1.
INTRODUCTION

1.1 Introduction

The advancement of modern wireless communications systems has increased considerably the demand of internal antennas, capable to be embedded in portable devices which serve a cellular or terrestrial-satellite network. With the time and requirements, these devices become thin and smaller in size. In order to meet the miniaturization requirement, the antennas embedded in mobile terminals must have their reduced dimensions accordingly. Besides, this has resulted production of handsets with antennas that are internal or hidden within the devices. An internal antenna makes the mobile handset compact compared to the conventional monopole-like antennas which remained relatively large antenna height. Therefore, built-in antennas become very promising candidates for mobile handset applications. Currently, most built-in antennas used in mobile phones include microstrip antennas, inverted-F shaped wire-form antennas, and planar inverted-F antennas (PIFAs). Planar antennas, such as microstrip and printed antennas have the attractive features such as low profile, light weight, compact size, conformability to mounting hosts, and low fabrication costs which satisfy the design consideration. In addition, PIFAs are also being used as internal antenna as it has more advantages over microstrip antenna. Conceptually, it can be designed to have a wide-bandwidth, so it can operates in dual-band and tri-band phones. PIFA renders itself capable of operating in two or more discrete frequency bands. PIFAs are concealable within the housing of the mobile phones. It also capable to reduce backward radiation toward the user's head and enhances the antenna performance. For these reasons, compact and broadband design techniques for planar antennas have attracted much attention from antenna researches. Recently, especially after the year 2000, many novel planar antenna designs have been developed to meet out the bandwidth specifications of the present-day mobile cellular communications system. Designing an internal antenna for a mobile phone is difficult especially when dual or multi-band operation is required. Although obtaining dual frequency resonance is straightforward, satisfying the bandwidth requirement for the respective communication bands is difficult. Further complications arise when the antenna has to operate in close proximity to objects like shielding cans, screws, battery, and various other metallic objects. At present, many mobile phones commonly use one or more of the following frequency bands: the Global System for Mobile Communication (GSM 850/900) band, the Digital Communication System (DCS) band, and the Personal Communication System (PCS) band, and the Universal Mobile Telecommunication system (UMTS) band. The various frequency band and its applications in mobile communication are given in the Table 1.1.

Table 1.1: Frequency bands for various wireless communication applications

Wireless Application		**Frequency Band (MHz)**
LTE 700	Long Term Evolution	698–806
GSM 850	Global System for Mobile Communications	824–890
GSM 900		880–960
GPS	Global Positioning System	L1-1565–1585 L2- 1227–1575
DCS 1800	Digital Cellular Service	1710–1880
PCS 1900	Personal Communications Service	1850–1990
IMT 2000	International Mobile Telecommunications	1885–2200
UMTS 2000	Universal Mobile Telecommunications Systems	1920–2170
LTE2300	Long Term Evolution	2300–2400
ISM 2.4/Bluetooth/ Wi-Fi	Industrial, Scientific and Medical/Wireless Fidelity	2400–2484
LTE 2500	Long Term Evolution	2500–2690
WiMAX	Worldwide Interoperability for Microwave Access	3300–3800
WLAN 5 GHz	Wireless Local Area Network	5100 –5800

1.2 Internal Antennas for Mobile Handset

Various possible antenna structures that can be used as internal antennas in mobile phones are as follows:

1.2.1 Microstrip Antenna

The concept of microstrip radiators was first proposed by Deschamps [Deschamps (1953)] as early as 1953. The first microstrip antenna was developed in Seventies by Howell [Howell (1972)] and Munson [Munson (1974)]. A microstrip antenna, consists of radiating patch and ground plane (Fig. 1.1) with dielectric substrate ($\varepsilon_r \leq 10$) in between. The patch is normally made of copper of any shape such as rectangular, circular, square, triangular, elliptical, and pentagonal. Rectangular and circular patch are generally prefer to simplify the analysis and performance prediction. The patch can be fed by coaxial probe or by microstrip line. Since the inception of this antenna, there has been excessive research and development in this area leading to the modern stage of microstrip conformal antennas. The results of these researches have contributed to the success of microstrip antennas not only in applications such as the military, aircrafts, missiles and rockets but also in commercial areas such as mobile communication, satellite communications, direct broadcast satellite (DBS) system, global positioning system (GPS), remote sensing biomedical, and hyperthermia treatment of tumors. Inspite of numerous advantages, the microstrip antennas have low operational bandwidth, which limits their applicability in practice.

