This chapter gives an overview of printed antennas which find application in compact electronic gadgets like mobile and WLAN systems. Challenges for the design of compact antenna are elaborately described. Different printed antennas are well explained with special emphasis on printed monopoles and dipoles. Various excitation methods and techniques for achieving multiband characteristics are discussed. The motivation of the research section well explains how a printed monopole configuration has been suitably modified to achieve dual resonance and compactness.
1.1 Introduction

Communication industry made a revolutionary remark in this 21st century with the development of modern communication equipments having ultra compact size with multiprofile applications. Mobile phones are now equipped with multiple services such as Bluetooth, GPS, DVB-H etc and the compactness has been achieved without deteriorating the performance. Another remarkable development is wireless system for local area network including Wireless Local Area Network (WLAN) and Bluetooth. WLAN is able to provide mobility and quick connectivity with high data rate.

Antennas, becoming a key element in wireless communication devices undergone amazing developments especially in the direction of compactness. Antenna history starts with Hertz when he proved Maxwell’s theoretical prediction of electromagnetic waves by the classical experiments in 1880s [1]. But the long distance communication using antennas was first realized by Marconi’s transatlantic experiments in 1901. During these period our Indian scientist J.C.Bose also conducted experiments on high frequencies even in millimetre waves and developed first horn antenna, which he called a collecting funnel. World War II made some historic developments in antenna research, especially in centimetre wave antennas. Dipoles, loops, reflectors, horn radiators and lens antennas were introduced and the concept of antenna array were proposed [2]. But during the last two decades personal communication industry undergone a tremendous growth especially in mobile communications. Strong need for the integration of multiband, multi-purpose services to the mobile phones focuses the antenna research to compact multiband printed antennas.

In earlier devices wire antennas were used which protruded outside and make the device bulky. Research and developments in the printed
antenna designs allow antenna to be integrated to the printed circuit board of the communication device, thus allows compactness. Planar inverted antennas (PIFA), printed monopoles and printed dipoles are commonly being used for compact applications. But the demand for the integration of more and more services to the mobile phone while reducing its size has been a great challenge for the antenna designer.

1.2 A brief introduction to printed antennas

In this modern communication age, mobile phones and other personal communication devices are becoming smaller and light weight. Printed antennas are well exploited in these compact applications because of its features like low profile, small size, conformal to the mounting host etc [3]. Printed antenna history started in 1953 with Deschamps when he first proposed microstrip antenna [4]. Almost all printed antennas are developed based on microstrip configuration or its modifications. In this section an attempt is made to briefly explain various popular printed antenna configurations starting from microstrip antenna to the newly reported metamaterial based printed antennas.

1.2.1 Microstrip Antenna

Microstrip antenna consists of a radiating element or a patch printed on a grounded low loss dielectric substrate. Usually the ground plane is very large compared to the radiating patch. Radiating patch can be of any shape; but rectangular or circular are more popular. Substrate is of low loss dielectric material to enhance the radiation performance. Commonly used dielectric materials are FR4, RT Duroid, Alumina etc. Configuration of a typical rectangular microstrip antenna is shown in Fig.1.1.
Microstrip antenna can be excited using a microstrip line as shown in the Fig.1.1. Electromagnetic coupling, aperture coupling or coaxial feed can also be used for the excitation of microstrip antennas.

![Fig.1.1 Geometry of a rectangular microstrip antenna excited by microstrip line](image)

Microstrip antenna geometry became popular because of its features like [5]

- Low volume, low profile and conformal configuration
- Low fabrication cost
- Easily integrated with microwave integrated circuits
- Feed lines and matching networks can be fabricated simultaneously along with the antenna structure.
- Any desired polarisation

Along with these advantages, microstrip antenna has some drawbacks, which limits its direct application in compact devices. They are

- Narrow bandwidth
- Limited half space radiation
- Large size, half wave length dimensions
- Comparatively large ground plane
- Poor end fire radiation
1.2.2 Planar Inverted F Antenna

