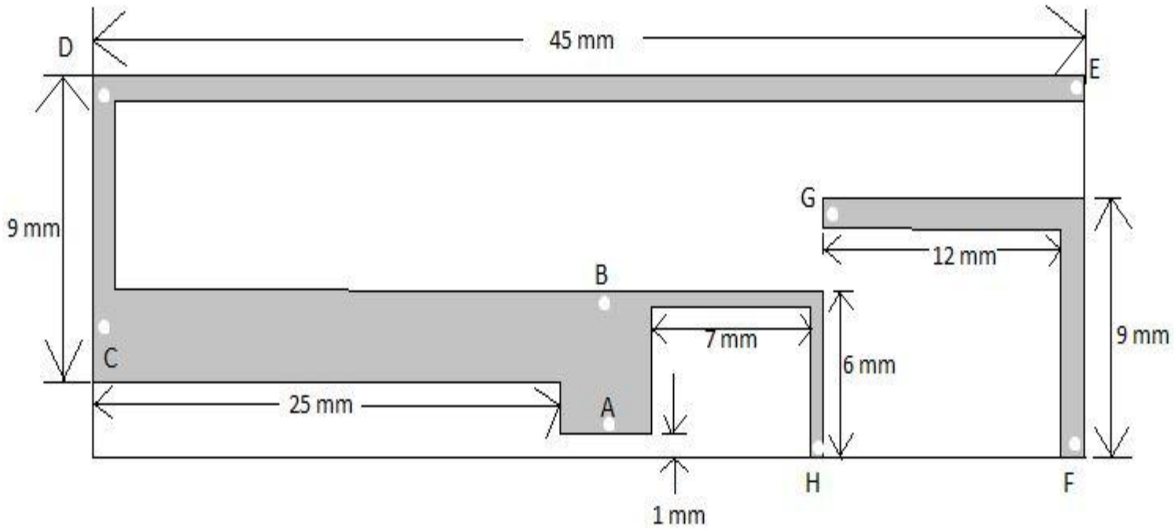


Figure 4.1: (b) metal pattern in the antenna area

point F of the ground plane, extends upward along the right edge of the substrate by a length of 9 mm, and then extends leftward by a length of 12 mm. The parasitic structure is implemented to excite one additional resonant mode to widen the upper impedance band. The impedance-adjustment structure is a 0.5-mm-wide inverted-L strip, whose **7-** mm-long horizontal section connects to point B of the main radiator and whose 6-mm-long vertical section connects to point H of the ground plane. This structure can improve the impedance matching in the lower impedance band. Finally, the AB and BC sections of the main radiator are widened to have a width of 3 mm, resulting in a much better impedance match in the upper resonant band. The design procedures along with the design ideas behind are elucidated in the next section.

4.2 PROCEDURES OF ANTENNA DESIGN

4.2.1 PRELIMINARY DESIGN OF MAIN RADIATOR

For size reduction, many existing multi-band monopole antennas have been constructed by bending a metal strip into meandered shape. The meandered strip can be designed to resonate around multiple pre-selected frequencies. The quarter-wavelengths of the first few resonant modes are roughly the total length of the meandered strip or the lengths of some particular sections bent in the meandered strip [13]. In this study, the main strip, whose route is E-D-C-B-A (see Fig. 4.1(b)) with a total length of 80 mm, is also of meandered type. For convenience, the antenna so constructed is a folded monopole antenna referred to as the type 1 antenna. As shown in Fig. 4.2, the first three