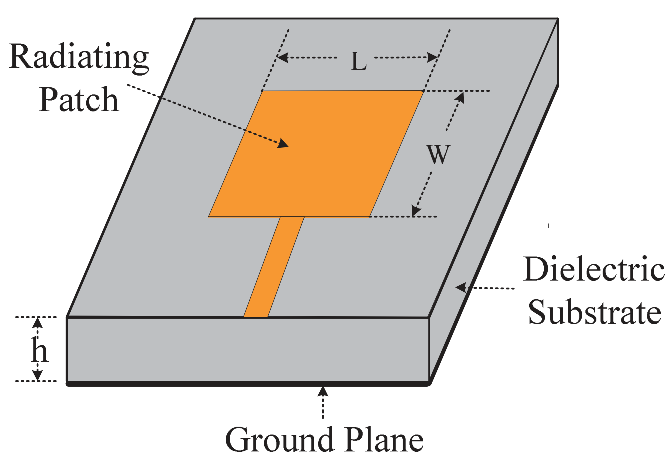

Fig. 1.1: Geometry of the rectangular patch antenna.

1.2.1.1 Design of Microstrip Antenna

A design procedure for the designing of rectangular microstrip antenna requires the specific information about the resonant frequency (f), dielectric constant of the substrate (ε_r), and the height of the substrate (h).

Then the designing of the patch can be done as follows [Garg *et al.*(2001)]:

a) Width of the patch is calculated as:

$$W = \frac{1}{2f\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1.1}$$

b) Find the effective dielectric constant of the microstrip antenna as

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \tag{1.2}$$

c) Now determine the extended length of the patch ΔL as

$$\Delta L = 0.412h\frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \tag{1.3}$$

d) Now the actual length of the patch can be determined as

$$L = \frac{1}{2f\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L \tag{1.4}$$

1.2.1.2 Radiation Mechanism of Microstrip Antenna

To understand the radiation mechanism of microstrip patch antenna, consider the patch is energized with a microwave source. On excitation, a charge distribution over the upper and lower surfaces of the patch and on the surface of the ground plane appears. The corresponding movement of these charges took place around the edges of the patch due to repulsive nature of like charges and attractive nature of unlike charges. Patch can then be modeled as cavity with electric walls at the top and below and four magnetic walls along the edge of the patch. The four sidewalls of the cavity represent four narrow apertures or slots through which radiation took place [Garg *et al.*(2001)].

1.2.2 The Inverted-F Antenna (IFA)

The inverted-F antenna is shown in Fig. 1.2. While this antenna appears to be a wire antenna, after some analysis of how this antenna radiates, it is more accurately classified as an aperture antenna. The feed is placed from the ground plane to the upper arm of the IFA. The upper arm of the IFA has a length that is roughly a quarter of a wavelength. To the right of the feed (as shown in Fig. 1.2), the upper arm is shorted to the ground plane. The feed is closer to the shorting pin than to the open end of the upper arm. The polarization of this antenna is vertical, and the radiation pattern is roughly donut shaped, with the axis of the donut in the vertical direction. The ground plane should be at least as wide as the IFA length (L), and the ground plane should be at least $\lambda/4$ in height. If the height of the ground plane is smaller, the bandwidth and efficiency will decrease. The height of the IFA (H), should be a small fraction of a wavelength. The radiation properties and impedance are not a strong function of this parameter (H). Because the structure somewhat resembles an inverted F, this antenna takes the name "Inverted F Antenna".

1.2.2.1 Design of IFA

The IFA design generally requires a top radiating element supported above a ground plane by a shorting wall and a single probe feed, which normally excites only a single operating band at its fundamental frequency mode [Garg *et al.*(2001)]. However, the design of inverted-F antenna is not unique. Variations in the height of the radiator, the length of the horizontal element as well as the tap point all impact the electrical performance characteristics of the IFA.