The planar Inverted F Antenna (PIFA) consists of a top patch, ground plane, a feed wire and a shorting mechanism which short circuits the top patch to the ground as shown in Fig. 1.2. The shorting mechanism makes it a quarter wave resonator, thus reduces the electrical length by 50% compared to a microstrip antenna[6]. Resonant frequency is mainly controlled by the length of the radiating patch. Bandwidth of the antenna can be enhanced by increasing the height, the width of the shorting plate and width of the radiating patch. [7]

![Fig.1.2 Geometry of a PIFA](image)

The major features of the PIFA, which makes it a popular choice for compact applications, are highlighted below

- Reduced size
- Easily integrated on the housing of mobile phones
- Comparatively low backward radiation
- Ability to facilitate multiband operation

Planar inverted F antennas are widely used in mobile phones and laptops mainly due to the easiness to achieve multiband response with its conformal design.
1.2.3 Printed monopoles

Conventional quarter wave monopole when printed on a dielectric substrate act like a printed monopole. The radiating element can be a strip or a patch of any shape such as circular, rectangular etc. Fractal geometries are also being used for achieving wideband or multiband responses. The basic configuration of a conventional rectangular printed monopole antenna is shown in Fig.1.3.

But this configuration is not entirely planar because of the large ground plane. So for compact applications, microstrip fed or coplanar waveguide fed printed monopoles are preferred. Geometry of the microstrip fed and coplanar waveguide fed printed monopole antennas are shown in Fig.1.4. These printed monopole antennas offers low profile, conformal configuration, omni directional radiation coverage, wide bandwidth and simple design.

It has been reported that by truncating the ground plane, bandwidth can be increased to a substantial level [8]. By properly optimising the ground plane dimension and offset space between the patch and the ground plane, ultra wideband response can be achieved [9].
1.2.4 Printed dipoles

A printed version of the free space dipole is shown in Fig. 1.5. As in the case of free space dipole, electric field is along the axis of the dipole.

The dipole is fed in such a way that a horizontal field distribution exists between the gap of the dipole arms and a balanced current distribution exists...
on the dipole arms. So normally baluns are used when connected to an unbalanced coaxial transmission line. The first reported broadband printed dipole [10] with integrated balun is shown in fig.1.6.

![Fig.1.6 Geometry of a broadband printed dipole antenna](image)

This is a microstrip configuration, in which dipole arms are printed on the ground plane. A folded Microstrip line is used as the feed. Feed line and narrow slot on the ground plane are well designed to excite the horizontal electric field between the dipole arms.

A combination of coplanar waveguide (CPW) and coplanar strip line (CPS), with a printed balun is also being used to excite the printed dipoles [11]. This configuration is given in Fig.1.7.

Similar to the CPW-CPS configuration, a combination of Microstrip line (MSL) and parallel strip line (or bifilar line, BFL) is also reported in the literature for the excitation of printed dipole [12, 13]. Fig.1.8 illustrates the configuration of a printed dipole excited by MSL-BFL combination.
1.2.5 Metamaterial Antennas

In 1968, the Russian scientist Vesalago proposed the concept of Negative refractive index materials or metamaterials [14]. According to him a medium with simultaneous negative permittivity and permeability could support backward wave propagation and exhibits negative refractive index. Later this concept has been proved by Smith et al [15]. Recently this concept has been well explored by the antenna designers for miniaturisation and bandwidth enhancement.

Configuration of a recently reported metamaterial based patch antenna is shown in Fig.1.9 [16]. In this a rectangular microstrip antenna,
having a combination of Double Negative (DNG) medium and normal Double Positive (DPS) medium as substrate is demonstrated. DNG medium consists of a 40 x 2 DNG unit cells. Schematic illustration of a double negative (DNG) unit cell is shown in Fig.1.9.b. It employs split ring resonators and thin wires. Thin wires can produce effective negative permittivity in some frequency range and split ring resonators can produce negative permeability in a given frequency range. Thus by overlaying these two frequency ranges, a double negative or a negative refractive index performance can be achieved.