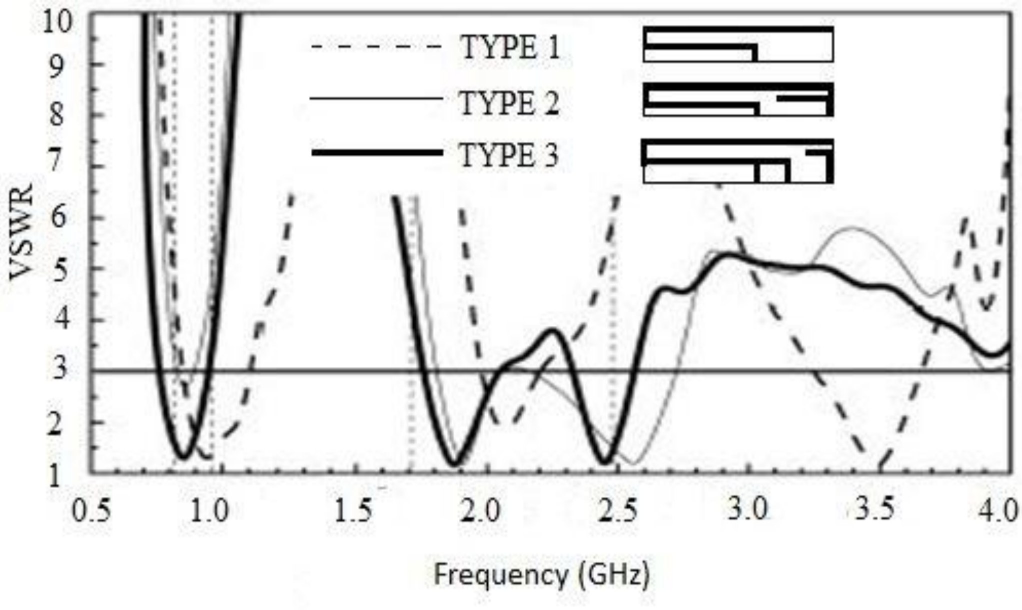


Figure 4.2: Measured VSWR against frequency for the types 1, 2, and 3 antennas.

resonant modes of the folded monopole antenna are excited at around 960, 2100, and 3500 MHz Simulated using Ansoft HFSS, the electric current distributions of the resonant modes on the meandered strip of the type 1 antenna are shown in Fig. 4.3 (a). The quarter-wavelength route of the electric current distribution at 960MHz roughly has the same length of the entire main radiator, whereas the A-B-C quarter-wavelength route at 2100MHz has a much shorter length of about 35.7 mm. For the third resonant mode at 3500 MHz, the half- wavelength route of the main electric current distributed between two current nulls (depicted as circular dashed lines in Fig. 4.3 (c) has a length of about 33 mm. Since the impedance band associated with the third resonant mode is far beyond our frequency bands of interest, the frequency response of that band will not be studied in the remaining antenna design procedures

4.2.2 DESIGN OF PARASITIC STRUCTURE

Note that the upper (i.e., the second) VSWR · 3 impedance band of the type 1 antenna is far from wide enough to cover the desired higher operating band (i.e., 1710-2484 MHz) for DCS, PCS, UMTS, and 2.4-GHz WLAN operations. To achieve the goal, an additional