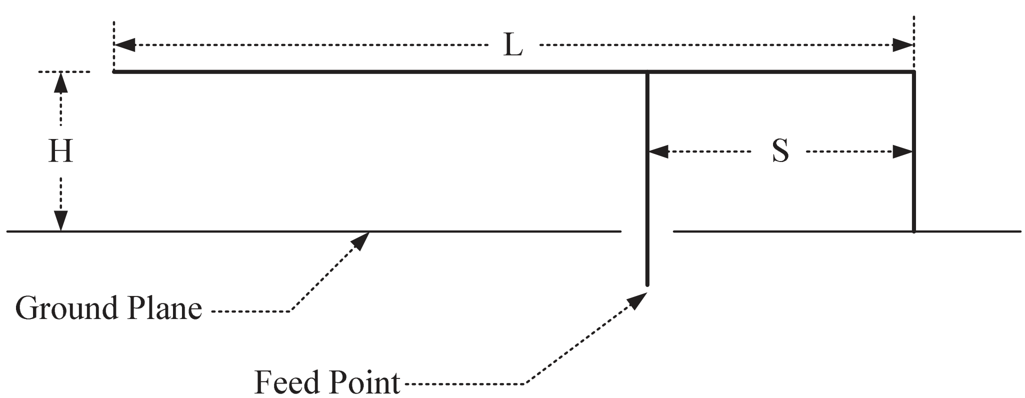

Fig. 1.2: Inverted-F antenna geometry.

1.2.2.2 Radiation Mechanism of IFA

The inverted-F antenna is a variation on the inverted-L antenna that modifies the input impedance to be nearly resistive and thus provides reduced mismatch loss. The inverted-F antenna is known as a "shunt-driven inverted-L antenna-transmission line with an open end". The inverted-F oriented with its radiating element in the z-direction has a pattern that is omni-directional in the azimuth plane. The inverted-F however has an additional E_θ component due to the horizontal arm and the non-zero currents along the horizontal arm cause the radiation pattern in the azimuth plane to deviate slightly from omni-directional.

1.2.3 Planar Inverted-F Antenna (PIFA)

The PIFA may be considered a combination of the inverted-F (IFA) along with the short - circuit rectangular microstrip antennas (SC-MSA). Both of them, the IFA and also SC-MSA obtain small bandwidths, however the PIFA has sufficient bandwidth to covers widely used communication bands. The PIFA could be regarded a direct extension of the inverted-F antenna which has the horizontally wire replaced by a plate to improve its bandwidth. Fig. 1.3 shows the basic layout of the planar inverted-F antenna. PIFA designs invoke the quarter-wavelength operation. PIFA has an advantage over the whip/rod/helix antennas that it may conveniently be placed into the casing of cellular phones.

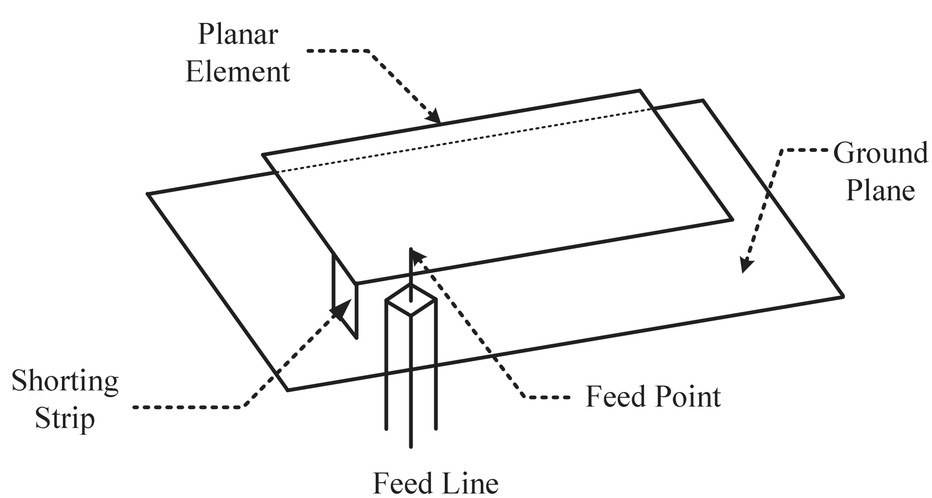

Fig. 1.3: Basic layout of the planar inverted-F antenna.