By using the combination of DPS-DNG medium it is claimed that resonant length has been decreased from $0.5\lambda_d$ to $0.2\lambda_d$.

![Configuration of a metamaterial based patch antenna](image)

**Fig.1.9** Configuration of a metamaterial based patch antenna
(a) DNG-DPS patch antenna (b) DNG unit cell

### 1.3 Overview of research in compact antennas

Communication industry is going through a developmental era. Personal communication equipments, especially mobile phones became more popular and an essential device now a days. Evolution of mobile phone technology is unbelievable. When it was introduced, it was only a
communication equipment with one single band (GSM). Later more mobile standards have been integrated, thus giving triple band operations (900/1800/1900MHz). Around the same time, Bluetooth modules with a separate internal antenna and FM radio receivers using the earpiece cord as antenna, started to become standard features in phones. In about few years, mobile phones became a multiband, multifunction device. Another important feature is, along with multi-functionalities mobile phones became more compact and aesthetic in appearance. At present, mobile phones with additional facilities like Bluetooth, WLAN, GPS, and DVB-H are common in market. As the device became compact, space allotted for antenna also became less and this will be a real challenge for the antenna designer. Miniaturisation has direct impact on antenna performances like gain, efficiency and bandwidth.

1.3.1 Design challenges

There are some critical aspects, to be considered for designing an antenna for a compact module. Some of these important aspects are mentioned below.

1.3.1.1 Device specifications

As the antenna performances deteriorate with size reduction, prime importance is given to the device size and allotted volume for the antenna element [17, 18]. As the thickness of the device decreases, the freedom for giving some heights between the radiating element and the ground plane also decrease. This has a huge adverse impact on the bandwidth and efficiency. All the compact communication modules are built around a multi-layered PCB and at least one of the layers of this PCB is completely metallized to act as a ground plane for the system. All currently used RF modules have unbalanced I/O ports with the ground plane as a reference terminal, implying that the antennas should also be implemented in an
unbalanced configuration [19]. Another crucial element is the device chassis; the metallized PCB layer along with metallic parts of the chassis forms the ground plane for many of the subcomponents in the device. So antenna designer cannot customise the chassis as per his requirement. But still chassis is also being used as a radiator along with the primary radiator and chassis dimensions have significant impact on antenna resonance.

1.3.1.2 Impedance bandwidth & Efficiency

Normally almost all compact personal communication applications are in low frequency range, and require a reasonable bandwidth for the proper functioning. Mainly for GSM and DVB-H applications even device dimension is very less than the operating wavelength. So some meandering techniques or the use of high dielectric substrate is needed. This it self reduces the efficiency and bandwidth. So there exists a compromise between miniaturisation and performance. Another important hurdle is deriving multiband responses with optimum bandwidth, gain and polarisation. Usage of multiple antennas for this purpose is usually not preferred because of the unavailability of space, mutual coupling between the antennas etc. Normally for multiple services either multiband or wideband antennas are preferred.

1.3.2 Present state of art

Initially mobile phones were introduced in the market with external antenna. This was a quarter wave monopole with metallic case of the phone as a ground plane. In the next stage down sizing of mobile terminals happened and metallic case has been replaced by plastic case. External antenna is replaced by compact internal antenna. But still the performance is not deteriorated much because of the effective usage of the conductive plate or metalised layer of the PCB inside the case. So the effective radiating surface increases. Different techniques are already been adopted in various
antenna configurations for achieving compactness. Mostly the ground plane of the antenna is the hindrance in miniaturisation. Planar inverted antennas are commonly used for these applications with metal shielding inside the phone as ground plane. When the device became compact, obviously ground plane dimensions reduces and the configuration behaves as asymmetrical dipole with ground plane as one of the arms. So ground plane also has to be considered as a primary source of radiation rather than a separate entity [21]. Research on this ground plane truncation has revealed some interesting results, such as wide bandwidth, nearly omnidirectional radiation pattern etc [22].

1.4 Printed dipoles for compact applications

The basic parameters of printed dipoles are already mentioned in section 1.2.4. This section highlights the different techniques adopted for achieving compactness and multiband behaviour in printed dipole configuration.