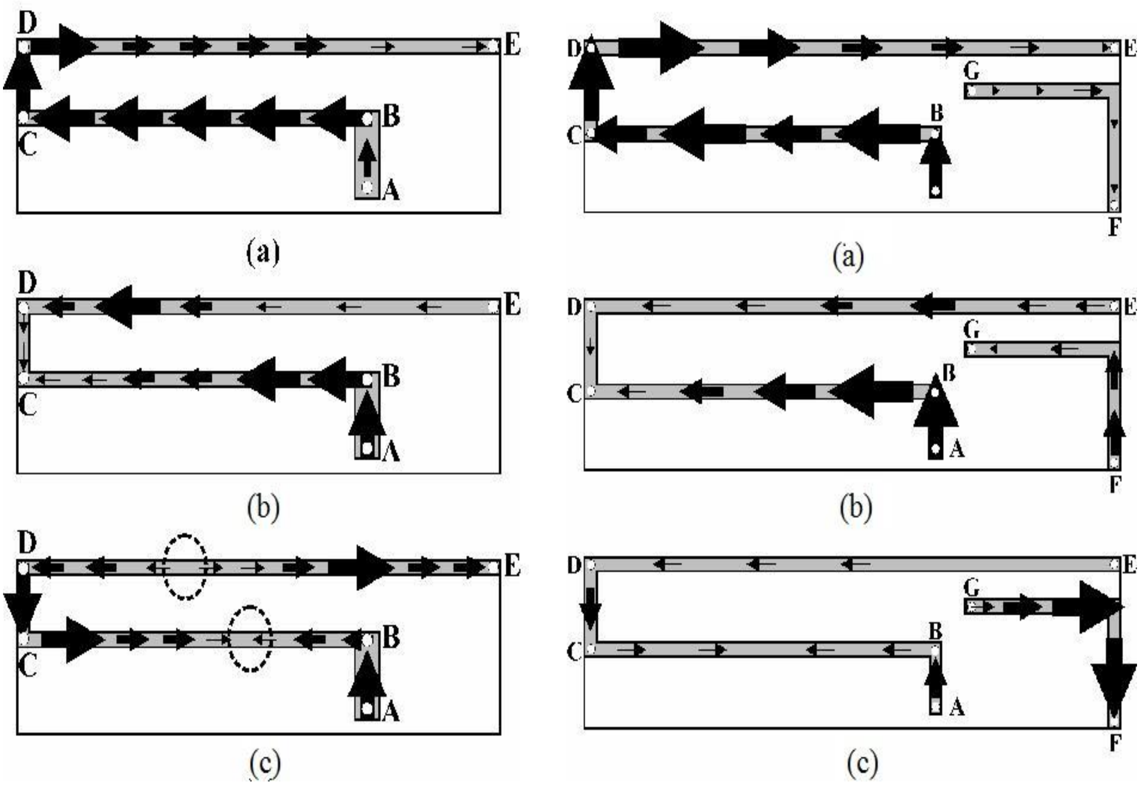


Figure 4.3: Electric current distribution

resonant mode excited in the desired upper operating band is needed. For that purpose, a grounded inverted-L strip functioning as a parasitic structure is added in the lower-right corner of the antenna area to form a type 2 antenna. Note that the right edge of the vertical section of the parasitic structure is aligned with that of the substrate; the horizontal section of the parasitic structure is set to be equal vertical distance away from the two horizontal sections (i.e., the DE and BC sections) of the main radiator.

With the length of the parasitic structure's vertical section fixed at 9 mm, the resonant mode excited in the parasitic structure can be controlled by varying the length of the horizontal section. When the length of the horizontal section is adjusted to 12 mm, the additional resonant mode is excited at about 2500 MHz, whereas the first and second resonant frequencies are slightly lowered from 960 and 2100MHz of the type 1 antenna to 850 and 1907 MHz, respectively. The changes in resonant frequencies can be explained by examining on the type 2 antenna the electric current distributions depicted in Fig 4.3.Because of the presence of the parasitic structure, the open end of the meandered strip around point E experiences a larger fringing capacitance, resulting in a larger effective length of the meandered strip than that of the type 1 antenna. Hence, although the current distributions of the first two resonant modes on the meandered strips of the types 1 and 2 antennas are very similar, the resonant frequencies of the latter are slightly lower than those of the former. By contrast, the quarter-wavelength current distribution of the additional (third) resonant mode shown in Fig. 4.3 (c) mainly concentrates on the parasitic structure of the type 2 antenna, and the associated current distribution on the meandered strip is much weaker and is quite different from that of the third resonant mode of the type 1 antenna. The resonance occurring mainly in the parasitic structure instead of the main radiator explains why the third resonant frequency of the type 2 antenna is farther away from that of the type 1 antenna than are the first two resonant frequencies of the type 2 antenna away from those of the type 1 antenna. Since the two resonant frequencies of the second and third excited modes are close to each other, a wide upper impedance band of 1800-2720MHz is established. Unfortunately, the parasitic structure has downgraded the impedance matching in the lower resonant band, leading to a minimum VSWR of as high as 2.7 in that band.