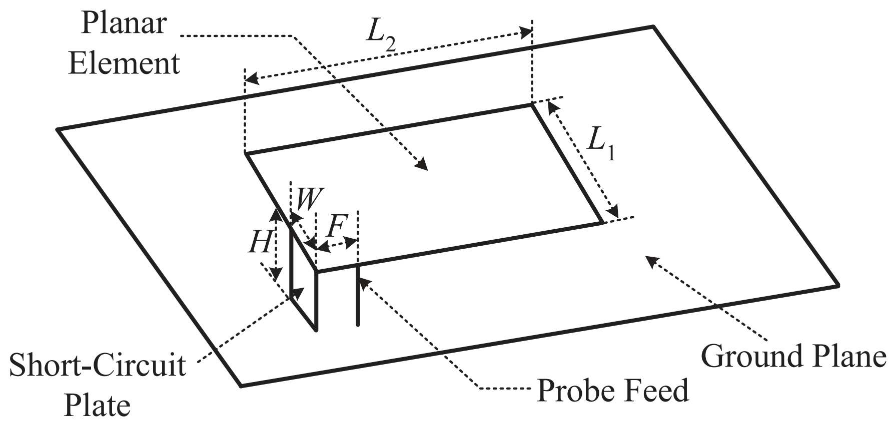

Fig. 1.4: Schematic of planar inverted-F antenna.

1.2.3.1 Design of PIFA

Fig. 1.4 shows the schematics of the planar inverted-F antenna. The patch length and width are L_1 and L_2 respectively. The shorting pin (or shorting post) is of width *W*, and begins at one edge of the PIFA. The feed is at a distance *F* from the shorting pin. The PIFA is at a height *H* from the ground plane. Air ($\varepsilon_r = 1$) is used as a substrate in between the patch and the ground plane. The following cases can be considered for getting the expression of frequency at which PIFA radiates.

Case 1: $W = L_1$ i.e., when the width (*W*) of the short-circuit plate is equal to the length of the planar element, say L_1. This corresponds to the case of the short-circuit MSA, which is a quarter-wavelength antenna. The effective length of the MSA is $L_2 + H$ where, *H* is the height of the short-circuit plate. The resonance condition then is expressed as

$$L_2 + H = \frac{\lambda}{4} \tag{1.5}$$

where λ is the desired wavelength.

As $\lambda = c/f$, where f is the desired operating frequency of PIFA and *c* is the speed of light. Thus,

$$f = \frac{c}{4(L_2 + H)} \tag{1.6}$$

Case 2: $W = 0$ i.e. short-circuit plate is represented by a thin short-circuit pin. The effective length of the current is then $L_1 + L_2 + H$. For this case, the resonance condition is expressed as

$$L_1 + L_2 + H = \frac{\lambda}{4} \tag{1.7}$$

Therefore,

$$f = \frac{c}{4(L_1 + L_2 + H)} \tag{1.8}$$

Case 3: $0 < W < L_1$, the resonant frequency f is a linear combination of the resonant frequencies associated with the limiting cases and is given as

$$f = \frac{c}{4(L_1 + L_2 + H - W)} \tag{1.9}$$

1.2.3.2 Radiation Mechanism of PIFA

The planar inverted-F antenna has quarter wavelength of operation. In this antenna one edge is short circuited to the ground and thus it has only one radiating edge. Due to this PIFA has following difference in its characteristics when compared to half wavelength patch antenna.

a) The E-plane pattern of the quarter-wave patch becomes broader because the array effect of the two radiating edges for a half-wave patch is absent here. Also, the half-length nature of the patch gives rise to a cross-polarized E_θ component in the H-plane.
b) The radiation conductance G_r of a quarter-wave patch is due to radiation from a single edge. Its value is lower by a factor of about 2 compared to that of a half-wavelength patch. Therefore, the radiation resistance at resonance will be about two times.
c) The stored energy in a quarter-wave patch is exactly one-half that of the half-wave patch because of identical field distribution over half the area.
d) Q factor calculations shows that bandwidth of the quarter-wave patch is about the same as that of half-wave patch.