Most of the printed dipole antennas are based on the design developed by Edward and Rees in 1987[10]. Even though this configuration gives a wideband performance, dimension of the antenna is too large for a compact module. The major problem in the printed dipole configuration is the feeding. To excite a balanced current distribution in the dipole arms, baluns are required. The balun design is complicated and bandwidth of the antenna is limited by the balun. For the compact applications integrated printed circuit baluns are preferred.

Several modifications of the above configuration have been reported [23,24,25]. But most of them use complicated baluns with shorting pin, highly critical slots etc. These designs are having wide bandwidth, still because of large size and complicated designs; they are not well suited for compact applications. A coplanar waveguide fed coplanar strip dipole antenna with a wideband printed circuit balun is reported in [11]. This configuration is more popular in printed circuits because of the simple
balun. In another attempt, a combination of microstrip line and parallel strip line (bifilar line) is proposed to excite printed dipoles [12, 13].

Several methods have already been implemented in printed dipoles for achieving multiband performance. Dual band printed dipole antenna reported in [12] uses a combination of microstrip line and parallel strip line for feeding the dipole. For dual band operation a spur line was etched on the dipole arms. In [13] multiband operation was realised by the use of parasitic elements on the same plane of the dipole. Dual band is also achieved [24] by the use of a series fed printed dipoles. In another attempt dual band is achieved by etching slots on the dipole arms [25].

1.5 Printed monopoles for compact applications

The basic configurations of printed monopoles are explained in section 1.2.3. Normally printed monopoles are excited using microstrip line or coplanar line as mentioned in section 1.2.3. Printed version of the monopoles is well suitable for integration with other circuit elements on the printed circuit board. Printed monopoles with its inherent wide bandwidth, broad radiation coverage and moderate gain are suitable for modern communication equipments.

Microstrip fed printed monopole antenna reported in [20] shows wide impedance bandwidth with simple design. It has been also reported that impedance bandwidth of the antenna strongly depends on the ground plane size. For compact applications monopole antennas with truncated ground plane are preferred.

There are different attempts to achieve dual band /multiband behaviour in printed monopoles. The coplanar waveguide fed dual frequency antenna reported in [26] uses combination of two monopole strips connected in parallel to the feed point, to achieve dual resonance. In this paper it is also reported that ground plane dimensions shows significant impact on impedance bandwidth. The printed double T monopole antenna mentioned
in [27] uses two stacked T shaped monopoles for achieving dual resonance. In this case also the ground plane dimensions have significant impact on resonant frequency and bandwidth. It is also proposed that ground plane has to be considered as an integral part of the radiating structure.

1.6 Motivation of the present research

Modern communication devices are equipped with antennas printed on the circuit board itself for achieving compactness. Printed monopoles and dipoles are widely preferred because of wide bandwidth and omnidirectional radiation coverage. Microstrip fed printed monopole antenna shows wide impedance bandwidth as mentioned in [20]. It has been reported [8, 20] that impedance bandwidth of the microstrip fed printed monopole antenna strongly depends on ground plane dimensions.

Further on our analysis it has been observed that microstrip fed printed monopole antenna shows a second higher resonance with poor impedance matching, other than the expected resonance, when the ground plane length is large (>0.75λd). Impedance matching for the second resonance can be improved by offsetting the feed towards the edge of the ground plane as shown in the Fig.1.10.

Fig.1.10 Microstrip-fed printed strip monopole antenna
a. Symmetric  b. Offset
A detailed investigation on the simulated surface current distribution shows that the first resonance is due to the monopole strip and the second resonance is due to the L shaped path (abc) including the ground plane as shown in Fig. 1.11.