4.2.3 DESIGN OF IMPEDANCE ADJUSTMENT STRUCTURE.

For the type 2 antenna, the enhancement in the upper impedance bandwidth accompanies an impedance mismatch in the lower resonant band. To overcome this problem, we sought to adjust the input impedance, especially in the lower resonant band. With a 0.5-mm-wide grounded inverted-L strip connected to point B of the main radiator to form a type 3 antenna, the first three resonant modes are excited around the frequencies that are close to the resonant frequencies of the type 2 antenna (the current distributions on the meandered strips of these two antennas are very similar and are not shown here for brevity). This grounded inverted-L strip provides adequate impedance matching in the lower resonant band (see Fig.4.1) and hence can be used as the impedance-adjustment structure. The refection coefficient loci of the types 2 and 3 antennas are shown in the Smith charts of Fig. 4.4.

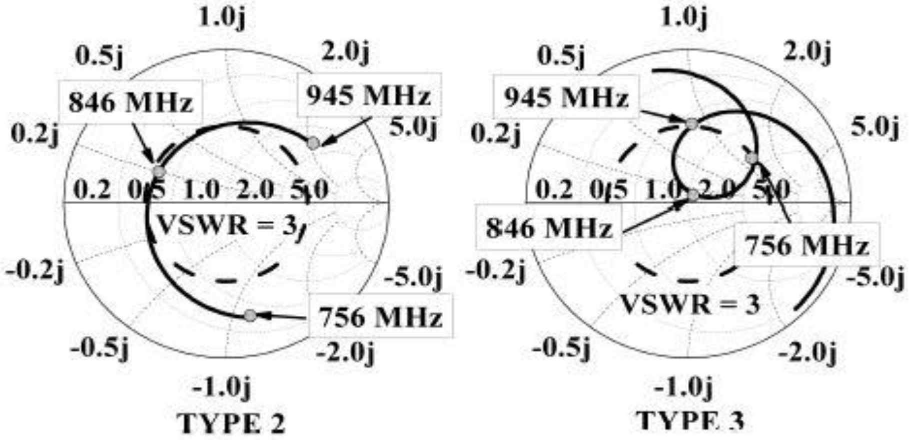


Figure 4.4: Reflection-coefficient loci around the lower resonant bands for the types 2 and 3 antennas.

This impedance-adjustment structure helps improve the impedance matching in the lower resonant band around 850 MHz, leading to a tightened resonant locus in the Smith chart for the type 3 antenna. The resulting lowest VSWR is as low as 1.2, and the VSWR ≤ 3 impedance band now ranges from 756 to 945 MHz, only slightly insufficient to cover the desired lower operating band (i.e., 824-960 MHz) for GMS 850 and GMS 900 operations.

4.2.4 FINAL DESGN OF MAIN RADIATOR FOR BETTER IMPEDANCE MATCHING.

Although the impedance matching in the lower resonant band of the type 3 antenna is greatly improved as compared with the type 2 antenna, the impedance matching around 2.2 GHz in the upper impedance band is downgraded. Obviously, the type 2 antennas' upper VSWR ≤ 3 impedance bands has been split into the type 3 antenna's two disjoint bands, which are even more insufficient for completely enclosing the desired upper operating band of 1710-2484 MHz. To overcome this problem, the strong variation of the electric current on the main radiator needs to be smoothened. This can be accomplished by widening the A-B-C section of the main radiator. The horizontal BC section is widened toward the *¡z* direction, whereas the vertical AB section is widened symmetrically toward the *+y* and *¡y* directions. With the width (*w*1) of the A-B-C section changed from 1 to 3 mm, not only can the upper VSWR ≤ 3 impedance band be enlarged to 1705-2505 MHz, but a lower impedance band of 810{1010MHz can also be obtained, as shown in Fig.4.4. Each of these two impedance bands can completely cover its associated desired operating band. Hence, the type 3 antenna with *w*1 = 3mm is selected to be our final designed antenna. From Fig. 4.5, it is observed that the electric current on BC section is smoothened after widening the width of the A-B-C section