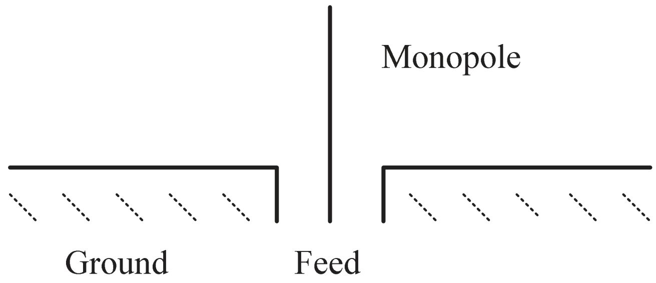

Fig. 1.5: Quarter wavelength monopole antenna.

1.2.4 Monopole Antenna

Monopole antenna is easy to design which is light weight, and has omni-directional radiation pattern. However, the physical length of a monopole antenna is a quarter of the wavelength at the operating frequency making it impractically long when sticking out from the mobile devices. Wire antennas such as monopole shown in Fig. 1.5.

The monopole antenna consists of one half of half wave dipole antenna located on a conducting ground plane. The monopole antenna is perpendicular to the infinite and perfectly conducting plane. Using image theory, the fields produced in the region above the ground plane due to monopole with its image is the same as the field due to half wave dipole. As the monopole antenna radiates only in the hemisphere so it radiates only half the power as radiated by dipole antenna with the same current.

1.3 Antenna Performance in User Proximity

User body is placed near the mobile phone (antenna with mobile environment) to check the robustness of the antenna performances. There are two different parameters are considered for performance evaluation of mobile antenna i.e., specific absorption rate (SAR) and total radiated power (TRP).

1.3.1 Specific Absorption Rate (SAR)

The radiation in human body can be evaluated by Specific Absorption Rate (SAR), which represents the time rate of microwave energy absorbed inside the tissues [Durney *et al.* (1986)],

$$SAR = \frac{\sigma}{2\rho}E^2 \tag{1.10}$$

where, ρ and σ are the density (S/m) and electrical conductivity (kg/m^3) of the tissue, respectively. E is the internal induced electric field (V/m).

However, the average SAR is defined as the time rate of change of the total energy transferred to human head tissue, divided by the total mass of the head tissue [Durney *et al.* (1986)];

$$Average\ SAR = \int_V \langle P_C \rangle dV / M \tag{1.11}$$

When handset antenna is placed near to SAM phantom, the electromagnetic absorption in phantom is estimated through average SAR. In this thesis, average SAR is calculated inside the human head phantom by using Eq. (1.11). Based on the FCC standard,

Now-a-days, two standard of SAR are adopted: Europe and country uses 2W/kg averaged over 10g tissue (average mass of human tissue is 10g) [Hadjem *et al.* (2011)]. Meanwhile, the U.S. Federal Communication Commission (FCC) requires that the SAR should be lower than 1.6W/kg averaged over 1g tissue in U.S [CTIA standard (2005)].

1.3.2 Total Radiated Power (TRP)

The TRP is defined as the quantity that correlates the field performance of the antenna and is influenced by the transmission power and the antenna efficiency. In this study, the conducted power is normalized to 1 W or 30 dBm. Mathematically TRP is defined as [CTIA standard (2005)],

$$TRP = \int_{\theta=0}^{\pi} \int_{\phi=0}^{2\pi} EiRP(\theta, \phi) sin\theta d\theta d\phi \tag{1.12}$$

$$EiRP(\theta, \phi) = P_T \cdot G_T(\theta, \phi) \tag{1.13}$$

where, P_T and G_T are the power delivered to the antenna and the antenna gain, respectively.

In addition to this simplified formula of TRP can be defined approximately as,

$$TRP(W) = Conducted\ Power\ (W) \times E_{miss} \times E_{rad} \qquad (1.14)$$

where, E_{miss} and E_{rad} are the mismatch and radiation efficiency of antenna, respectively and the conducted power is the transmitted power.

1.4 Note

Design and radiation mechanism of various planar antenna used in mobile handset are discussed. Furthermore, specific absorption rate (SAR) and total radiated power (TRP) as antenna performance in user proximity are discussed.

Before going to the actual problems, an attempt has been made to survey the available literature on the topic and consequently, a brief historical review is presented in the next chapter 2.