Reduction in ground plane length results in decrease of L shaped resonant length and the second resonance shifts towards the higher side. So in compact ground plane, even with feed offset, antenna shows only one resonance in the lower frequency range. Since the second resonance partly depends on the edge current on the ground plane as shown in Fig.1.11b, an attempt has been made to meander the current path (L-shaped) corresponds to the second resonance by adding another strip to the ground plane as an extension as shown in the Fig. 1.12.
The simulated surface current distribution for this dual strip configuration is as shown in the Fig.1.13.
After adding the additional strip, resonant length corresponding to the second resonance has been increased and the frequency has been shifted to the lower side. In this case as shown in Fig.1.13.b, the L shaped path becomes U shape with an ‘I’ and ‘reflected L’ as mentioned Fig.1.14. This path includes edge of the ground plane between the signal strip and ground strip. This configuration behaves as an asymmetrically fed dipole with one ‘I’ shaped strip on top of the substrate and an ‘inverted L’ shaped strip on bottom of the substrate. Electric field between the microstrip feed line tip and the ground plane excites the asymmetric fed dipole as shown in Fig.1.14. This is achieved by the current path of length ‘s’ which is also acting as a balun. This avoids the use of balun in the design and leads towards a simple dipole configuration.

Currents on the vertical strips are in the same direction, which favours the radiation. For the first resonance current strength is maximum on the monopole strip as shown in the Fig.1.13a.

![Fig.1.14 Equivalent model of asymmetric fed dipole](image)

This concept has been well explored for the design of a compact dual band dual strip antenna. This technique gives two wide resonances with compact ground plane compared to the other techniques mentioned in
Another important point is for generating the additional resonance, only ground plane edge is utilised without disturbing the ground plane. This will give more freedom for the integration of antenna to the circuit board. In that case common ground plane of the circuit board can be used as the ground plane of the antenna. Since only the edge current on the ground plane is utilized for the resonance, placement of other components on the circuit board will not affect antenna performance.

For more compactness, electrical length is increased by meandering the signal strip and ground strip as shown in Fig.1.15. This folding analysis further reduces the dimensions of the antenna, including the ground plane. Thus a compact dual band antenna can be designed using the above mentioned concept.

A detailed investigation on this concept has been well explained in the following chapters. Based on this a compact dual band dual strip antenna and compact folded dual strip antenna have been designed for mobile and WLAN applications.
1.7 Thesis organisation

Chapter 1 describes an overview of compact antennas. The challenges in compact antenna design and present state of art in compact antenna research are summarised. It also explains the scope of printed monopoles and dipoles in compact applications. Motivation of the present research and objective of the thesis are illustrated at the end of the chapter.

Chapter 2 is the review of literature which was referred for the present work. A thorough review of compact antennas, antennas for mobile/WLAN applications, wide band and multiband techniques has been carried out. Multiband techniques adopted in various printed monopole and dipole configurations are refereed. Literature related to Finite Difference Time Domain (FDTD) and theoretical analysis using FDTD are also presented.

Chapter 3 gives a brief description of the measurement and simulation techniques used for the thesis work. This chapter also explains briefly the FDTD method which is used in the present thesis for the analysis of compact dual band antenna.

Chapter 4 illustrates the theoretical and experimental investigation on the resonance and radiation mechanism of the dual band dual strip antenna. Evolution of a dual band antenna from microstrip fed printed monopole configuration is well explained with the help of experiment and simulation. Effect of various antenna dimensions on antenna performances has been analysed by experiment and simulations. Based on that, design equations are derived. The design equations are validated for a dual band antenna for DCS/2.4GHz WLAN applications.

Chapter 5 explains the design of a compact dual band folded dual strip antenna based on the above concept. Effect of folding/top loading has been well studied. Design formula is also developed based on the experimental and simulation analysis. Using these design equations compact dual band
folded dual strip antennas for various applications such as GSM, DCS and WLAN have been designed and presented.

Chapter 6 gives the conclusion of the thesis. Scope of the work and future proposals are also described.

Appendix 1 gives the design of a planar branched monopole antenna from a simple microstrip fed printed monopole antenna.

In Appendix 2, A planar multiband printed antenna for GPS/DCS/PCS/WLAN applications are presented.

1.8 References


[7]. Design of Conformal Antennas for Telephone Handsets, Thesis by Andrew James Causley, University of Queensland.