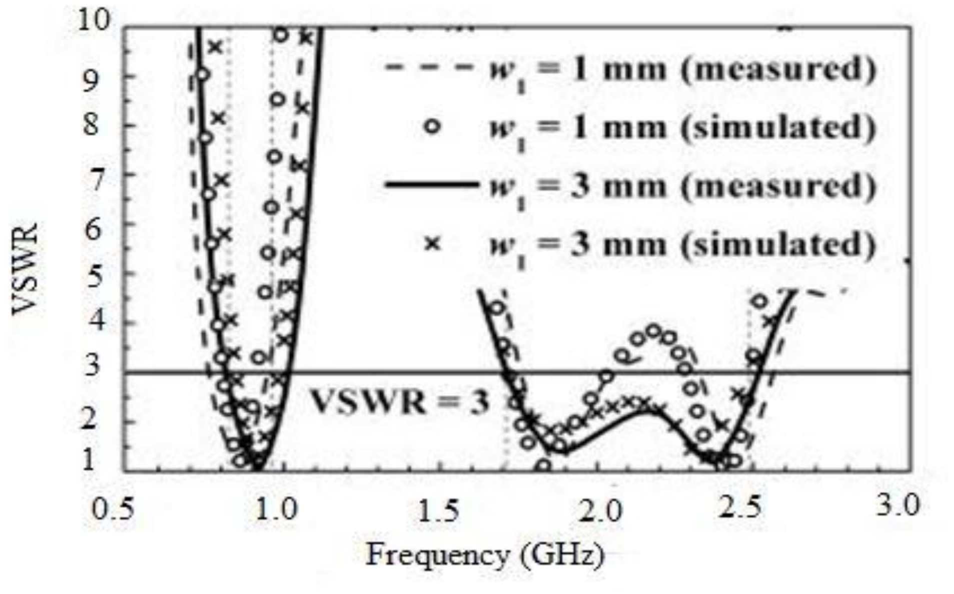


Figure 4.5: Measured VSWR for the type 3 antenna with different values of *w*1

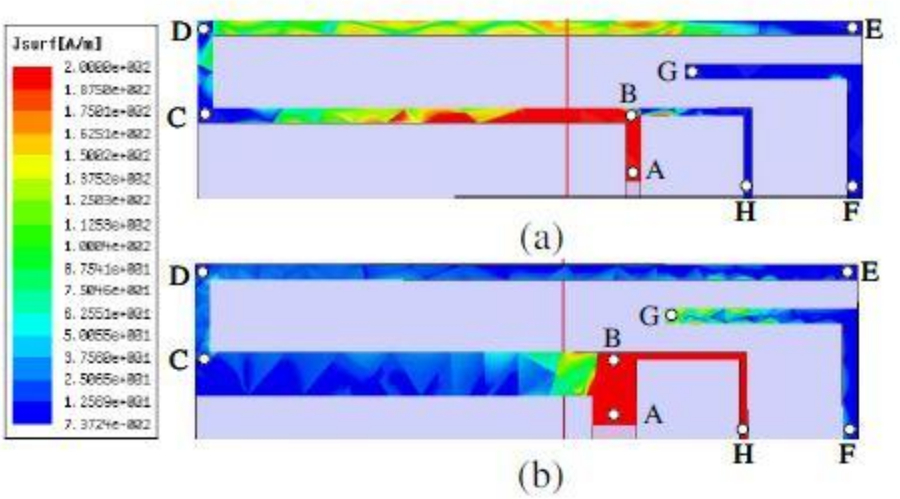


Figure 4.6: Simulated electric current distributions of type 3 antenna at 2200MHz with different values of *w*1: (a) *w*1 = 1 mm; (b) *w*1 = 3 mm.

SUMMARY

In this chapter first we have discussed the antenna configuration and geometry, the length of the radiator, about the thickness of substrate and. The designed antenna, according to its inherent functions, can be divided into three parts: a main radiation structure (or called a main radiator), a parasitic structure, and an impedance-adjustment structure. And we have studied the different steps to obtain the desired antenna. Here we discussed total 4 steps to study the internal mobile antenna. Next step provides the better design and performance as comparison to last step. This is a multi-band antenna therefore to excite an additional resonant mode at about 2500 MHz we need to design a parasitic structure which is illustrated in step 2. And to adjust the input impedance, especially in the lower resonant band (824-960 MHz), this can be achieved by using the impedance adjustment structure described in step 3. And step 4 describes the final design of main radiator for better impedance matching.

CHAPTER 5
SIMULATION IN ADS

5.1 INTRODUCTION AND OVERVIEW OF ADS

In order to perform any design or simulation using CAD software it is very important to understand the basic of software which is to be used as every tool can have different steps to be followed. To use ADS following things needs to be understand for successful and error free simulation. Followings are the typical steps needs to be followed in ADS while performing any type of simulation:

- Set up the parameters like length, width, height, dielectric, types of substrate etc.
- Draw the required lay out design
- Set up the operating frequency range
- Simulate the design
- View the result n Data Display Window

Following section outlines some of the basics of software ADS which help designers to understand ADS environment better to get basic familiarity and use software wth great ease.

5.2 Specification

Thickness = 0.8 mm
Width = 45 mm
Height = 112 mm
Substrate = FR-4
Dielectric constant = 4.4
Area of ground plane = 45×100 mm^2

5.3 LAY OUT DESIGN IN ADS

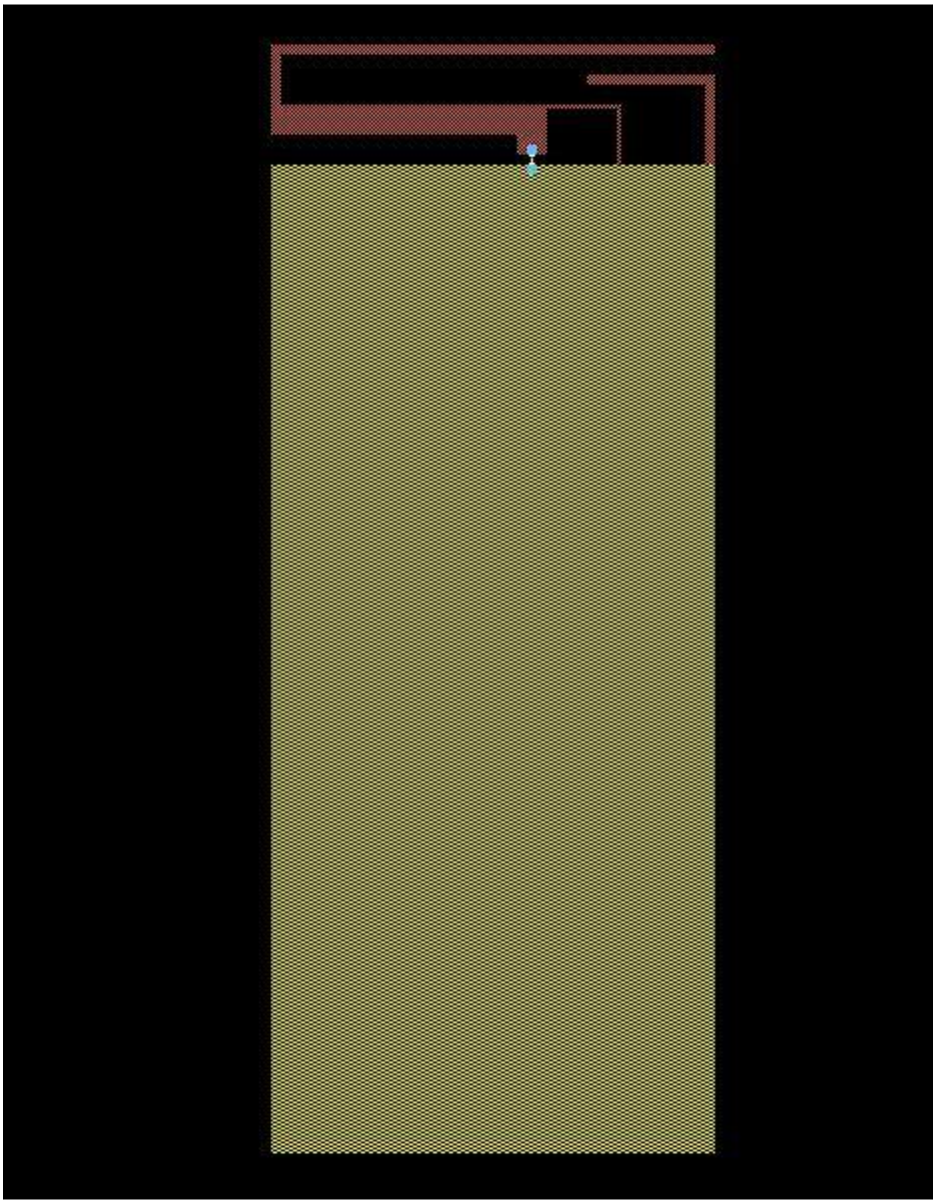
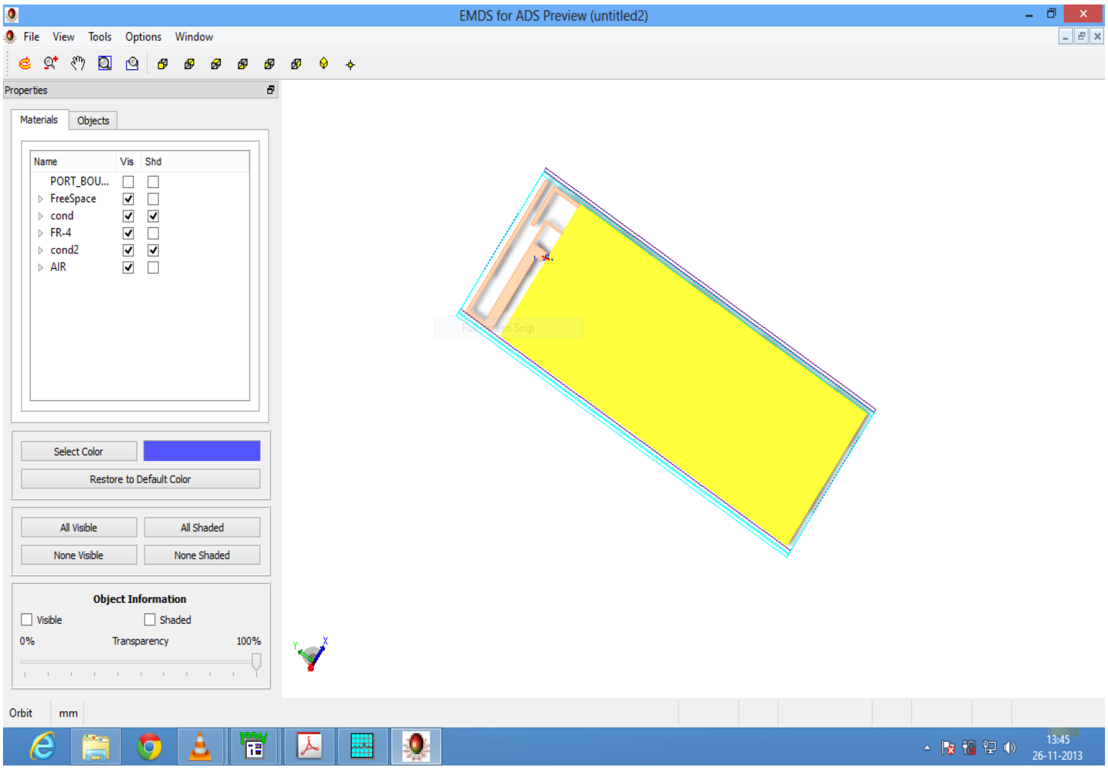


Figure 5.1: Final lay out design of compact planar multi–band antenna for mobile phone



Name	Vis	Shd
PORT_BOU...	☐	☐
FreeSpace	☑	☐
cond	☑	☑
FR-4	☑	☐
cond2	☑	☑
AIR	☑	☐

Figure 5.2**:** Design of multi-band mobile antenna in ADS (3D Geometry View)

5.4 RESULTS OF SIMULATION

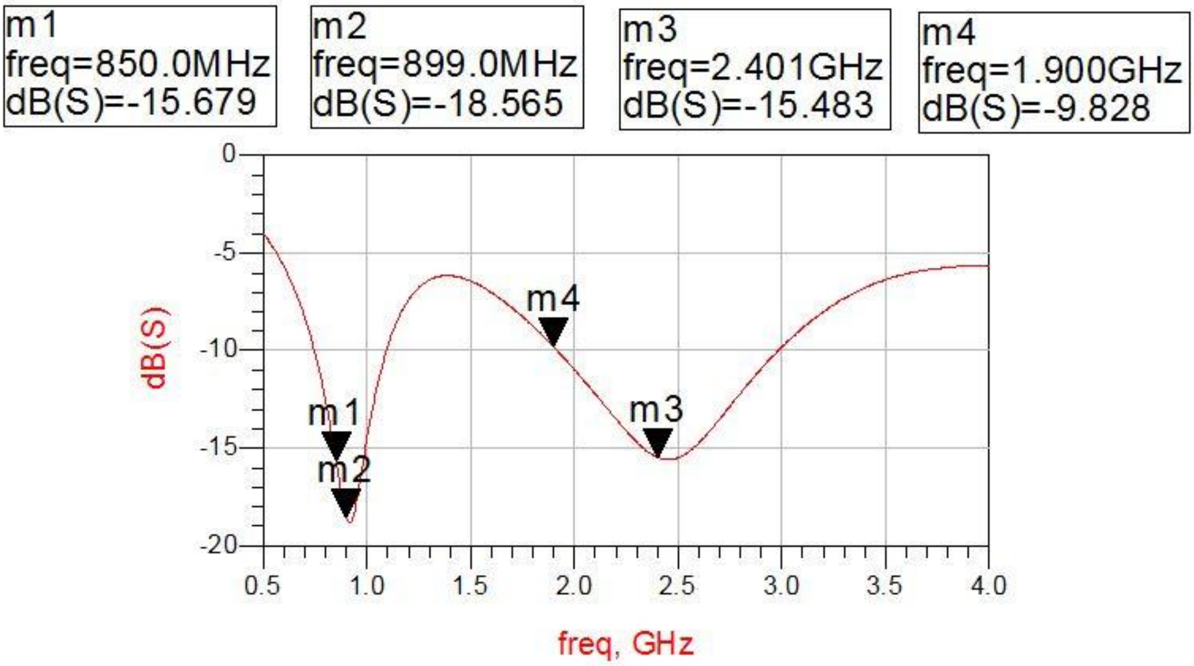


Figure 6.3: S-Parameter Display for multi-band mobile antenna

5.5 RESULT

The design of compact planar multi-band antenna for mobile phones, radiating frequencies are the five communication standard bands and an additional band known as WLANs. And reflection coefficient is less than -9db which is well above the satisfactory limit of -6db.

SUMMARY

In this chapter we have design compact planar multi-band internal antenna for mobile phone with the help of Advanced Designed System (ADS) software. First we calculated the length and other parameters like substrate thickness, dielectric constant of material etc in the previous chapter. Now by using the same configuration we have design the antenna in the lay out design. We have shown the 3D model of antenna. And the reflection coefficient which is less than -6 dB for the entire five commutation standards and an additional band called as WLANs.

CHAPTER 6

FINAL CONCLUSION AND FUTURE WORK

FINAL CONCLUSION

A planar multi-band internal antenna for mobile phone is proposed in this project has been successfully realized and discussed. The antenna was initially designed as a meandered monopole and subsequently step-by-step developed into a direct-fed printed PIFA with a parasitic resonant unit. The structurally simple antenna not only occupies a small area of only $45\times12\text{mm}^2$ but also has two VSWR ≤ 3 impedance bands of 810-1010 MHz and 1705-2515 MHz, which can cover the desired operating bands required for GSM 850, GSM 900, DCS, PCS, UMTS, and 2.4 GHz WLAN operations

FUTURE WORK

For this project the Meander line geometry was used, but other structures can also be used. Other geometries could be simulated and described and finally compared so the best geometry for a certain application could be found. Usually the size of the antenna is very important, mainly for wireless applications so other different geometries need to be tested to achieve a reduced size with the best performance. The area or length of radiating antenna can further be decreased with very minimum coupling and other losses and thus saving the material or by manipulating the properties of substrate. This can also be implemented in future with this to have a much more cost effective antenna.

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